Emotion by Motion:
Expression Simulation in Virtual Ballet

by

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The candidate confirms that the work submitted is his own and that the appropriate credit has been given where reference has been made to the work of others.

Abstract

Learning and teaching choreographies can be an arduous task. In ballet, most dancers learn by emulation i.e. "watch, copy and learn". The teaching process not only instructs the order of steps but also requires explaining the quality required for the performance. Notational systems are used in almost all fields of study, and dance notation with inferred domain rules are used to aid in the teaching of choreographies and dance. Few professional performers can read written choreography let alone visualise the movements involved, and this represents a considerable barrier to the utility of choreography in its written form.

Real-time computer graphics are ideally suited to bridge the gap between written choreographic notation and performance, via the creation of a virtual dancer. It would be useful for professionals to better understand choreography and notated ballet scores as well as assisting to teach dance at all levels. To understand the needs and derive methods for a virtual ballet dancer system, there are three distinct parts and these provide the structure for this thesis. The first part researches into the fidelity that is required for a virtual ballet dancer. From this analysis, expressive motions are parameterised using Laban's effort parameters and results presented how participants distinguished between the different emotions performed at various levels of fidelity. The results provide understanding on how Laban's parameters define variations performed during the different expressive movement and the level of interpolation required for a user to distinguish the expressive performances.

The second part presents methods for setting and evaluation of specified ballet positions (key poses) which form the foundation for ballet steps. Mathematical rules are developed and explained within the context of the ballet domain rules being represented. The resulting poses defined by the dance notation and the mathematical descriptions are evaluated by professional teachers and notators. The results are presented showing how basic ballet positions are accurately posed for a perfect dancer and variations from the perfect pose to the real-world. These poses are used as the foundation for layering the expressive algorithm on.

The final part presents how Laban's Effort factors can be used for expressive interpolation between key poses, i.e. the quality of movement. Methods are analysed and algorithms implemented to develop variations in the movement between the set dance positions. These variations are matched to the expressive performances of real dancers analysed in the first part of this research in order to evaluate the algorithms derived with actual expressive performances. The results presented are the first major steps to produce an animated "virtual ballet dancer".

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Neagle, R.J., Ng, K. and Ruddle, R.A., "Studying the fidelity requirements for a virtual ballet dancer", In *Proceedings of Vision, Video and Graphics Conference*, July 2003, pages 131–133.

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Chapter 1

Introduction

Terpsichore, dancing as an art. Dance, a definite succession or arrangement of steps and rhythmical movements constituting one particular form or method of dancing or a rhythmical skipping and stepping, with regular turnings and movements of the limbs and body, usually to the accompaniment of music; either as an expression of joy, exultation, and the like, as an amusement or entertainment; the action or an act or round of dancing. These definitions from the Oxford English Dictionary (Simpson & Weiner, 1989) present dance as a description of movement or as a medium for expression. Other definitions describe dance as an artistic form of nonverbal communication and movement selected and organised for aesthetic purposes. Expression and mood can be obtained from a dance performance by many different aspects including music, lighting, synopsis, sequence of movement (choreography), facial expressions, and the expressive nuances by the performer. Irrespective of the different aspects, good dancers for generations have been characterised as emotional performers with lyrical quality.

Learning and teaching choreographies can be an arduous task. While choreography can use patterns of movement to portray moods and emotions (Price, Douther & Jack, 2000), more is required from the dancer. In ballet, most dancers learn by emulation. Normally, the teaching process not only instructs the order of steps but also requires explaining the quality required for the performance. This usually involves teachers, the choreographer, and/or trained choreologists. A performer is aiming to not only recreate the combinations of steps but add nuances and expressive qualities so that an audience will understand the emotions being felt and portrayed. The realisation of a dance piece; from dance symbol notation to a performance, is a complex process, in need of tools to aid the process.

As a professional teacher, A.I.S.T.D (CB)[1], and dancer for more than twenty five years, the process of teaching, choreographing and learning of choreographies was extremely difficult and time consuming. Particularly when a specific style or expression was required to obtain the required results. Demonstration by the teacher, choreologist or choreographer was not always successful where the dancer was learning by emulation and a common phrase heard in a rehearsal/dance studio is “do as I say, not as I do”. These experiences sowed the idea of creating a tool to help visualise a choreography. Real-time computer graphics are ideally suited to bridge the gap between written choreographic notation and performance, via the creation of a virtual dancer. In theory, a realistic virtual performance can be driven from a machine-readable version of dance notation with a virtual dancer. Such a tool could be used to aid professionals in the learning process and the visualisation of dance movement.

Currently applications used to aid in the creation of ballets are still in the early stages with various approaches. We propose in this research to define new methods for setting the dance steps on a virtual dancer and to better understand how expressive motion is performed within the bounds of classical ballet. While current research has analysed emotions through dance and synthesised dance motions, the novel approach to understand how balletic movement is varied based on the motion descriptors developed by Rudolf Laban (Laban, 1966) has currently not been achieved. It is the belief of the author that the rules for expressive ballet movement can be used not only to create an expressive virtual dancer but be used in the animation of a virtual character.

To develop expressive algorithms, subtle variations to the defined dance movement is required. However, the variations in the shape of the pose during the motion are required to adhere to the rules of classical ballet. Due to the strict nature of classical ballet, the author proposes a novel contribution where mathematical rules are devised, presented and evaluated to pose the virtual dancer which are reused during the interpolation process between the key poses. The key poses are defined by the dance notation used as the input to the dance sequence and are defined ballet poses from the ballet repertoire e.g. *fifth en haut*.

The final novel contribution is the expressive algorithms developed for ballet movements. Research in expressive movement is currently still in the early stages towards creating expressive realistic movement. Laban parameterised the quality of movement for his movement notation system (Labanotation) and while Chi (2000)

[1] Qualified as an Associate teacher by the Imperial Society of Dance Teachers (Cecchetti Branch)

presented work related to these parameters to vary the gestures being performed, there is currently little research to map it to dance with the notable exception in the EyesWeb project (Camurri & Trocca, 2000). Furthermore, there is currently no research to specify quality of movement where key poses are defined and domain rules are strictly enforced as required in classical ballet as presented in this research.

1.1 Visualising Dance

Dance notations are used to archive choreographies, and allow their subsequent resurrection by dancers and choreologists. The symbolic representation of a dance notation is similar to music and with an underlying mathematical content that lends itself well to machine representation. Many methods of notation systems have been attempted and the two most common that succeed in rigorous professional conditions are *Labanotation* (Brown & Parker, 1984) and *Benesh notation* (Benesh & Benesh, 1983; Wilks, 1980). Within the choreographic environment of dance, there is currently no means of displaying annotated choreography to aid visualisation. Unlike common music notation, understood by most musicians, professional and amateur, many professional dancers and choreographers can not read dance notation.

Like any other symbolic notation system (such as common music notation) there are abstract differences between the representation and the artistic interpretation (Lansdown, 1995; Herbison-Evans, 2001) of the notation as a performance. The overall goal of this PhD is to develop a system that allows professionals to see an animated 3D virtual dance that is driven by written dance notation.

1.2 Approach to Developing a VBD

This research is divided into three parts: (1) understand the requirements of a system for generating expressive dance movement by researching the level of fidelity required for distinguishing different emotions (Chapter 3), (2) devise rules and methods defining the ballet key poses for animation (Chapter 4), and (3) develop methods for animating movement between the key poses including expressive qualities and nuances (Chapter 5).

To understand the applied problem for achieving a system displaying expressive movement, there is a need to rationalise the real-world and answer questions such as: How does real-world dancing translate to virtual animations and what level of fidelity is needed in a virtual dancer? Chapter 3, used Laban's effort theory to characterise the motion, devised experiments where participants were required to differentiate emotions. Two experiments are discussed, designed to identify the accuracy of distinguishing emotions in ballet at lower levels of fidelity. The experiments analysed the effect of the visual appearance on a 2D display and looked into aspects of realism in the movement between key frames defined by a dance notation. This section of research explored understanding the quality of movement required for a virtual dancer, specifically, the expressivity encapsulated in the motion between key poses. The results were published in the paper titled *"Studying the fidelity requirements for a virtual ballet dancer"* (Neagle, Ng & Ruddle, 2003).

Chapter 4 involved the devising and development of the rules and mathematical equations to orientate the skeleton joints of the VBD into each key pose. Setting the key poses for a virtual dancer included defining a dance notation representation that is machine-readable to set the ballet poses (Neagle, Ng & Ruddle, 2002; Neagle & Ng, 2003). The application for demonstrating the virtual dancer was coded for a user to be able to step through each key pose imported using the Benesh notation file representation. The poses were evaluated by: (1) using my expert opinion and making comparisons with text books on ballet, and (2) by professional teachers and choreologists. The results from these evaluations and experiments were presented and published in the paper titled *"Developing a Virtual Ballet Dancer to Visualise Choreography"* (Neagle, Ng & Ruddle, 2004).

Chapter 5 of this research was the development of the interpolation algorithms with respect to the Laban parameters discussed in the first section of research (the real-world). Data from a Vicon motion capture system was used to analyse the movement path of the wrists (the most expressive part of the classical dancer is the use of the arms). From these results algorithms were developed for the user to manipulate sliders representing Laban's time, weight and space parameters, and the tempo of the animation. This provides the means for the user to change the way the movement of the VBD is performed. The quality of the VBD was assessed by setting the VBD to perform arm movements with different qualities to match the real-world dancers from the first stage. The frames of the VBD and the real-world videos were compared and evaluated.

Chapter 2

Related Work

2.1 Introduction

Simulation of dance in a virtual environment is a series of performed gestures with defined postural dance position. A dance form or method (e.g. the Cecchetti method in classical ballet) uses a set of postural and motion rules to define how the execution of the movement is to be applied i.e. the dance technique. The motions of dance are either used as an expression of emotion or as an act. The teaching of dance requires the understanding of three parts: (1) the defined poses used in the dance method, (2) the movement descriptions and combination of poses to perform a dance step in the dance method, and (3) understanding the quality of the movement. This can be a general description of the method such as the difference between performing a waltz or a tango or a description of performing a series of steps in a given style or emotion.

This chapter reviews: the methods for computer input of dance poses, pose recognition, and movement; the understanding of gestures in a system-oriented context; and various research methods in the simulation of dance. This provides the background for developing the rules and methods for inputting and simulating dance poses and movements with a computational expressive model.

2.2 Dance Notation and Computers

Dance, a series of rhythmical motions and steps, prescribed or improvised, usually to music, exemplifies motor control, motion perception and gesture recognition. Its appreciation involves perceiving gestures, according to a movement vocabulary that may be peculiar to a style of dance, or that may bear a relation to everyday movement (Ahmad, Salway & Lansdale, 1998). Examples of movement vocabulary usually include terminology to describe the pose or the movement required, for example, classical ballet has terms such as *pliés, relevés, pirouettes*. Some terms cross genre and may represent the same fundamental action although the actual motor control is different. Examples include in dance where a ballet, jazz, or tap dancer performs a pirouette (turn).

Notational systems are used in almost all fields of study, and especially for the communication and expression of ideas. Dance notations are used to archive choreographies for resurrection by dancers and choreologists. The best known systems for doing so are Labanotation (Brown & Parker, 1984; Laban, 1966), Eshkol-Wachman (Eshkol & Wachmann, 1958) and Benesh Notation (Benesh & Benesh, 1983). Unlike music, where the common notation is widely understood, many professional performers and choreographers are not able to read dance notation. In professional practice, the process for resurrecting choreography tends to involve the use of the choreologist translating the notation to verbal explanation for dancers to interpret and rehearse. The transformation from symbol notation into a performance is a large step with few tools to aid the process.

2.2.1 Dance Notation

T. Parsons is quoted as saying: *"Dance notation is never simple, since there is so much that needs to be specified for every dancer: positions of the feet, arms, hands, head, and torso; whether the dancer is standing still or moving and, if moving, in what direction (horizontally, vertically, or both) and how fast...and so on"* (Parsons, 2004). There are many different forms of dance notations including:

Action Stroke Dance Notation is a movement shorthand designed so that the basic movements can be written quickly (as "action strokes"), and details added later. The dancer's body is left and right symmetrical and the score represent movements of the left and right arm, or the left and right limb, in a left-and-right symmetrical manner. Therefore, the horizontal dimension is reserved for representing the symmetry of the body, and the vertical dimension is the time dimension. The notation separates the legs, arms and torso to separate staves. The system makes repeated efforts to avoid "false precision." e.g. a movement starts exactly 1/4 beat before the count or indicating a limb to be lifted at exactly a 45 degree angle. Exact details are added separately.

Benesh Notation is a written system for recording any form of human movement and provides an accurate three dimensional representation of movement. It is a visual method indicating the whereabouts of a person, the direction in which he or she is facing/travelling, and the movement and positions of the limbs, head, hands, feet and body. Movements are described by plotting the body's changing positions along a five-lined stave in a series of notated 'frames', directly linked to musical accompaniment with rhythm and phrasing. The system is used by many major ballet companies around the world and in many cases using their own choreologists. The Benesh Institute (formerly The Institute of Choreology) is an international organisation which acts as the custodian for Benesh Movement Notation (Institute, 2004).

Eshkol-Wachman Movement Notation treats the body as a sort of "stick figure." Each pair of joints define a line segment, called a "limb". For example, the forearm is a limb, with the wrist and elbow joints defining its endpoints. Similarly, the foot is a limb bounded by the ankle and the end of the toe. The relationship of the limbs is achieved by writing limb positions using a spherical coordinate system. Selection of which joint is the centre of the sphere is selected on a "heaviest" joint. A "heavy" limb move modifies the position of "lighter" limbs connected to it. The joint weight is not absolute, e.g. a person doing a handstand, any movements of the wrist joint would alter the positions of the forearm and upper arm – and the rest of the body. In that case, the hand is the heaviest limb. Descriptions begin with the heaviest limb and proceed to the lightest. Units of time are represented from left to right, and limbs are written on a different line from top to bottom. Eshkol-Wachman's main deficiency is it is not good for temporal analysis.

Beauchamp-Feuillet Notation is a notation devoted to the dance styles for Court dancing from the baroque period which includes the relationships of steps to music in such dance types as the minuet, gavotte, bourrée, sarabande, passacaille, loure, gigue, and entrée grave.

Laban, Labanotation and Effort-Shape is a system of analysing and recording of human Movement. There are three different descriptions: a "Structural Description" for which tries to record every aspect of motion as precisely as possible; a "Motif Description", simplified Structural Description where you only write down what you think of as important; and "Effort-Shape Description" used to record the energy content of a motion. It is used in various research including human motion in industrial work lines as well as in physiotherapy and psychotherapy. The Structural Description captured on the page where a single symbol can provides: the direction of the movement (the shape of the symbol), the part of the body doing the movement (the position of the symbol), the level of the movement (the shading), and the length of time it takes to do the movement (the length). For dance movement, the staff is laid out in measures to match the measures of the music. Tick marks are used to indicate the beats, bar lines across the staff show the start and end of the measure.

Effort-Shape is related to the simulation of movement which attempts to extract emotive qualities from human movement i.e. the qualitative and expressive aspects of movement. Effort is described in dimensions of weight, space, time and flow. Shape describes the body's creating of or adapting to contour in terms such as rising, spreading, advancing, sinking, enclosing and retreating. For example, if you mould your arms around a ball and allow your trunk to accommodate to its shape, you are introducing a quality of shaping into the movement repertoire.

Morris Dance Notation using *abc*. *abc* is a language designed to notate tunes in an Ascii format. It was designed primarily for folk and traditional tunes of Western European origin (such as English, Irish and Scottish) which can be written on one stave in standard classical notation. There are numerous programs which convert the *abc* source code into beautifully typeset score and/or audio outputs. One of these abc client programs is abc2ps by Michael Methfessel. Starting with version 1.2.4 abc2ps implements an experimental extension to the abc language (w:) which permits alignment of lyrics with notes. This extension can be applied to the problem of communicating the notations of folk dancing; i.e., stepping and hand motions, where each Ascii character is mapped to a cue required to recreate the Morris dance.

Sutton System represents dance by annotating a stick figure written on a five-lined staff. Each line of the staff represents a specific level i.e. the floor line (represents the ground), knee line, hip, line, shoulder line with the fifth line above the head. When the figure bends its knees or jumps in the air, it is lowered or raised accordingly on the staff. The five-lined staff acts as a level guide. Figures and symbols are written from left to right, notating movement position by position, as if stopping a film frame by frame. When more detail is necessary, two rows of special 3-D Symbols for the upper and lower body, representing the third dimension, are written under the stick figures. Both use round circles providing an overhead view with spokes projecting from the circles showing the direction of the limbs in relation to the centre of the body.

Theodor Vasilescu Dance Notation mainly used in "folk" dancing is a visual system defining the orientation of the legs, body, arms and head where the amplitude of the movement is specified in degrees. As well as notation to represent specific folk movement e.g. spurs (clapping the heels), symbols also define the position and direction of the dancer.

It is worth noting that there are different versions of Laban. Great Britain and the U.S.A. use Labanotation while the rest of Europe adopts a dialect called Kinetography-laban. Though Benesh Notation and Laban Notation are the main notations in use today, this is not a reflection on the relative merits of the other notations. For example, some of the other notations such as Morris Dance Notation are for different dance styles and have been designed accordingly.

Others forms of annotation have been researched and in "(An)notating dance: Multimedia storage and retrieval" (Ahmad, Salway & Lansdale, 1998), a study is presented of how to build digital multimedia libraries that comprise moving images accompanied by sound and other media. A protocol analysis is suggested as a knowledge acquisition method for eliciting verbal descriptions of dance to annotate dance videos. Three types of indexing based on acquired knowledge are used: (1) sections: an index of video dance segments (electronic table of contents to the dance); (2) motifs: notions of abstracts, key frames and moving icons (a dance motif); and (3)commentaries: of a verbal or symbolic nature. As a retrieval system, the concept is useful in digital video queries. This is not a method for annotating dance itself but a metadata description to understand what is occurring in the digital media. The methods of description rely on interviewing an expert in dance and these descriptions alone would not provide enough detail to recreate the dance movements. However, the descriptions would be useful for finding dance motifs within the digital media.

The two most common notation for classical ballet are the Benesh notation and Labanotation. Labanotation is an excellent notation for recreating the exact movement while Benesh relies on the choreologist applying the inferred rules of ballet. The system in this research not only is required to pose the virtual dancer but is required to apply the rules of ballet which are also applied during the interpolated motion between the key poses. The exact definition of the movement provided by Labanotation is deemed unnecessary and Benesh notation using the inferred ballet rules is at the required level to input the balletic dance movement where expressive motion can be added. Therefore we used Benesh notation.

2.2.2 Dance Notation Editors

Several programs now exist or are currently under development to create, store, modify and print scores. Current research is involved mainly with the Benesh notation and the Laban notation. Many are still works in progress and below is a list of online resources associated with each editor.

Benesh Notation

Benesh Notation Editor is a software program designed as a 'word processor' for writing and editing multi-stave notation scores. Created primarily for the use of professional notators working in a dance company environment, it can be used on any PC capable of running Windows 95 or later, with a minimum of 64MB RAM. (Institute, 2004)

MacBenesh is a Macintosh application that creates single-dancer Benesh Movement Notation scores that can be printed on a postscript printer, or pasted into other documents. (DanceWrite, 1995)

Laban Notation

Calaban (Computer Aided Labanotation) provides windows-based computer solutions for work with Labanotation. The interface is controlled through pull-down menus, dialogue boxes, icon-driven toolbars floating palettes and icon menus to produce from a single page of notation to a level including text, photographs and Labanotation graphics for digital storage. Calaban is a special applications development of the Autodesk software Autocad. (University of Birmingham, 2004)

Labanpad PDA is a program for interactive Labanotation input. It will be implemented on a pen-based palmtop-computer (currently: Apple Newton) and uses a specialised recognition algorithm for handwritten input. Using a pen, the symbols could be written directly in place on the score. The system recognises the symbols and converts them in a tokenised code. A semantic representation of the score will be generated. Editing and reformatting of the score is now possible. Editing will be done using pop up menus and by gestures like mark and cross out. (Griesbek, 1996)

Labanwriter is a Labanotation editor for the MacIntosh and the current version will run on any MacIntosh computer running system 8.6 or greater. Labanwriter is a software program that includes more than 700 symbols that indicate parts of the body, direction, levels, and types of movement and the durations of each action. (Ohio State University, 2000)

LED written in C for use under Unix, with X-Windows with the basic operations controlled by the mouse. The editor provides 109 basic symbols partitioned into 10 menus. symbols on a score can be deleted, copied, or altered, and the score scrolled up or down. scores can be created, stored, retrieved for further editing, and written out as postscript files for printing. (Herbison-Evans, Edward, Hunt & Politis, 2004)

Lansdown (1995) commented: *"It is relatively easy to put about 80% of any of the notations into computable form. the difficulty arises with the remaining 20%. To be really useful, however, a notation program has to be complete. Thus I know of no system that is used on a day-to-day basis by choreologists."* Researchers have been looking at human movement notation system with respect to virtual humans for decades (Badler & Smoliar, 1979; Badler, 1989) and recently more importance in building computational models have used components of Laban's Movement Analysis and in particular the components for Effort and Shape (Chi, Costa, Zhao & Badler, 2000; Camurri & Trocca, 2000).

2.2.3 Dance Animation Systems and Interfaces

This section looks at two groups of animation systems: the first are systems related to dance and either associated with the aforementioned editors or built in dance libraries and/or dance models for manipulation; and the second is commercial systems commonly used as aids to choreography (i.e. planning human movement, visualising and editing animated dance notation (Calvert, Wilke, Ryman & Fox, 2005)). Renown choreographer Merce Cunningham is one high profile choreographer using this technology and with the choreographed work, "Biped", demonstrated the use of technology in a live performance at a professional level (Abouaf, 1999a,b). In "Virtual humans in CyberDance", performances involving both real and virtual dancers was presented describing the modules used to make a single system framework capable of handling all aspects of the show (Carion, Sannier & Magnenat-Thalmann, 1998). The following descriptions are taken from the main dance research using interpreters, parsers and 3D applications to rendering dance animations:

LINTER is an interpreter which takes a file of a Labanotation score from LED, and generates from it an animation script for the Nudes (Herbison-Evans, Green & Butt, 1982) animation system (sets of ellipsoids forming a figure that can be manipulated).

Ballones 'ballet animation language linked over NUDES ellipsoid system', is a proposal by Hall and Herbison-Evans (Hall & Herbison-Evans, 1990) for a classical ballet interpreter using a lexical analyser (suspect lex was used), a yacc parser, and a set of NUDES procedures.

Limelight proposed by Christian Griesbeck (Griesbeck, 1996) is associated with Labanpad. It is defined as a modular program which integrates components necessary for professional computer aided choreographing.

LabanWriter and LifeForms through the Dance Notation Bureau have an interface researched and under development to translate Labanotated scores into computer animation. It proposes that the user will have the functionality to type movement notation and have the computer play it back in animation (Fox, Ryman & Calvert, 2001). LifeForms Dance 4.0 is a special version of the program with Ballet Moves and has detailed more than 100 ballet positions and transitions geared towards teachers and choreographers. The application can also be used for scripting ballet choreography.

To again quote Lansdown (1995): *"While theoretically movement notations are capable of describing positions and movements to almost any desired degree of detail, in normal conditions all of these notations require some element of interpretation for their effective use. Humans can make these interpretations: computers can't (at least, not today they can't)."* This statement points out the difficulties faced using notation systems to generate animations. No two dancers will perform the same step exactly the same. Dance notations do not notate every nuance, and instead provide more of a generalised overview. Therefore choreologists make interpretations based on their dance training as well as understanding of the notation and therefore will differ. Ryman (2001) stated that *"dance notation and computer animation can be used to enhance and complement one another. Each medium provides unique information and has inherent strengths and limitations"*. Art is not an exact science, however, providing a computer system follows the inferred domain rules (Campbell & Bobick, 1995) of the dance type then it is possible to animate a virtual dancer with key poses correctly positioned exactly as a choreologist would do. The biggest problem is describing unusual or non conventional body positions or movements. To produce these, the user or rules must specify much more information than is actually notated including adjustments in the pelvis and spine, the turnout of the legs, etc. Some information can be understood from human anatomy and some according to ballet conventions (Ryman, 2001).

The following sections describe research, applications and methods currently used to create dance animations. Each section discusses the skill level required and methods to create, edit and render a dance animation sequence.

2.2.3.1 Herbison-Evans' LED, LINTER and NUDES

LED was designed to run under the X-Windows system under Unix with a simple interface controlled by a mouse to create, retrieve, edit and store digital scores of Labanotation that can be written out as postscript files for printing. It assumes the user has a background in Labanotation with the ability to compose a score. A file contains a coded record of a single script and includes a list of all the symbols (i.e elements of the Labanotation language) that are part of a score and their attributes such as type, size, position and modifiers. The script and internal record of the script in the system (lexically analysed) consists of an array of the symbols. Each Labanotation symbol within the editor is an intrinsic object that can be selected, added, moved, deleted and modified. Control objects are used to control these actions. Given the complexity of human movement and the large number of symbols to describe them in detail, LED does not provide all the symbols of Labanotation, however, Herbison-Evans state that by using and combining the symbols provided, many commonly used symbols can be generated (Edward, Hunt, Politis & Herbison-Evans, 2004).

NUDES, A Numerical Utility Displaying Ellipsoid Solids, can group and link ellipsoids to form a human figure. NUDES allows a user to manipulate a set of ellipsoids for which various actions can be performed distributed over specified sets of frames. NUDES scripts are written in a formal language which allows the definition of the figure and their required actions (Herbison-Evans, Green & Butt, 1982). The LINTER interpreter turns a LED output into a NUDES script. NUDES allows a choice of linear, quadratic, or cubic profiles as well as constant acceleration or deceleration of which LINTER uses the quadratic option. From simple experiments, the linear and cubic profiles were found to create unnatural movement. The interpolation profile ranges from a specified start and end frame for the movement and are used to calculate the amount of rotation for each joint during this sequence of frames.

The creation of a NUDES animation using LED and LINTER requires an understanding of Labanotation, however, assuming this background knowledge, the learning process of the LED editor appears elementary providing the user with a simple interface to select and position Labanotation symbols on a stave. Creating an animation without using the editor requires an understanding of the formal language defining the figures and the movements in the data scripts. This is not such an easy task and it is expected to require a certain amount of trial and error. The time to create an animation using LED is defined by the users ability to create an animation score in Labanotion with the interface. Without the editor, a certain amount of trial and error is expected and would be as time consuming as setting up keyframes using an animation package such as Maya or 3DStudioMax.

2.2.3.2 3D Commercial Packages and Libraries

There are a number of commercial third party solutions for 3D modelling and animation including 3DStudioMax, Maya, Blender, Lightwave, Poser and LifeForms. Animation of biped models is achieved by specifying the key poses for a key frame. Major advantages of using these applications are the tools that are provided for modelling and animation. To completely animate by hand would be very time consuming and therefore these packages provide methods for creating animations: (1) keyframe animation where the user poses the character at a specific time and specifies the method for interpolation. Methods for interpolation involve specifying the animation control methods including linear and spline, quaternion based rotation (TCB), and motion paths for the application to calculate the orientation for each skeleton bone; (2) scripting e.g. MEL for Maya and Max Scripting for 3DStudioMax where scripts can be used to specify key poses, animation control methods etc.; and

(3) using motion capture data to control the virtual character.

Controlling a character animation for keyframe and scripting requires the character to be rigged i.e. specify the skeleton. The specification of the orientation and constraints for each bone is important especially when controlling characters using scripts and API's for the packages. While motion capture can provide nuances in the motion, the animator has very little control on the animation. However, for key framing and scripting creating various nuances is difficult and time consuming unless different interpolation methods are developed and is dependent on the skill of the animator.

Cal3D is a stand alone skeletal based 3D character animation library written in C++ (Heidelberger, 2005). It is designed for putting 3D characters into an interactive graphical application. It is composed of a skeleton and a mesh and all the mesh vertices are attached (known as 'skinning') to one or more bones of an underlying skeleton (see Figure 2.1). Cal3D keeps track of each bone orientation both locally (relative) and globally (absolute) as quaternions. Cal3D is designed to store an animation inside the model. An animation comprises of a track for each bone that is affected by the specific motion. The animation is stored as keyframes and the transformation data for a bone is stored in several keyframes contained in the corresponding track. The current system interpolates between keyframes using a SLERP algorithm. Dance notations specify dance movement as a sequence of key poses (i.e a pose at a keyframe) with a description of the movement either notated or inferred. The Cal3D library lends itself well to posing a virtual human, however, there is a need for specifying rules for inputting dance poses and methods for the interpolation between key poses so the movement is appropriate as defined by the notation.

2.2.3.3 Ryman's Ballet Moves and DanceForms 1.0

DanceForms' interface uses dance friendly terminology and familiar concepts to aid dance teachers and choreographers using the system to develop dance movement faster by posing the character and playing back the results on a stage. This is achieved by chronicling the details of motion step by step in a core window and seeing the final product in the performance window. It is bundled with the Ballet Moves CD-ROM and Modern Dance Moves CD-ROM (based on Daniel Lewis's book, *The Illustrated Dance Technique of José Limón* (1984), with Labanotation by Mary Corey) where the user can select dance poses and movements (Ryman, 2001). Time can be saved by mixing, matching, and blending sequences from these

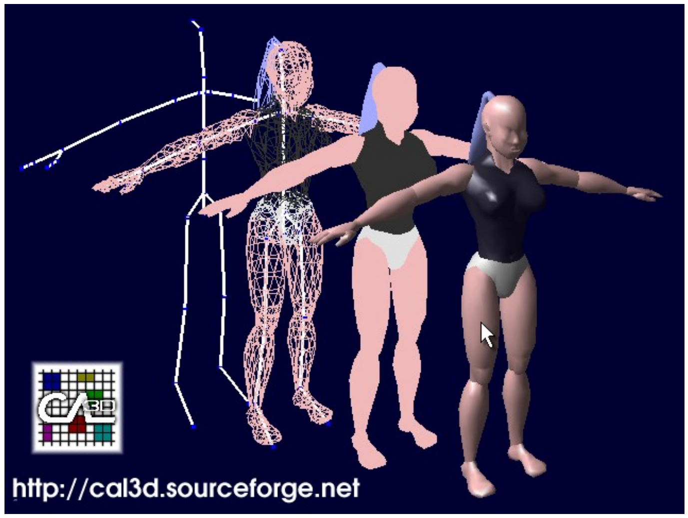


Figure 2.1: The Cal3D phrases showing the skeletal structure, the overlaying mesh and the material of the mesh. Image belongs to Heidelberger (Heidelberger, 2005).

libraries.

DanceForms uses Euler angles and quaternions to orient each body segment in space and provides different options for calculating transitions between positions (e.g. spline versus linear interpolations). While third party applications apply constraints to the orientation of the bones when calculating the rotations using inverse kinematics, further constraints are required for dance movement to capture the dance movement rules and currently there are no methods in current commercial software where constraints relating to dance can be specified. To represent transitions between positions in Labanotation, Ryman *et al.* are currently researching new interpolation options which are being developed for the Dance Notation Bureau's Interface Project (Fox, Ryman & Calvert, 2001) involving LabanWriter and LabanDancer, a program to translate the LabanWriter scores into 3D animation.

2.2.3.4 LabanWriter and LabanDancer

The Interface project was started in 2000 with Ryman, Calvert and Credo Interactive with support from the developers of LabanWriter with the aim to develop software that combines Labanotation scores and computer animation. LabanDancer uses an inverse kinematics algorithm and applies constraints to ensure that articulated limbs carry the movement in an appropriate plane. Intermediate keyframes are used with additional constraints to ensure that articulated limbs do not move inappropriately (Calvert, Wilke, Ryman & Fox, 2005). The score is parsed into three streams. The first interprets gestures (i.e non-weight-bearing movements); the second interprets the weight changes; and the third involves other issues such as sequence repetition, paths etc. Ryman and Calvert (2005) also state a translator program must also include an inferred knowledge base so movement can be interpreted in context of the dance style, for example, the foot may be pointed in ballet but not in folk dancing.

2.2.3.5 Comparison of Animation Systems and Interfaces for Expressive Dance

This section is limited to applications that have the capabilities of or are used for rendering dance animations. For the Interface project, there has been discussion on standardising Labanotation with reference to LabanXML and in the future these standardised data files may be used to input from any Labanotation Editor. However, currently, research using LabanDancer to output to a 3D readable format for DanceForms is currently being developed. In Table 2.1, the Interpreters/ Parsers refers to setting key poses based on dance scripts, and dance notation editors using inferred domain rules to specify the 3D animation sequence to be rendered.

3D Visualisation Applications	Dance Input	Interpreters/ Parsers	Dance Domain Rules	Expressive Model/ Nuances
Third party software (Maya, 3DStudioMax, Blender etc.)	Key frames; Motion Capture; Scripts	No	No	No
DanceForms 1.0	Key framing; Motion Capture; Scripts; Pre-made animations	No	No	No
NUDES	LED files; Scripts	LINTER	Yes⋆	No
LabanDancer Interface	LabanWriter	LabanDancer	Yes†	No
Jack	Key framing Motion Capture	No	No	EMOTE

Table 2.1: A comparison of 3D applications used for creating animated dance sequences. ⋆ LINTER interprets using ballroom domain rules. † LabanDancer is currently researching interpolation methods based on domain rules

Using third party 3D applications such as Maya, 3DStudioMax and Blender to animate dance sequences is not an easy task, because the user needs to understand the dance rules for posing and movement and also have detailed knowledge of the application. Though some tools are provided such as various interpolation methods, a lot of specialist knowledge is required to generate an animated dance sequence. LifeForms (Credo Interactive Inc., 2005b) understood this difficulty and created DanceForms (Credo Interactive Inc., 2005a) designed to be dancer friendly and to be used specifically in the generation of dance animations.

The DanceForm interface was designed with the dance choreographer in mind with ballet positions and movements added to the animation using pallets. This content includes the English and Russian school as well as some of the Italian school. For the animator to create nuances in the animation to reflect different emotions, the traditional approach of changing the poses on the timeline is required. Compared to the other 3D modelling and animation software, this is made easier by a studio window to change the pose of the dancer and a score window to reflect how the dancer moves over time. However, it is worth noting that to create variations, extra key poses are required to be created by the animator.

The most advanced project related to animating dance is the Interface project (Fox, Ryman & Calvert, 2001) which is currently researching interpolation methods. The plan is to use inferred domain rules for the dance style, inputted from the Laban files. However, once created using this method, any further changes, such as adding variation to the movement, requires the animator to import the saved animation into editing software such as 3DStudioMax, DanceForms and Maya where adaptations to the dance sequence can be made by editing the keyframes, adding keyframes and manipulating the timeline.

Compared to the above applications, NUDES is a fairly crude dancer model, however, it is still extremely useful as a visualisation tool for the Labanotation. The ballet rules are specified in the NUDES scripts such as turnout and the orientation to pose the rounded arms. Mainly devised for ballroom with some ballet examples, it is currently unclear exactly what inferred domain rules are used by LINTER when parsing LED output to the animations scripts read by NUDES.

The EMOTE model using Jack is the other end of the spectrum. Here the user can alter parameters (Laban's Effort-Shape) to change the quality of the movement. There are currently no methods where ballet rules are specified to create animations based on a dance notation and therefore no garantee EMOTE would adhere to the rules of classical ballet when altering the motion path and orientation of the extremities to create expressive dance movement.

The above applications have many pros when setting dance animation. Motion capture can provide a dance sequence with nuances while animation based on the interpretation of dance editor outputs has been shown to have the potential to specify keyframes for 3D animation packages. To create various styles of animation using these packages, various interpolation methods can be selected including linear and spline. However there is no guarantee that the rules for dance movement will be followed and therefore other interpolation methods are being researched (Calvert, Wilke, Ryman & Fox, 2005). With these current methods, nuances to the movement requires the animator to alter and/or add key poses either on the time line or in the animation script. The two means for making subtle changes are making these changes using a 3D application timeline after the original animation sequence has been imported or manually changing the scripts that have been created from the interpreters of the dance notation editors.

2.2.3.6 Conclusion to Dance Animation Systems and Interfaces

The length of time taken to research and develop dance notation editors and animation systems using their machine-readable format highlights how difficult it is to achieve a system to read, edit, store and display virtual dance. Once achieved, a further question arises. Is the quality of the dance movement acceptable enough? Whereas motion capture creates natural movement (all the detail and nuance of live motion for all degrees of freedom), its disadvantage is not providing full control over the motion plus being labour intensive and costly. Animation systems use movement profiles for interpolation between key poses to create more natural looking movement with control over the animation and there is now research looking into expressive movement (Chi, Costa, Zhao & Badler, 2000).

For all above applications, translators and parsers, the research focus is on making natural movement with constraints so inappropriate movement is not animated during the interpolation process. Currently, the above applications interfacing with a notation editor do not focus on the different qualities of movement related to expressiveness and therefore creates an animated dance sequence and not an animated dance performance. LabanDancer does however, use an inferred domain knowledge base considering different dance styles when recreating the 3D animation though this is still in the research stage.

To achieve an animation where the virtual dancer is performing and not unnatural in the movement will require another layer, for example, a movement model or a style analyser. In terms of animation systems, linear movement between keyframes is not enough and an excellent book to read is the Illusion of Life (Thomas & Johnson, 1981) explaining the art of creating believable characters. Two methods to create more natural movement are: (1) the animator setting more key poses with linear interpolation similar to the traditional way of flick book animation where the dance quality of the animation is limited to the capabilities of the animator, and (2) allowing a choice of different movement profiles, i.e. linear, quadratic or cubic, or other interpolation methods.

A VBD is needed where the specification of the key poses required to create dance animations is supplemented by interpolation methods where the expressive qualities can be manipulated in real-time. A classical ballet teacher not only teaches the techniques required to pose ballet positions and how to move from pose to pose i.e. movement rules but also the quality of the movement. In the real-world, many methods are used to achieve this including setting exercises to music which assists the student to perform with the appropriate nuances. When choreographing, the choreographer will devise and set the dance steps (sequence of movement) and explain the quality required not only for each individual motion but the sequence as a whole. A VBD system that sets dance poses and movement from a machine-readable format following the inferred domain rules and with the functionality to change the quality of the movement in real-time would be beneficial not only for teaching and choreographing but for creating a virtual performance.

2.3 Expressive Dance Gestures and Personality

As discussed earlier, one of the definitions of dance is as non-verbal communication. Many ballets are narrative (e.g. Swan Lake, Giselle, Petruchka etc) where the choreographer and performer together are telling a story through dance to abstract where the choreography is designed to portray feelings and moods. Within the bounds of the choreography, the performer is trying to express their emotions through the defined gestures (i.e. choreography) and the quality of the movement (i.e. how the gesture is performed). Each dancer in a performance not only tries to relate their feelings to the audience but provide an insight into the character's personality being portrayed or in the case of an abstract performance with no story line and characterisation an insight into their own personality. Methods for inputting dance using dance notations and applications such as LifeForms as discussed earlier represents the choreographed gesture. However, while accurately recreating the dance (i.e. a sequence of gestures) can provide an audience with cues to the emotions being portrayed, there is no sense of feeling and personality. This section looks into different research for gestures and in particular, research related to expressive dance motion and the quality of the gesture.

Gesture has many definitions: (1) manner of carrying the body; bearing, carriage, deportment; (2) manner of placing the body; position, posture, attitude; (3) employment of bodily movements, attitudes etc. movement of the body or limbs as an expression of feeling; and (4) a movement expressive of thought or feeling (Simpson & Weiner, 1989) to list a few. Any number of the earlier definitions can be applied to the different scopes of research. With respect to speech phases, Kendon described gesture as action which makes it stand out as a gesture (Kendon, 1980) and later further quantified it as moving away from a rest position and always returning to a rest position. This, interestingly, can be applied to dance. Most dance methods define a set of basic positions/poses. These basic poses are the start and end of a dance gesture. In simulating dance as a sequence of gestures, the definition used in this thesis is a movement expressive of thought and feeling. Dance terminology and its rules can describe the poses and movement of the limbs, it is the expressive qualities added to the movement that distinguishes the motion as dancing.

Gesture research can be separated into two parts. The first set of works can be categorised as research by linguists, psychologists, neurologists, choreographers, physical therapists, etc., and are largely concerned with the conceptual understanding of gesture and its function. The second set of research operates in areas such as computer vision, human computer interaction (HCI), human motor control, and computer graphics (Zhao, 2001).

Dance is used consistently for research on gesture analysis and personality. This is due to artists simplifying the movement by eliminating extraneous movements and then exaggerating it to ensure that its meaning is conveyed to the audience (Neff & Fiume, 2004). In one study, Shastra (Thirumalai, 2001) emphasised the role of gestures as building blocks in the creation of a performance (Kahol, Tripathi & Panchanathan, 2004). Campbell and Bobick (1995) recognising human body motion using phase space constraints used classical ballet with its finite number of discrete movements and descriptions used for over a hundred years. Using the domain rules of ballet, nine "atomic" ballet moves were discriminated and classical ballet steps were recognised. Perlin's Improv project was first demonstrated in "Danse Interactif" (Perlin, 1994) at SIGGRAPH94. Dance movement was used to introduce the texture of motion to avoid computation of dynamics and constraint solvers (Perlin, 1995). The Improv system for the creation of real-time behaviour-based animated actors and presented a system for scripting interactive actors in a virtual world (Perlin & Goldberg, 1996). Actions were simply defined as a list of DOFs together with a range and a time to vary the expression for each DOF. The Improv characters key ingredient for realism is the use of coherent noise giving the impression of naturalistic motions such as the randomness of blinking and the small motions of a character trying to maintain balance.

Camurri with the EyesWeb project (Camurri & Coglio, 1998; Camurri, Mazzarino, Trocca & Volpe, 2001) focuses on tools to analyse expressive gestures, particularly categorising the type of motion in relation to dance. Analysis by groups such as Badler and the Thalmanns is leading towards the simulation of expressive naturalised motion and is discussed in §2.4.

2.3.1 Camurri, the EyesWeb System and MEGA

Early research proposed an architecture to build agents that embed artificial emotions to allow more effective, simulating, and natural interaction (Camurri & Coglio, 1998). Camurri's work on expressive gestures centred around KANSEI Information Processing and Laban's Effort theory. The concept of KANSEI is strongly tied to the concept of personality and sensibility (Camurri, Hashimoto, Suzuki & Trocca, 1999). Expressive gesture communicates information such as feelings, moods, affect and intensity of emotional experience. Movement is considered using two points of view: (1) detailed movement of a single person, e.g. centre of gravity of the dancer in his own kinesphere, and (2) the movement of one or more persons in a wider space, i.e. the general space such as a stage (Camurri, Mazzarino, Trocca & Volpe, 2001).

The system is designed to analyse expressive cues in the dancer's movement such as fluid/rigid or energetic/weak. Camurri *et al.* (2005) accomplished this by extracting syntactic features for movement representation by detecting the amount of motion (called in their case, quality of motion). A gesture or a sequence of gestures can be performed in different ways and nuances, in order to convey different emotional and expressive content. The gesture "raising a hand" can be performed, for example, with different velocity and/or shape nuances of the trajectory. Results from their work have included segmenting dance movements and the contraction and expansion of space used by the dancer according to Laban's Theory of Effort, i.e. the space around the body called Kinesphere (Camurri & Trocca, 2000).

EyesWeb and its components, such as the Motion Analysis Library, the Space Analysis Library and the Trajectory Analysis Library (Camurri, Mazzarino & Volpe, 2003), has led to the Multisensory Expressive Gesture Applications (MEGA) project, which centred on the modelling and communication of expressive and emotional content in non-verbal interaction by multi-sensory interfaces in shared interactive Mixed Reality environments. As well as music performance, the focus is on full-body movements as first class conveyors of expressive and emotional content. The research issue in the MEGA project is the study of the mapping strategies of the recognised expressive content onto multimodal outputs.

2.4 Virtual Human Emotions, Behaviour and Expressions

Development towards creating a realistic expressive virtual human is no easy task and there are many approaches to creating a virtual human with personality and emotions generated through expressive synthesis. Recently there has been an upturn in research towards expressive nonverbal behaviour and expressive virtual humans. The most common approach is to parameterise expressivity attributes whether derived from psychology literature or movement analysis such as Laban's Effort-Shape theory. To represent, simulate and integrate different degrees of human movement touches on diverse areas such as computer graphics, computer vision, robotics, and computational linguistics

A different approach is the use of parameterised expressivity attributes in the behaviour selection mechanism where the selection process includes the emotional state of the behaviour based agent and its perception of its environment. Behaviour selection based on sensory inputs can lead to more realistic characters with personality by reacting with their environment and other virtual characters. Ballin, Aylett and Delgado (2002) present the project to develop Intelligent Virtual Agents using BALSA (Behavioural Architecture for Lifelike Synthetic Agents). Characters, in this case teletubbies (©Ragdoll Productions (UK) Ltd.), are given internal drives and imperatives including hunger, excitability, happiness and sleep. The characters interact using virtual sensor inputs coupled to virtual actuator outputs. For further interesting interaction, the need for a richer emotional model is introduced, particularly when agents have little verbal interaction and emotional interaction is required to stimulate behaviour. Delgado and Aylett (2004) discuss work extending a behavioural agent architecture to include a low level emotional system and communication of emotions between agents using virtual odour. This is presented using virtual sheep and demonstrates how emotion can be used to mediate between individual and group behaviour.

Unuma *et al.* (1995) described a method for modelling human figure locomotion's with emotions using a continuous rescaled Fourier technique to allow smooth transitions between two motion captures using interpolations as well as generating exaggerated motions using extrapolation. They showed walking and running examples with different emotions or moods including 'tiredness' and 'briskness'. Amaya *et al.* (1996) presented a more general method for adding emotions. Using techniques for signal processing, they calculate emotional transforms which are applied to existing neutral emotions giving the motion a quality such as angry or sad.

The HUMAINE project (Humaine, 2005) aims to lay the foundations for European development of systems that can register, model and/or influence human emotional and emotion-related states and processes - "emotion-oriented systems". It identifies six areas: theory of emotion; signal/sign interfaces; the structure of emotionally coloured interactions; emotion in cognition and action; emotion in communication and persuasion; and usability of emotion-oriented systems.

Other major groups focusing on personality and emotion simulation include: Miralab led by Magnenat-Thalmann (Magnenat-Thalmann & Thalmann, 1989) and the Center for Human Modelling and Simulation led by Badler (Badler, O'Rourke & Kaufman, 1980; Noma & Badler, 1997; Badler, Chi & Chopra-Khullar, 1999a; Granieri, Crabtree & Badler, 1995).

2.4.1 Badler, Notation and EMOTE

Synthesised characters are expected to make appropriate face, limb and body gestures during communicative acts. In "To Gesture or not to Gesture: What is the Question", Badler *et al.* (2000b) presented the need for non-facial movements to elucidate what is intended and argued looking at only the psychological notion of gesture and gesture type is insufficient to capture movement qualities. In "A Computational Alternative to Effort Notation", Badler (1989) states without motion dynamics, computer animation looks flat or mechanical at best; discontinuous or jerky at worst. This paper discussed the implementation of kinetic and dynamic control looking at attack acceleration at the start of the motion and the decay acceleration at the end of the motion and compared dynamic versus keyframe parameter control. Using the Effort qualities derived from Laban's Effort-Shape theory, dynamic changes were created by altering the spacing of the keyframe times, i.e. varying the kinetic interpolation.

Using Badler's Jack (Badler, Phillips & Webber, 1999b), movement observation science was used to simulate expressive movement qualities. Chi devised methods to apply parameterised Effort and Shape qualities to movements to improve gestures (Chi, Costa, Zhao & Badler, 2000; Chi, 1999a) which they called EMOTE (Expressive MOTion Engine).

Chi (1999b) created and implemented a kinematic analog to the Effort part of Laban's Effort-Shape theory for her PhD dissertation. Focusing on the arm and torso movement, the four features they felt were essential to convey naturalness and expressiveness were: (1) a given movement may have Effort and Shape parameters applied, (2) the parameters may be varied along distinct numerical scales, (3) different parameters may be specified for different parts of the body, and (4) the parameters may be phrased across a set of movements (Chi, Costa, Zhao & Badler, 2000). By applying effort to the trajectory definitions, path curvature and interpolation space, and parameterising the timing control, changing the keyframe time and the number of frames between key points, controlled change in the movement quality is achieved based on Laban's Effort. The shape model was applied to the torso and arms. For the arms, shape is based on the horizontal, vertical and sagittal dimensions to vary the kinespheric reach space. The torso associates spreading, enclosing, rising, sinking, advancing and retreating to specify displacement angles of the pelvis, spine neck and clavicle joints.

Zhao and Badler described a new paradigm in which a user will be able to produce a wide range of expressive, natural-looking movements of animated characters by specifying their manners and attitudes with natural language verbs (Zhao, Badler & Costa, 2000). Using EMOTE and a Parameterised Action Representation (PAR), a natural language interpreter was devised as an interface between natural language instructions and expressive movement by translating the adverbs into modifiers which modify the the Effort-Shape parameters (Badler, Bindiganavale, Allbeck, Schuler, Zhao & Palmer, 2000a). The manner obtained from the PAR is passed to the EMOTE engine which governs the movement of the performance and the user does not need to worry about the low-level interpolation parameters. In Zhao's PhD dissertation (Zhao, 2001), he also researched into the syntheses and acquisition of communicative gestures by extracting from live performances, either in 3D motion capture or 2D video data, to correlate with observations validated by Labanotation notators. By looking at the quality of movement using Effort and Shape components, he provided an initial framework where key poses, timing and Effort parameters can be extracted from live data input and for the procedural generation of expressive gestures for computerised communicating agents.

With FacEMOTE (Byun & Badler, 2002), Byun and Badler proposed a control mechanism for facial expression by applying a few chosen parametric modifications to pre-existing expression data streams. The parameters are adapted using Laban's Effort-Shape theory by mapping the values onto sets of Facial Animation Parameters (FAP). The paper discusses the possibility to generate different shades of expression from a single base expression by adding subtle changes.

2.4.2 Cassell, Behaviour and Animated Conversation

Cassell *et al.* first introduced a system for automatically animating and generating conversation between human-like agents, described in Animated Conversations (Cassell, Pelachaud, Badler, Steedman, Achorn, Becket, Douville, Prevost & Stone, 1994). The speaker/listener relationship, the text, and the intonation in turn drive expressions, lip motions, eye gaze, head motion, and arm gesture generators. The four basic types of gesture during speech were demonstrated: Iconics represent some feature accompanying speech such as drawing a rectangle while asking for "the check"; Metaphorics represents an abstract feature concurrently spoken; Deictic indicate a point in space; and Beats are small formless waves of the hand that occur with heavily emphasised words. Gestures were selected from a library of predefined hand shapes and the expressiveness was represented by adjusting the size of the gesture space.

Cassell focused on natural movement and behaviour based on linguistic and contextual analysis of typed text. In 2001, Cassell *et al.* presented the Behaviour Expression Animation Toolkit (BEAT) which allows animators to input typed text that they wish to be spoken by an animated human figure (Cassell, Vilhjálmsson & Bickmore, 2001) relying on rules derived from extensive research into human conversational behaviour. Extensible so new rules can be added, BEAT was designed to plug into larger systems that may also assign personality profiles, motion characteristics, scene constraints, or the animation styles of particular animators.

The non-verbal behaviour researched includes attention, positivity, and coordination. This focus is primarily to understand and simulate a sense of rapport between two people in conversation and the implementation of *virtual peers*.

2.4.3 Thalmann and Magnenat-Thalmann

In "Motion Control of Virtual Humans", it was discussed that computer animation technologies let users generate, control, and interact with lifelike human representations in virtual worlds (M.Cavazza, R.Earnshaw, N.Magnenat-Thalmann & D.Thalmann, 1998). They presented the different approaches and defined the different actors as (1) 'autonomous virtual humans' that should be able to demonstrate a behaviour, which means they must have a manner of conducting themselves; (2) 'guided actors' which do not correspond directly to users' motions but are a type of avatar based on the concept of a real-time direct metaphor. Participants use input devices to update the virtual actor's position; (3) 'interactive-perceptive virtual actor' are actors aware of other actors and real people; and (4) 'real-time synthetic actors' representing users so that they can interact with the environment and other avatars. They also discussed language interpretation and behavioural models. Guye-Vuilléme and Thalmann (2000) also argued sociological concepts are important for the creation of autonomous social agents capable of behaving and interacting realistically with each other and the development of an architecture fulfilling the requirements for social interaction to provide realistic and rich behaviours.

Thalmann (2000) discussed virtual humans and gesture in "The Virtual Human as a Multimodal Interface". Gestures were defined as two types: predefined gestures and task-oriented motion. The motor functions required for each gesture were generally based on biomechanical experiments and considered different parameters. For expressing emotions, the head was used as an example problem and was segmented as: high level actions concerning the emotions, the sentence and the head movements of the virtual actor; mid-level actions, defined as expressions of the face; and low-level actions defining the 63 regions of the face corresponding to facial muscle.

Synchronisation of speech, facial expressions and body gestures is one of the problems in realistic avatar animation in virtual environments. Kshirsagar *et al.* (2002) used low-level animation parameters, defined by the MPEG-4 standard, to demonstrate the use of the Avatar markup Language (AML). IMPROV and BEAT for controlling character animation were discussed and the paper made comparisons with VHML (Virtual Human Markup Language), its deficiencies and how AML is an improvement. With respect to expressive motion, a behaviour library is triggered and processes (e.g. mixes predefined animations, changes of speed, etc.) the animations generated.

Magnenat-Thalmann, a member of HUMAINE, and MiraLabs work on personality and emotion simulation is similar to earlier research where the personality and emotion is linked to response generation and expression synthesis powered by a dialogue system. A personality module is devised where the virtual human response depends not only on input given by the user, but also on the personality and emotional state of the virtual character(Egges, Kshirsagar & Magnenat-Thalmann, 2002b). Presenting a generic model for describing and updating the parameters related to emotional behaviour, existing theories such as OCC (Ortony, Clore & Collins, 1988), using goals, standards and attitude, and OCEAN (Costa & McCrae, 1992) which has five factors: openness, conscientiousness, extraversion, agreeableness, and neuroticism are integrated into the framework (Egges, Kshirsagar & Magnenat-Thalmann, 2002a).

2.5 Motion Synthesis for Natural Movement

Research in stylistic motion synthesis or creating animations with a small number of key frames has involved dance and sets of motion capture. One of the main groups focusing on motion synthesis is the New York University Media Research Lab and in particular the department for Human Movement. Brand and Hertzmann's early work approached the problem of stylistic motion synthesis by learning motion patterns where each choreographed sequence was performed with distinct style (Brand & Hertzmann, 2000). This work focused on the different styles of movement such as ballet and modern dance. Their work proposed the learned model can synthesise novel motion data in any interpolation e.g. convert novice ballet motions into modern dance of an expert. The system was trained on four performances by classically trained dancers (man, woman-ballet, woman-modern-dance, woman-lazy-dance) of 50-70 seconds with approximately twenty moves and new choreography was generated.

Pullen presented a method for creating animations from a small number of key frames with motion capture data used to enhance the animation (Pullen & Bregler, 2002). The motion captured data provides a data set with all the detail of live motion. Texturing was presented for generating variations to the animation and based on the key poses and captured data, synthesis generates animation. The paper presents an example where the upper body synthesis is driven using the left knee and hip angles. Modern dance was used to investigate a wider range of motion than those of walking and running, this was because unlike ballet and other classical forms, the constraints are more relaxed. In the conclusion, one drawback of the method stated is that it does not incorporate hard constraints and therefore it is not possible to texture for example where the feet are meant to remain in contact with the floor. This would be a problem texturing classical dance where constraints are applied throughout.

More recently, led by Hertzmann, an inverse kinematics system was developed based on a learned model of human poses (Grochow, Martin, Hertzmann & Popović, 2004). Given a set of constraints, the system produced the most likely pose satisfying those constraints in realtime. Training the model on different input data leads to different styles. By restricting the space of valid poses, there was a greater potential for generating the motions of characters to both look realistic and satisfy the constraints. Examples presented in this paper are catching a ball or jumping. The potential towards ballet and other dance styles with the constraints applied defined by the dance rules can be seen as future work, however, the discussion states too many hard constraints can prevent the problem from having a feasible solution.

Liu and Popović (2002) presented a general method for rapid prototyping of realistic character motion. The paper discusses how realistic motion can be achieved by enforcing a small set of linear and angular momentum constraints. This paper focused on dynamic movement such as jumping, kicking, running, and gymnastics and not low energy motions such as walking and reaching. A user specifies a number of keyframes and using three constraints: environmental that correspond to user-intended motions and separate the original motion sequence into constrained and unconstrained stages; transition pose between constrained and unconstrained animation stages; and momentum according to the Newtonian laws and biomechanical knowledge. This method is best suited to highly dynamic motion governed by Newtonian physics.

Li *et al.* (2002) presented a technique for synthesising character motion related to creating a dance sequence setting a start frame and an end frame that is statistically similar to the original motion captured data. Motion texture is presented by a set of motion textons. A texton is defined as the local linear dynamics and though difficult to extract, repeated patterns were modelled. The global dynamics were set by switching between the textons. This method was best suited to motion of frequently repeated patterns and synthesised motion lacked global variations when data sets were limited.

Biological motion contains information about the identity of an agent as well as his or her actions, intentions, and emotions (Troje, 2002). Using simple gender examples, classifiers were constructed and compared. A simple motion modeller was presented that can be used to visualise and exaggerate the difference in male and female walking patterns. The study showed that the dynamic part of the motion contains more information about genre than structural cues. In this paper, it is discussed how the linearisation of motion data for classification purposes can be extended to include other attributes such as age, weight, emotional state, or personality traits and include other actions, however, this would require its own formalisation.

2.6 Summary

There is a notion in the Arts of "believable characters" meaning that the audience believes what they see, i.e., providing the illusion of life (Bates, 1997). Many performers judge their performances not only by the application of the skill but whether it was a believable performance.

Creating believable performances whether expressive gestures, circular motion such as walking gaits, or generalised motion, the researchers in this chapter are searching for realism and natural movement. They are looking to analyse, adapt, simulate and/or synthesise realistic natural motions that fuel the viewer's suspension of disbelief.

In "Disney Animation: The Illusion of Life", Thomas and Johnson (1981) explain Disney's technique claiming that action shows the thought process and how the emotion is accentuated. However, as more research is presented and discussed, particularly with the use of motion capture data, it can be seen that virtual characters are successfully being simulated by replicating real motion.

In this chapter, various methods were discussed relating to expressive gestures and behaviour with the overall objective to better understand how to generate realistic expressive characters. Dance has been a component to better understand behaviour and expressive motions by focusing on parameterising how the dancers move. Research to create realistic dance motion on a virtual dancer has mainly focused on (1) motion capture techniques where the dancer emulates various motions performed by the captured subject or (2) using animation systems where key poses have been inserted nuances are created by adding extra key poses.

Motion capture research utilises algorithms for texturing and synthesising dance movement with some excellent realistic results, however, there is currently little concept of what quality is being performed and controlling that quality. It is not possible to specify happy or sad movement by description or parameterisation. With respect to using animation systems, the most advanced research by Calvert *et al.* (2005) is providing methods related to the ballet rules. All movement is specified by the dance notation system used and therefore no nuances to the motion are applied to generate expressive motion.

Chi (2000) provided methods that parameterised how gestures are performed using Laban's Effort theory. This proved to be an excellent starting point towards developing a VBD. Using these parameters, Chi varied the gestures including adapting the key poses. While this works for gestures used in conversation, this can not be applied to classical ballet where the dance pose has to adhere to the ballet rules that define it. It is worth mentioning that this method could be applied to contemporary dance. Camurri (2001) provided research demonstrating how these parameters could be used to define contemporary dance movement, however, parameterisation of contemporary dancing defines the shape of the complete movement rather than the qualities of the individual parts as is required for classical ballet where strict rules determine the shape of the movement to be performed.

Both Pullen (2002) and Li *et al.* (2002) demonstrate through their research on texturing and synthesis how the subtle variations in the motion determine the various qualities being performed. This, however, like Camurri was again applied to modern dance where the constraints are more relaxed meaning that dance movement is not performed incorrectly providing the motion looks natural and realistic. To apply realistic natural movement to ballet is not easy and therefore an approach is needed somewhere between the work performed by Chi and the research by Camurri, Pullen and Li.

To develop a system to demonstrate the performance of a VBD, many aspects of the research mentioned were looked at and analysed. Though not applied to dance, for expressive motion, the work performed by Chi was the closest to the expressive requirements for a VBD. Using Laban's parameters, the algorithms presented by Chi adapted final pose of the gesture and varied the velocity with other parameters affecting the amount of orientation performed in the wrist and elbow joints. This research needs to apply the same concepts with the exception of the final pose adaptation. However, their mathematical equations can not be applied to a VBD which adheres to the rules of ballet. Another aspect is the flow of the movement in ballet, while anticipation and overshoot effects are important for the start and end of a movement, this cannot be applied at each key pose in classical ballet which may be an intermediate pose describing a complex dance step. Therefore a VBD requires a new profile to represent the motion along a movement trajectory.

Chapter 3

Analysing Differences in Real-world Emotive Movements

3.1 Introduction

To develop a student dancer into a performer takes years of hard grafting of repetitive movement starting with the most basic of motions. Once the basics have been taught to a level where the dancer can pose and move using the rules of ballet, another layer is added to the movement to turn the dance movement from exercises into performances. Using my experience as a professional ballet teacher and ex-professional dancer, the same approach is used to develop a virtual ballet dancer (VBD) i.e. setting the combination of ballet poses and then layering an expressive algorithm to the animation sequence.

The following requirements have been identified to develop a system for viewing and varying the performance of an expressive VBD:

Requirement 1 The way a dancer moves with different emotions are understood and parameterised

Requirement 2 The system can present a VBD where the variations in motion can be distinguished

Requirement 3 The virtual dancer has a structure that can be manipulated using a dance notation

Requirement 4 The system reads and parses a machine-readable representation of a dance notation (this research will use Benesh notation)

Requirement 5 The system can pose the VBD using a dance notation adhering to the rules of the notated dance

Requirement 6 The system can set a series of poses at specified times to create a dance sequence from the parsed notation

Requirement 7 The VBD pose adheres to the rules of classical ballet

Requirement 8 The system can change the quality of the interpolated motion using motion description parameters

Requirement 9 The variations in the movement to simulate expression is within the bounds of the ballet movement rules and the movement specified by the dance notation

These requirements are highlighted throughout the research when being applied.

To understand the requirement for expressive dance simulation, this chapter has been designed to identify features which distinguish different emotions. These features can be categorised into three main objectives:

1. (Requirement 1 and 2) Defining the level of interpolation a dance visualisation system requires where a user can identify the difference in emotions from the expressive movement animated. To identify the level of fidelity needed from real-world dance performance to simulated dance animation in a virtual environment (VE).

2. (Requirement 3 to 7) Developing mathematical rules to pose a virtual character correctly to layer the expressive movement onto. See Chapter 4.

3. (Requirement 8 and 9) Developing an algorithmic model to manipulate the movement parameters to simulate expressive motion that can be interpreted by the user. How does real-world dancing translate to virtual animations? See Chapter 5.

From understanding emotions discussed in Chapter 2 and my own experience, expressive movement is interpreted and distinguished by the users and audiences.

While ballet allows some leeway in the shape of the arms and the amount of rotation in the head and body, there are no changes to the shape of the gesture. As a professional teacher, we aim to teach the performer to 'feel' the movement to best present the emotions and qualities in the music. This includes variations in the accent of the movement, the shape of the movement within the rules of ballet, the tempo and the strength or weight of the movement. With this training audiences can distinguish various emotions being portrayed, even from the back of the auditorium. For recorded and televised production of dance, while there are some close-ups, most of the productions are still presented from a distance for the viewer to get an overall feel of the performance. This informs us the quality of the movement is as important as facial expressions, choreographed gestures and the ambience of the scene such as music and lighting.

The overall goal of our research is to develop a VBD that helps professional performers to visualise the choreography required for a certain performance. To achieve this, two broad categories of fidelity need to be considered. The first category is the visual appearance of the VBD, i.e. the physical characteristics of the VBD on a given computer display (size, resolution and (non)stereo viewing) and the second category is the realism with which the dancer moves, i.e. the smoothness and accuracy of the animation of the VBD's movement.

This chapter describes two experiments that manipulated digital videos of ballet performances to ascertain some of the fidelity requirements for a virtual dancer. Two experiments were designed to measure whether professional dancers could distinguish between the emotions when they were presented at reduced visual detail compared with the real-world and a reduction in the smoothness of the movement. Experiment 1 investigated whether participants could discriminate between ballet exercises performed with different emotions when those exercises were displayed as small videos on a computer screen (a reduction in size and resolution compared with the real-world). Experiment 2 investigated the effect of the video frame rate, which has implications for the fidelity required of the movement model.

The factors investigated for experiment 1 were ten different pairs of emotions performed with three different levels of complexity. Participants with a foundation in professional ballet were required to distinguish whether the ten pairs of emotions (combinations of happy, sad, angry and afraid) were the same or different for two exercises carried out at three different levels of complexity.

For experiment 2, the factors were six pairs of emotions performed with two levels of complexity at four different frame rates. Participants were required to distinguish between the emotions (combination of happy, sad and angry) from four two dance exercises at each of the lowest and highest level of complexity, which were displayed at four different frame rates.

The movements had three levels of complexity (*easy*, *medium*, and *hard*) with each level having two exercises. Easy movements were choreographed to involve movement of the head, upper torso and upper limbs. Medium movements extended the easy movements by including lower limb movements which added travel and one leg balances increasing the technical requirements. The hard movements involved jumping as well as upper and lower limb movements. The dancers were required to land on one foot and in one instance perform half a turn requiring even greater technique and were choreographed extending the medium movements. The four emotive themes (*happy, sad, afraid* and *angry*) generated different movement in relation to Laban's time, weight and space descriptors (Dell, 1977). The four emotions were chosen because of their combined effects in Laban categorisation. When combined, it can create significantly different and contrasting nuances for each emotion in the performance of the exercise.

3.2 Movie Collection and Manipulation of Dance Movement

3.2.1 Location, Personnel and Layout

The data was recorded in the University of Leeds Clothworkers' Centenary Concert Hall as shown in Figure 3.1. This allowed unrestricted movement by two classically trained ballet students who were separated by a partition to avoid being influenced visually by the movements of each other. See Figure 3.2 for the plan of the layout.

3.2.2 Dance Movement

This section describes the six exercises used for the experiments using both Cecchetti ballet terminology for describing positions and movement and the Benesh notation for each exercise. The positions described are the key poses used for the experiment and the movement and position has a number in brackets provides the count the pose is to be achieved when counting the exercise in tempo.

Figure 3.1: The experiment setup in the Concert Hall.

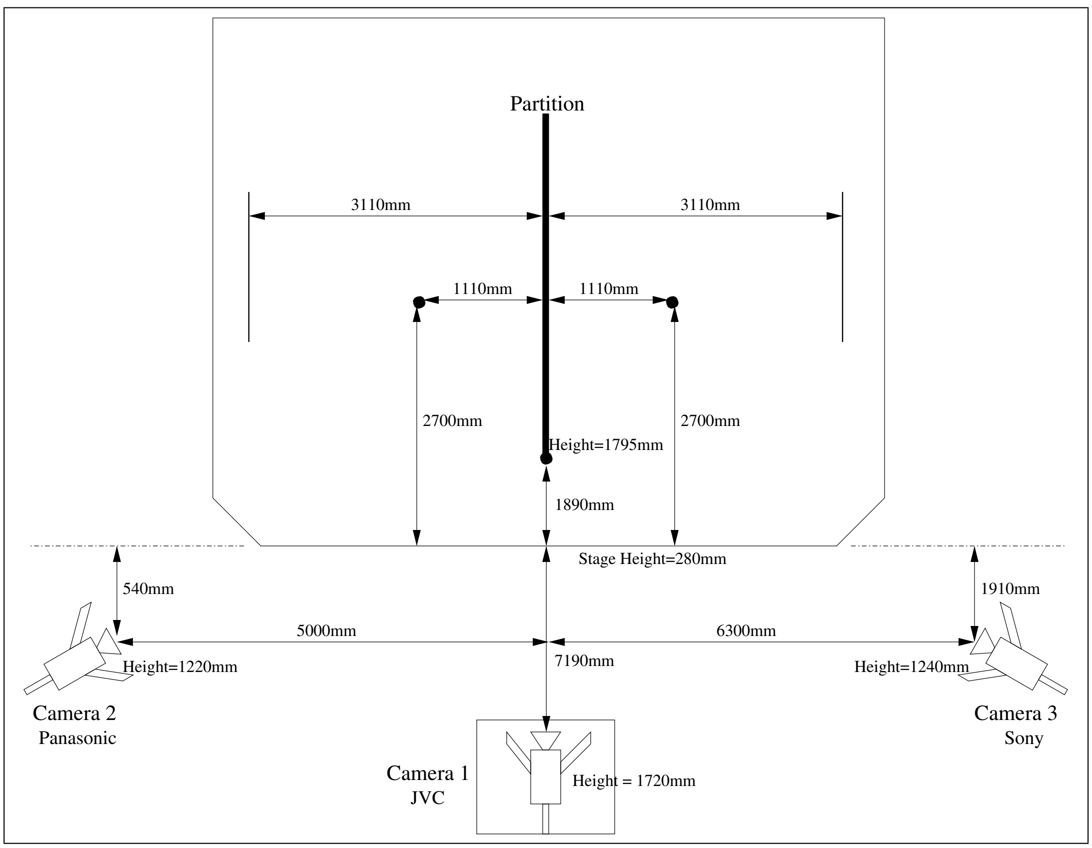


Figure 3.2: The Clothworkers Centenary Concert Hall set up for video capture of ballet movements. The movies for the experiments discussed in this chapter was the front perspective taken using camera 1 (JVC).

Easy **Exercises**

1. **Third port de bras** from the Cecchetti syllabus (in 4 counts)
   Fifth en bas to fifth en haut (1),
   transfer the head to the other side (2),
   open â la secondé (3),
   lower to fifth en bas (4).
   Repeat

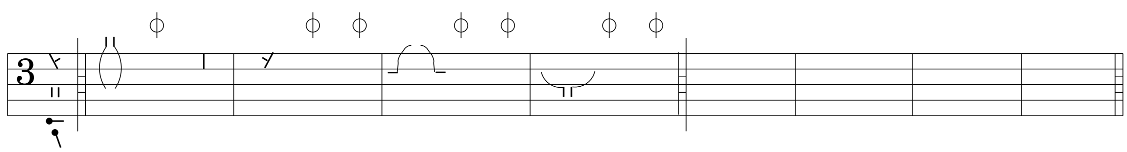


Figure 3.3: Benesh Notation for Easy Exercise 1 (Third port de bras).

2. **Fourth port de bras** from the Cecchetti syllabus (in 4 counts)
   Preparation to fourth en haut,
   open arms â la secondé (1),
   to fourth en haut on the other side (2),
   lower to fifth en bas (3),
   to fourth en haut(4).
   Repeat

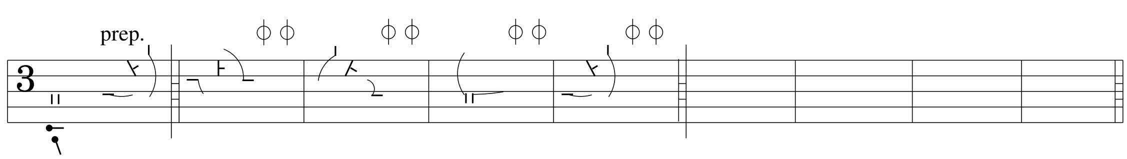


Figure 3.4: Benesh Notation for Easy Exercise 2 (Fourth port de bras).

Medium **Exercises**

1. **Temp Lie devant and derriére with grand battement**
   Grand battement fourth devant (1) [arms fifth en haut],
   transfer weight through fourth position (2),
   grand battement fourth derriére (&3)[arms first arabesque],
   close to fifth (4).
   Reverse [with the same arms]

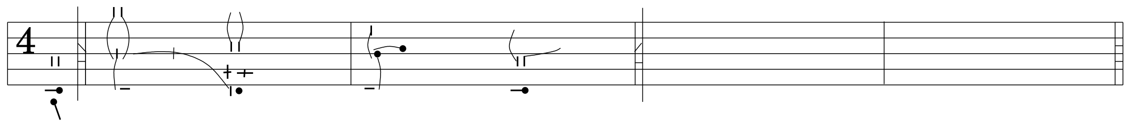


Figure 3.5: Benesh Notation for Medium Exercise 1 (Grand battement exercise).

2. **Adage to secondé**
   Développé â la secondé (1-4),
   releve fifth(5)[arms fourth en haut],
   fondu on right and cou-de-pied the left derriére[arms â la secondé],
   tendu secondé close devant.
   Repeat on other side

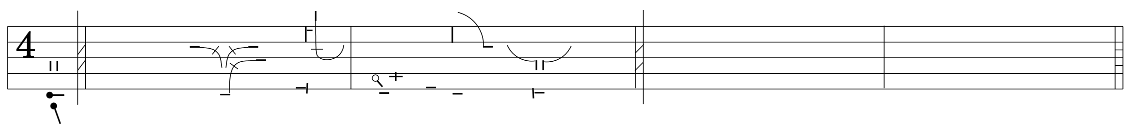


Figure 3.6: Benesh Notation for Medium Exercise 2 (développé exercise).

Hard **Exercises**

1. **Grand jete en tournant**
   Chassé to arabesque (prep) [arms first arabesque],
   step (1), grand jete en tournant (and 2) [arms through fifth en haut],
   coupe (&) chassé to arabesque (3, 4) [arms as preparation].
   Repeat

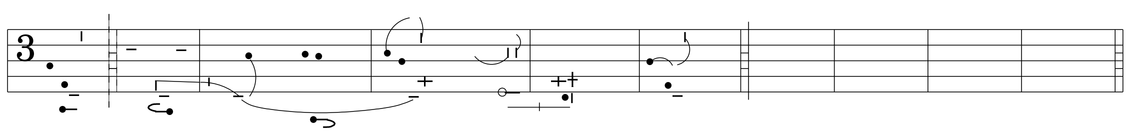


Figure 3.7: Benesh Notation for Hard Exercise 1 (Grand jete en tournant exercise).

2. **Allegro**
   Glissade(& 1), jete derrière (2) [arms fourth en avant],
   temp levé (3) [arms fourth en haut],
   assemblé coupé(4) [lower arms to fifth en bas].
   Repeat to the other side

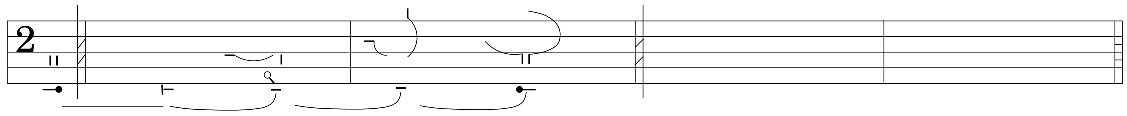


Figure 3.8: Benesh Notation for Hard Exercise 2 (Glissade jete exercise).

3.2.3 Procedure

The recording of the exercises were split into two sessions during a day lasting a total of 5 hours. Prior to the start of the first session, the dancers were given an explanation of the level of choreography required and the motives they would be given for each exercise. Each session involved the recording of an easy, medium and hard exercise, and used the following procedure.

1. Explain choreography to dancers
2. Allow a practise run through for the dancers
3. Give motive description
4. Start recording on all three cameras
5. Use labelled clapper board sheets on camera to mark video position of exercise and motive
6. Count the dancers in so they start at the same time
7. Stop cameras
8. Repeat 3 to 7 for all motives in a different order
9. Repeat 1 to 8 for second exercise at the same complexity level
10. Repeat 1 to 9 for medium exercise
11. Repeat 1 to 9 for hard exercise

3.2.4 Extracting the Movies and Application Construction

The original movies that were filmed contained both dancers. An application was developed to extract each dancer as a separate movie with a selection of frame rates (see below).

The video movies recorded at 25Hz were downloaded using Firewire into a format compatible with 'Quicktime 4 Linux' (found at `openquicktime.sourceforge.net/`) and an application has been developed to load and manipulate the movies on a frame by frame basis. The application had two main functional components. The first function allowed the movie to be cropped and each dancer to be displayed and stored separately as Quicktime encoded movies. The second function reconstructs the movie at different frame rates as specified. It would be simple to down sample the movie at a given frame rate. However, keyframes that correspond to the notated poses (Figure 3.3 - 3.8) often get culled using such a direct approach. (See Figure 3.9) Therefore, an alternative solution was implemented that preserved the keyframes at the expense of introducing jitter.

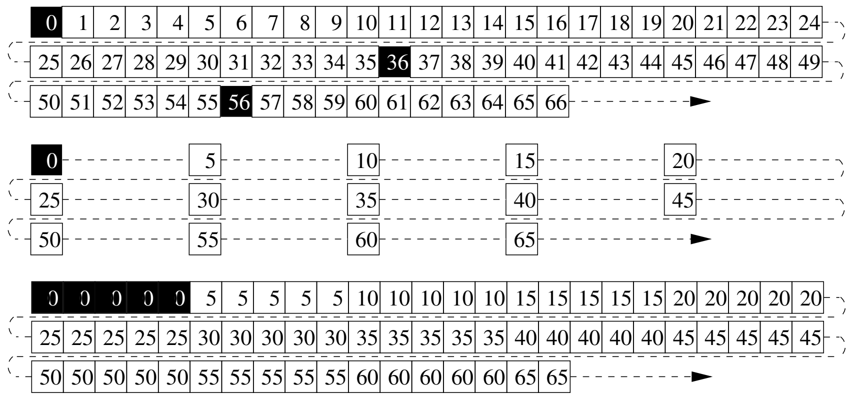


Figure 3.9: Down sampling a movie not taking into consideration the key frames. Black frames are the key poses shown in Figure 3.10 Top diagram at original frame rate 25Hz capturing all key frames, middle diagram demonstrating down sampling to 5Hz missing all key frames except the first, and the bottom diagram demonstrating emulating 5Hz playing at 25Hz also missing the key frames

The frame rates selected for analysis ranged from 5Hz (jerky movements) to 25Hz (smooth with the usual video flicker). Preserving key poses required two stages: (1) manually identify keyframes in every video and store frame rate numbers where the frame selected mapped the dancers position to the Benesh notation (see Figure 3.10); (2) to determine which frames should be displayed in-between keyframes (IBK) to approximate a given frame rate. The number of frames (n) between each pair of key frames was calculated using Equation 3.1 where (N) is the original number of frames, (r) the new frame rate and (R) the original frame rate.

$$n = \frac{N \times r}{R} \tag{3.1}$$

The value of n was rounded up to the nearest integer, and IBK frames chosen so they were approximately equally spaced. (see Figure 3.11) The following two examples illustrate how this works.

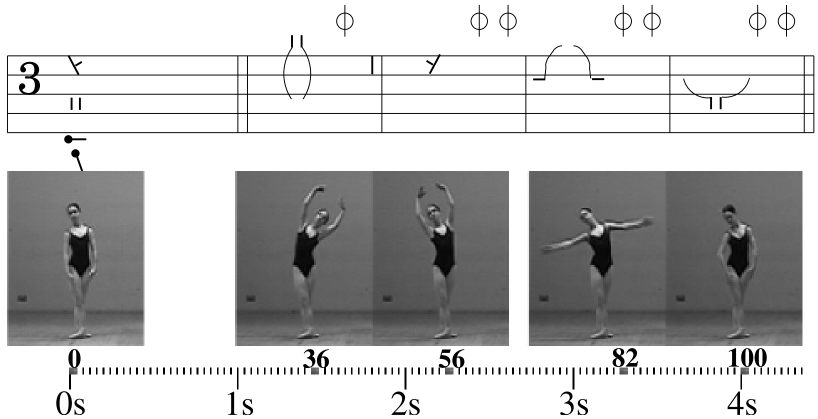


Figure 3.10: The top row of this figure shows a 'port de bras' in Benesh notation, the middle section illustrates the key poses with the bottom section presenting the elapsed time and frame numbers (0, 36 etc.) for the keyframes.

Example 1: Keyframes at frame number 36 and 56. From Equation 3.1 for 5Hz frame rate, $n = 4$ therefore the IBK frames are 41, 46, and 51.
Example 2: Keyframes at frame number 0 and 36. From Equation 3.1 for 5Hz frame rate, $n = 7.2$ (rounded up to 8) therefore the IBK frames are 5, 9, 14, 18, 23, 27 and 32.
Example 1 is a perfect fit. Example 2 introduced some jitter to the frame rate, but the most jitter in any of the videos was 0.02*sec* and this was accepted to be negligible to the human eye.

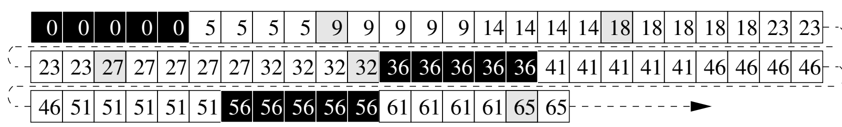


Figure 3.11: Down sampling a movie taking into consideration the key frames emulating 5Hz playback at 25Hz. Black frames are the key poses at the correct frame rate and grey frames are changes in the frame rate to keep the frames approximately equally spaced and capture the key frame shown in Figure 3.10.

3.3 Experiment 1

3.3.1 Introduction to Motion Recognition

Experiment 1 investigated the users' ability to distinguish emotions performed by a trained classical dancer. All the videos used a constant frame rate (25Hz). The fidelity level was lowered from the real-world to: a 3D representation displayed on a 2D

LCD display; a slight degradation in resolution (some artifacts from re-compressing the videos as MOVs); and a small image size (220×175 pixels). Participants viewed pairs of videos and judged whether each pair was danced with the same or different motive theme. Three sets of analyses are presented: (1) percentage correct judgements for same versus different emotions at the three levels of complexity; (2) the accuracy of participants judgements between pairs of the same emotions; and (3) the judgements between emotions that were different and had either similar or different properties in Laban's space, weight and time dimensions.

3.3.2 Method

Participants

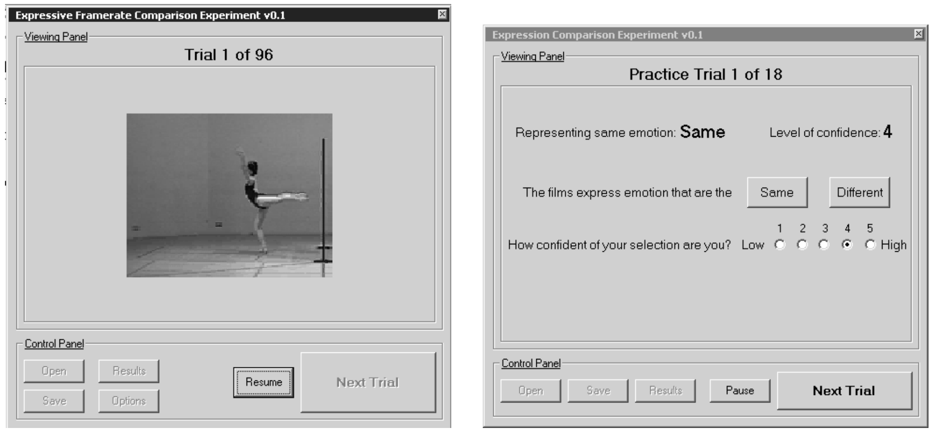
Six adults, three males and three females, participated in this experiment. The ages ranged between 28 to 40 years of age with a minimum of 8 years current or past professional experience in ballet and/or teaching dance at a professional level.

Materials and Procedure

For the real world experiments, a bespoke VB application developed to present pairs of videos which was run on a Dell Latitude C600 Intel Pentium III 600MHz with 256M RAM and an ATI Rage Mobility 128 video card (8M). The 14.1" XGA Color TFT display had a resolution set at 1024 x 768 x 16.7 million colours. The system ran the Windows 2000 operating system using Windows MCI for playing embedded multimedia.

With the four emotions, the software generated ten pairs of combinations. Of the ten paired combinations, four had the same emotion {*(happy, happy) (sad, sad) (angry, angry) (afraid, afraid)*} and six had different emotions {*(happy, sad) (happy, angry) (happy, afraid) (sad, angry) (sad, afraid) (angry, afraid)*}. To equalise the number of trials for the same and different pairs, there were three trials for each of the same emotional pairs and two trials for each of the pairs making 24 trials for each level of complexity. In total there were 72 trials (24 for each level of complexity). The trials were presented in three blocks of 24 and the order of presentation for the emotional pairings and complexities were randomised. Each trial featured two videos of one of the dancers chosen at random.

For each trial, the application played the pair of videos sequentially followed by two questions for the participants to answer by selections with the mouse (see Figure 3.12). The procedure was:



(a) (b)

Figure 3.12: Screenshots of the experiments video display window (a). Questions and selections interface (b).

1. Subject selects button "Start Experiment"/"Next Trial"
2. Two pairs of video's are played sequentially
3. The question *"The films express emotions that are the"* will pop up with 'Same' or 'Different' selection boxes
4. After the selection a second question pops up. *"How confident of your selection are you?"*. There is a radio selection box from 1 to 5 where 1 is the least confident.
5. The participant selects button "Next Trial"/"End Experiment" button to start the next trial or end the experiment.

During the running of the experiment, the "Next/End Experiments" button, concatenated the results for each trial to a text file.

3.3.3 Results and Discussion

Three types of analysis were performed. First, the percentage of trials that participants answered correctly with the three complexities of exercise, each divided into trials with same versus different pairs, were compared. Second, the percentage correct for the four emotions was analysed (using only trials that contained pairs of the same emotion). Third, the effect of Laban's time, space and weight dimensions was compared by analysing the percentage correct for trials in which different pairs of emotion were presented to participants. All of the analyses were performed using repeated measures analyses of variance (ANOVAs) and none of the interactions were significant.

Participants gave fewer correct answers as the exercises became more complex, but the difference was only marginally significant ($F(1,5) = 3.91, p = .06$). There was no significant difference between pairs of same exercises and different exercises ($F(1,5) = 0.52, p = .50$). See Figure 3.13.

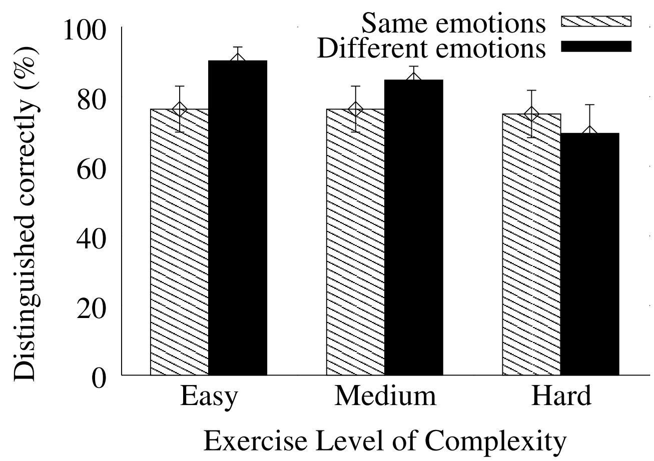


Figure 3.13: Mean number of correctly distinguished pairs of emotions for each exercise level of complexity. Error bars indicate standard error of the mean.

For trials in which pairs of the same emotion were presented, there was a significant difference between the percentage of trials that participants answered correctly for the four emotions ($F(1,5) = 3.43, p = .04$), but not for the three complexities of exercise ($F(1,5) = 0.52, p = .98$). See Figure 3.14. Participants made most errors

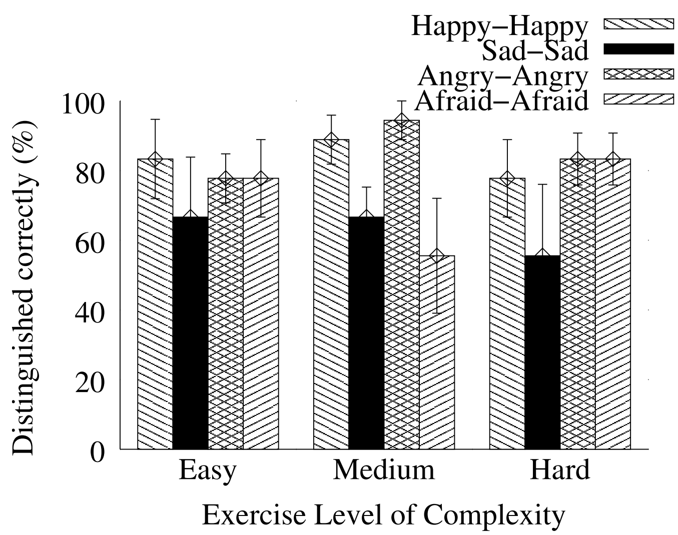


Figure 3.14: Mean number of correctly distinguished pairs of the same emotions for each exercise level of complexity. Error bars indicate standard error of the mean.

for sad-sad and afraid-afraid trials, and a common factor for these emotions is that they are both slow in Laban's time dimension.

For trials in which pairs of different emotions were presented, there was a significant difference between the six combinations of emotion ($F(1,5) = 9.51, p = .00$). When Laban's time parameter was fast for both emotions in a pair (happy–angry), the participants results were equivalent to chance as shown in Figure 3.15. Participants were still able to distinguish different emotions where both emotions of the pair were characterised as slow in Laban's time parameter (sad–afraid) though there is a marked drop off when compared to pairs with different time parameters.

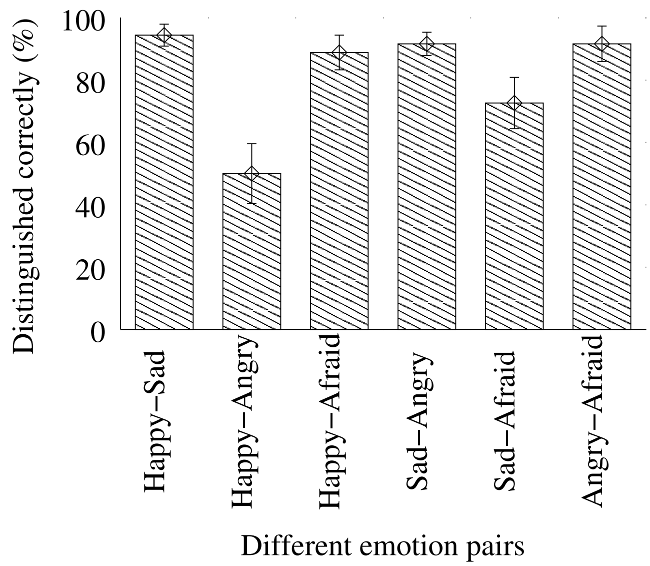


Figure 3.15: Mean number of correctly distinguished pairs of different emotions. Error bars indicate standard error of the mean.

Despite the reduction in the resolution, size, and display aspects of fidelity, the overall mean percentage correct was high ($M = 78.70\%$). The analysis undertaken to examine the accuracy for distinguishing emotions at the three levels of complexity showed a greater accuracy at the easier level for different pairs of emotions. The accuracy for the same emotional pairs was similar for all three complexity levels. One possible solution is the professionally trained dancers ability to accurately reproduce positions (Ramsay & Riddoch, 2001) provides less variation between the same emotions compared to different pairs of emotions showing greater movement variation. As movements become more complex for the dancers to perform, the amount of variation in the performance decreases and appears to the participants to have similar emotions.

The results for pairs of the same emotions establish the participants had generally less accuracy for emotions with a slow time factor. One possible hypothesis is:

the slower time for the movies to complete the exercises gave more time for the participants to overanalyse the movement and see more nuances, i.e. any extra deviation in the movement interpreted as differences between two emotions rather than variation in making movements. This result highlights that the participants found it significantly more difficult to distinguish certain emotions.

For different pairs of emotions, the common factor between pairs that were accurately distinguished over pairs that were not was Laban's time parameter. Different pairs with the same time characteristics were less accurately recognised, probably due to the participants finding it easier to differentiate using time. Pairs with the same time requires interpretation of other nuances in the performance of the movement by using the other Laban dimensions to distinguish the emotions. The greater the speed of movement, the more difficult the participants found it to read the visual clues. These results highlight that a key indication to distinguish different emotions is the time factor. Other visual clues such as Laban's space and weight dimensions were used to confirm their decision while emotions with similar times relied on the other dimensions highlighting the other dimensions aid the distinguishing process.

In conclusion, Experiment 1 has shown that on a small 2D visual display: (1) there was a high percentage correct overall despite the fidelity reduction; and (2) Laban's time dimension is a major clue when comparing different emotions.

3.4 Experiment 2

3.4.1 Introduction to Visualisation at Variable Frame Rates

Experiment 2 investigated the ability of participants to distinguish emotions when presented at four different frame rates (5, 8.33, 12.5 and 25Hz). To limit the number of trials, it was decided to use only the extreme levels of complexity (easy and hard) and three emotions (happy, sad and angry). As in Experiment 1, each trial display either the same or different emotions and used the same dancer, exercise and frame rate for both emotions. Experiment 2 used the same Visual Basic application as the first experiment.

3.4.2 Method

The same six participants were used for this experiment that were used for Experiment 1.

Procedure

There were six combinations of the three emotions. Three involved pairs of the same emotion {*(happy, happy) (sad, sad) (angry, angry)*} and the other three were pairs of different emotions {*(happy, sad) (happy, angry) (sad, angry)*}. Participants performed two trials of each combination of emotion, exercise and frame rate, resulting in 96 trials overall, that were presented in three blocks of 32. The procedure was the same as Experiment 1 and as before, the order of presentation of the trials was randomised (see §3.3.2)

3.4.3 Results and Discussion

The data were analysed using similar types of ANOVA to Experiment 1. Participants answered significantly more trials correctly when different pairs of emotions were presented than same pairs ($F(1,5) = 8.29, p = .03$), but the difference was almost entire due to the percentage participants answered correctly for different emotions in the easy exercise (see Figure 3.16). The effect of frame rate was marginal ($F(1,5) = 3.01, p = .06$), with participants answering fewer trials correctly at the fastest frame rate (25 Hz.).

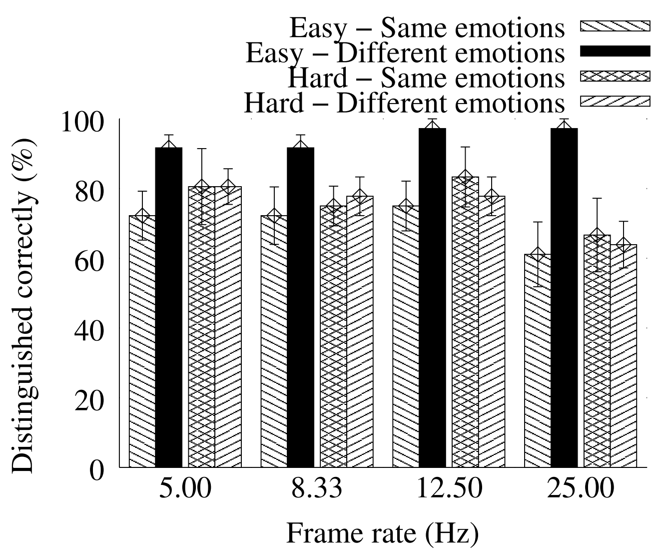


Figure 3.16: Mean number of correctly distinguished pairs of emotions for the easy and hard exercise level of complexity using four different frame rates. Error bars indicate standard error of the mean.

For trials in which pairs of the same emotion were presented, there was a significant difference between the three emotions ($F(1,5) = 4.47, p = .04$). Participants answered more trials correctly with the angry emotion ($M = 86.46\%$) than with the happy ($M = 71.88\%$) or sad emotion ($M = 61.46\%$). There was no significant difference between the frame rates.

For trials in which pairs of the different emotions were presented, there was a significant difference between the three combination of emotions ($F(1,5) = 13.63, p = .01$). Participants answered fewer trials correctly with happy–angry pairs ($M = 66.67\%$) than with the happy–sad ($M = 93.75\%$) or angry–sad pairs ($M = 93.75\%$). There was no significant difference between the frame rates.

Experiment 2 provides some understanding of the amount of visual detail required between keyframes for users to differentiate emotions on a VBD. The overall mean percentage correct was high ($M = 78.99\%$) despite using the different frame rate aspect of fidelity and produced similar results to Experiment 1. This result highlights the possibilities of interpolating between keyframes approximating 5 to 25Hz and achieving expressive animation.

An unexpected result was that participants were less accurate with the normal frame rate than the lower frame rates. A possible hypothesis is after making judgements with less visual clues at lower frame rates, the extra detail obtained from the higher frame rate made the distinction between pairs more confusing. Participants over compensated for the amount of detail provided at the normal frame rate and found it difficult to determine whether the observed differences in the expressive nuances were caused by different emotions, or variations of the same emotion. However, it should be emphasised the frame rates had only a marginal effect to distinguish emotions. More significantly, participants were more accurate on different pairs of emotions performed at an easy level of complexity matching Experiment 1.

The results for pairs of the same emotions and pairs of different emotions were similar to Experiment 1, and in both analyses, frame rate had no effect on accuracy of participants judgement. This second experiment also highlighted the importance of the time dimensions in judging the motive themes underpinning ballet movement.

3.5 Summary

This study analysed the different fidelity requirements to develop a VBD and looks into how these issues of fidelity affect the users judgement to distinguish emotions. Two aspects were considered in relation to the visual appearance of the VBD and the realism of the movement required. Using videos of real dancers provided the best possible 3D dancer model and movement algorithm to assess the different aspects of fidelity. The high percentage accuracy overall for Experiment 1 where the fidelity was lowered from the real-world to a 3D representation displayed on a 2D display highlighted that expressive motion can be distinguished by a user. The fidelity on the 2D display assessed included degradation in resolution and a small image size.

Experiment 2 assessed aspects of movement fidelity using different frame rates to assess levels of interpolation required for a VBD. The high percentage accuracy overall and the results showed different frame rates had only a marginal effect on the participants. This highlighted that interpolation between keyframes equivalent to 5-25Hz is capable of providing enough visual clues for the user to distinguish differences in emotions from the animated movement of a VBD.

Chapter 4

Development of Balletic Key Poses

4.1 Introduction

For a VBD system to be of use to the choreographer, teacher or choreologist, it must be able to perform certain requirements. The most fundamental is to position the virtual dancer in poses that are recognisable as ballet positions. For example *first*, *fifth*, *arabesque* and *attitude*. When animated, the system must be able to interpolate between these key poses to animate as the dance sequence (class exercise or choreography).

Virtual dance has developed over the last few years with two main approaches: (a) motion capture (Moeslund & Granum, 2001; Camurri & Coglio, 1998), and (b) animations driven from machine readable versions of dance notations (Badler, 1989; Herbison-Evans, Edward, Hunt & Politis, 2004; Neagle & Ng, 2003). Motion capture has mainly been used with contemporary dance with some development toward classical ballet such as research by Stevens (Stevens, Mallock, Haszard-Morris & McKechnie, 2002) using mathematical tools , Li *et al.* (Li, Wang & Shum, 2002)(2002) describing a statistical model, and Brand and Hertzman (Brand & Hertzmann, 2000) learning motion patterns. Animation driven approaches have a larger base in classical ballet. Several programmes exist to create, store, and modify dance notations and include Benesh Notation Editor; MacBenesh; Calaban; Laban-Pad PDA (currently: Apple Newton); LabanWriter; and LED. There are limited visualisation tools and the best known research in this area is LINTER by Hall and Herbison-Evans (Herbison-Evans, Edward, Hunt & Politis, 2004; Herbison-Evans & Hall, 1989) and the DanceForms choreographic software (Ryman, 2001; Calvert, Wilke, Ryman & Fox, 2005).

The input of data can be achieved by a number of means including motion capture (Moeslund & Granum, 2001; Camurri & Coglio, 1998), scripting (Badler, 1997; Badler, Phillips & Webber, 1999b; Perlin & Goldberg, 1996) and machine readable file formats (Badler, 1989). For this research, to pose the virtual dancer into classical ballet positions at key times in the animation, we are using a machine readable file format describing key poses based on Benesh notation. From the notation it is possible to reconstruct and visualise each pose and the movement required between the key poses (see Figure 4.1).

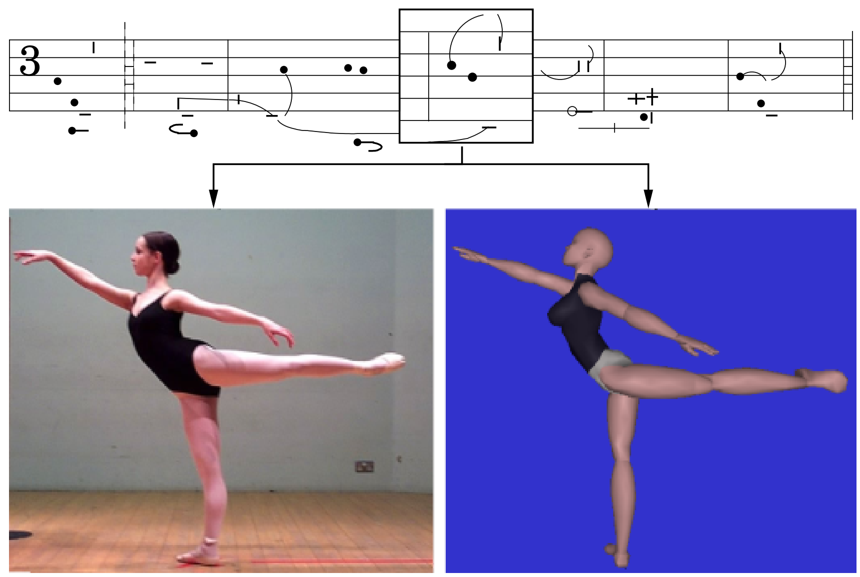


Figure 4.1: Example of a pose annotating using Benesh notation of an *arabesque* posed by a real dancer and virtual ballet dancer

Of the various methods proposed to input an animation sequence including VRML, motion capture (MoCap) and XML, none are a standard for defining a dance notation. While there are working groups developing XML definitions for music notation such as MusiXML, MusicML and Wedelmusic XML to name a few (Oasis, 2005), none exist for Labanotation or Benesh notation. It is not the scope of this research to formalise the XML definitions for the dance notation used or develop the parsers required to read the notation. While XML with a dance notation definition could be used to input a dance sequence, for this research an ASCII machine-readable format was used to devise the algorithms. This could be adapted in the future to a parsed dance notation standard probably using XML.

This chapter describes the method to represent the key poses of ballet positions described by the rules of classical ballet, i.e. the key frames in the animation of the VBD. Sections include the machine-readable format representing key poses (requirement 4 as described in Chapter 3) and the ballet rules that need to be applied to the key pose positions, either specified or implied (requirement 5 as described in Chapter 3).

4.2 Background

4.2.1 Benesh Movement Notation and Ballet Poses

In computer graphics, a skeleton-based approach is generally considered to be the most flexible way to animate characters (Badler, Phillips & Webber, 1999b; Herda, Fua, Plänkers, D., Boulic & Thalmann, 2000). Benesh notation provides information, directly or inferred, that can be mapped to an articulated skeletal structure to specify the positions of the bones or the angle of each joint of a dancer. The symbolic representation of dance notation is similar to music and with an underlying mathematical content that also lends itself well to machine representation.

Written from left to right on a five-line stave, the stave lines map to the height of a person's feet, knees, waist, shoulders and top of the head. To record a pose, the Benesh notation notes the exact locations occupied by the four extremities (the hands and feet). In addition, the position of a bend, such as the knee or elbow, may also be defined. Given these points and the body and head positions, it is possible to reconstruct and visualise the whole pose (see Figure 4.2).

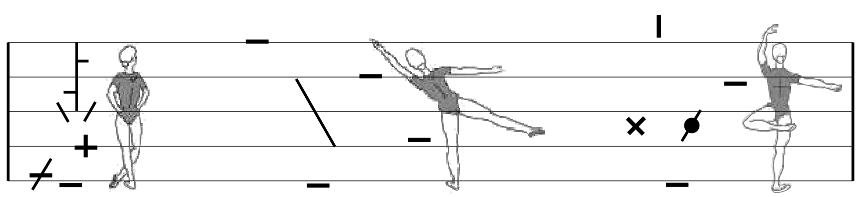


Figure 4.2: Examples of the Benesh notation showing signs to pose a dancer including orientation of the head and body, contact to the body (hand on hips), crossed positions of the extremities and different feet positions when in contact with the floor. The human figures show the actual poses that were defined.

Benesh also included floor patterns: direction, location and travel for the dancer or group of dancers written below the stave. Further details on travelling, direction, location can be found at page 87 in *Dance Notation for Beginners* (Brown & Parker, 1984) and page 70 in *Reading Dance* (Benesh & Benesh, 1983). Rhythm and phrasing are shown above the stave and include pulse beats, tempo and common dance rhythms. The pulse can be split into half, quarter and third beats and there are three methods for specifying the tempo: (1) set instructions, such as: Fast, Moderate, etc. (2) specifying the number of beats per minute by giving the pulse beat a metronomic speed; and (3) instructions as shown in music scores using Latin terminology, for example *Presto*, *Allegretto*, and *Adagio*.

For this chapter, we are only concerned with the *in*-stave signs which provide the direction and orientation of the limbs, and orientation of the head, body and head either directly or by inferred ballet rules.

4.2.2 Ballet Rules

The basic rules of ballet were defined by Jean-Georges Noverre (1727-1810), the author of *"Lettres sur la Danse et sur les Ballets"* (Letters on Dance and Ballet) (Noverre, 1760), and Carlo Blasis (1797-1878), the author of *"The Code of Terpsichore"* (Blasis, 1830). The material in these books is virtually indistinguishable from ballet as it is taught to-day and specify many ballet rules. As ballet grows, choreographers define new positions, more exceptions to the rules are created. However, the basic rules remain unchanged and these rules will be used for the development of the current VBD system.

The ballet rules for the arms include rounded arms (with the exception of the *arabesque*) and arm orientation. The stance of the dancer is kept erect unless specified with the neck straight over the spine. The position of the legs always assumes a degree of turnout from the hip joint unless the notation specifies otherwise by defining the knee and feet positions.

This chapter will be continually making reference to the following arm and leg ballet positions and the ballet rules required to pose them as described by the Cecchetti method. There are five principal positions of the arms:

1st Position. The hands are held at the side with the finger-tips near to the outside of the thigh.

2nd Position. The arms are extended to the side sloping downward and the position of the arms must not pass beyond the line of the shoulder.

3rd Position. One arm is placed in the fifth position, and the other placed at a slight distance from the side.

4th Position. One arm is placed in the second position and the other is in the fifth position, *en bas* (low), *en avant* (forwards) or *en haut* (high).

5th Position. Has both arms placed at shoulder width in front of the body. There are three derivatives of the fifth position: *en bas* (low), *en avant* (forwards), and *en haut* (high).

These five principal positions are posed with rounded arms, so that the point of the elbow is imperceptible. When the arms are to the side, the finger-tips of the hand or hands should be just within the range of vision.

For this research we will also consider the three principal positions for the arabesque line of the arms:

First Arabesque. The front arm is raised in line and above the shoulder line and the second arm is below and level or slightly behind the shoulder.

Second Arabesque. The front arm is in front and just above the shoulder line and the back arm is below and behind the shoulder line continuing the line of the front arm.

Third Arabesque. Both arms are in line with the shoulder and in front of the shoulder with one arm higher than the other.

This chapter will also refer to five principal positions of the feet:

First position. Standing with heels together and toes turned out to the side.

Second position. Keeping the turnout established in First position, the heels are aligned under the shoulders.

Third position. Cross one foot to the middle of the other with hips centred equally over the feet and not twisted.

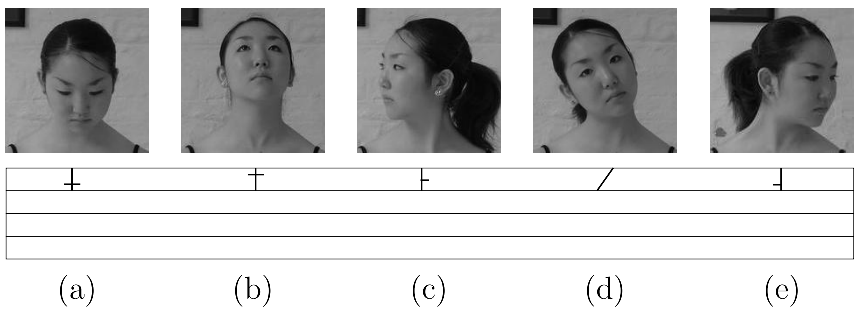
Fourth position. The feet are separated forward and back from either fifth or first position approximately one foot length with the weight evenly distributed between the feet.

Fifth position. The front heel crosses to the big toe joint of the back foot with hips centred over the feet and the weight equally distributed.

4.3 Inputting Key Poses

Movement of the VBD described in this chapter are driven by a machine-readable version of the Benesh notation (requirement 4 as described in Chapter 3). The format ASCII text is parsed using a bespoke tokeniser. Examples of the format are shown below, and it is described more fully in "Notation and 3D Animation of Dance Movement" (Neagle, Ng & Ruddle, 2002).

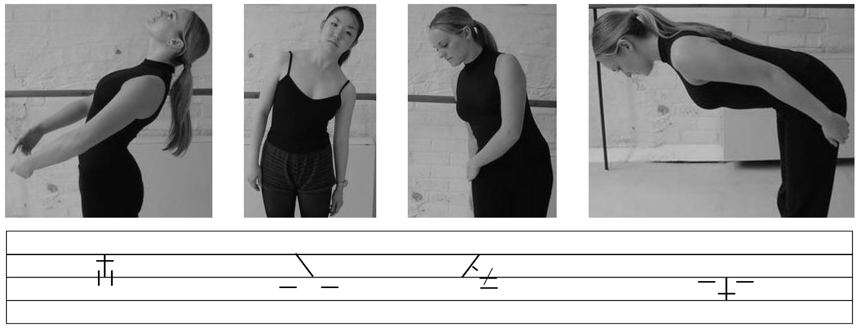
The orientation states for the head, body and pelvis are any combination of *tilt*, *turn*, *bend* (see Figure 4.3 and 4.4), and orientations represent rotations around the three cardinal axes. Benesh notation specifies these states using the top three spaces in the five-line stave. We see Benesh notation, using single signs to represent combinations of orientation. Examples of head orientation together with the associated machine-readable ASCII text are shown in Figure 4.3. Example of body and pelvis orientation are shown in Figure 4.4.




```
frame 1{head(bend,forward)}             #(a)
frame 1{head(bend,back)}                #(b)
frame 1{head(turn,right)}               #(c)
frame 1{head(tilt,right)}               #(d)
frame 1{head(bend,forward)(turn,right)} #(e)
```

Figure 4.3: Examples of the Benesh notation and machine-readable text format for head orientation. (a) and (b) are bends, (c) is a turn, (d) is a tilt, and (e) is a combination of a turn and a bend. NB. the notation is represent from behind the body and therefore the signs are notated in the opposite direction of the photos for the rotation and tilts.

To record a position or pose, the Benesh notation also notes the exact locations occupied by the four extremities, the hand and feet, in relation to the body of the dancer on the coronal plane. The position of extremity signs within the stave for each key pose denotes the position of the dancers hands and feet in relations to their anthropometrics. Benesh notation provides the height and width of the extremities' position in relation to a dancer standing upright. There are five defined height positions represented by the five lines of the Benesh notation stave: the floor (height



(a) (b) (c) (d)

```
frame 1{                      #(a)
  body(bend,back)
  lefthand(0.1,3.0)front
  righthand(0.1,3.0)front
}
frame 1{                      #(c)
  body(tilt,right)(turn,right)
  lefthand(-0.1,3.0)contact
  righthand(0.1,2.75)level
}
```

```
frame 1{                      #(b)
  body(tilt,left)
  lefthand(0.1,2.75)level
  righthand(0.1,2.75)level
}
frame 1{                      #(d)
  pelvis(bend,forward)
  lefthand(0.1,2.75)level
  righthand(0.1,2.75)level
}
```

Figure 4.4: Orientation of the Benesh notation body and pelvis signs. (a) is a bend of the body above the waist, (b) a tilt, and (c) a turn and tilt. Images (d) shows a bend of the body below the waist (pelvis).

is zero); knee height; waist height; shoulder height; and the head height. Width is specified proportionally to the horizontal reach of the limb along the cardinal plane. For example, a width specification for the hand of half way from the centre of the body to the maximum reach would position the hand approximately where the elbow is.

The depth of an extremity is inferred from its position mapped onto the coronal plane and the orientation of the relevant limb(s). Different sets of signs are used to add depth information to the two-dimensional information provided by the position of a sign on the stave. These sets of signs are: front (| , + , ⁄), level (− , + , ≠) or behind (• , × , ⌀) the body. The distance in front or behind the body is not specified as only one place is possible due to the fixed limb length. It is also not required to specify how bent the limb is, as this is governed by the position of the extremity and the position of the bent joint. The legs are positioned in a similar manner to the arms with the exception that the floor contact is specified. Unless a bent knee position is notated to define the orientation of the legs, the default turnout rule is applied (a rotation in the hip socket for the patella bone to face the side).

4.4 Defining Key Poses of a VBD

To teach dancers the movements prescribed by a particular piece of ballet notation, choreographers combine the information provided by the notation with their knowledge of the rules of ballet. The notation defines the positions of the key elements of a dancer's body, who then adopts a pose consistent with those positions and the standard rules of ballet. To define key poses for a VBD, the rules of ballet need to be expressed as a set of mathematical equations which were merged with the machine-readable Benesh notation data.

The VBD used in this research was the Cal3D software (Heidelberger, 2005) and has the degrees of freedoms (DOF) shown in Figure 4.5. The following sections explain how the information contained in Benesh notation can be combined with equations that capture the rules of ballet, to define the DOFs of a VBD's body. The centre of body nodes (pelvis, waist and neck), the shoulder nodes and the hips have three DOFs. The elbow nodes have to: (1) bend the elbow; and (2) rotate the forearm to orientate the palm of the hand. The wrist nodes have one DOF to raise and lower the hands when setting rounded arms. The knee nodes have one DOF to flex and straighten the leg and the ankle nodes have one DOF to flex and point the foot.

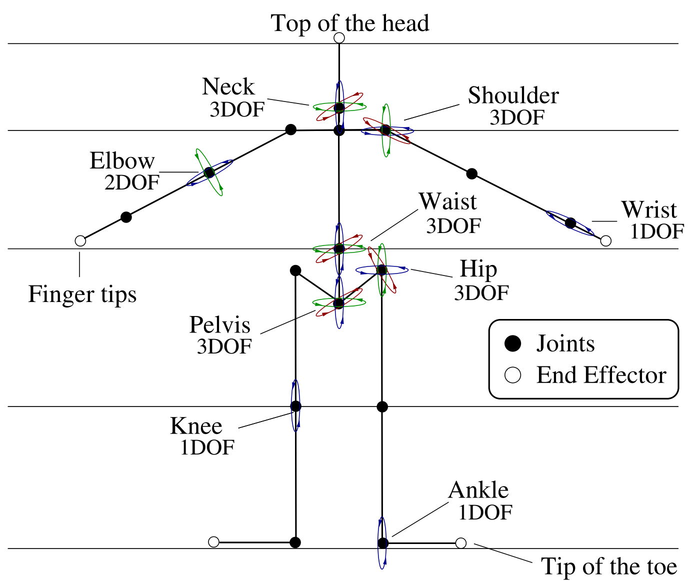
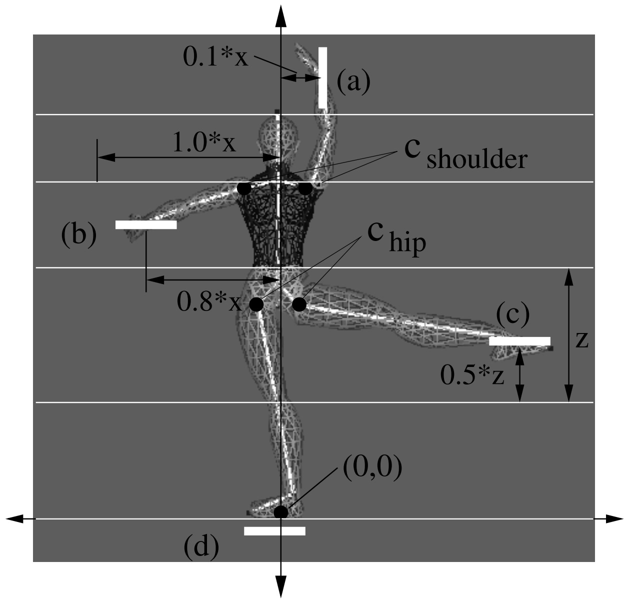


Figure 4.5: The skeletal structure of the VBD, showing the end effectors and the DOFs at each joint (Requirement 3 as described in Chapter 3).




```
frame 1{
   righthand(0.1,5.5)front #(a)
   lefthand(0.8,3.5)level  #(b)
   rightfoot(0.9,2.5)level #(c)
   leftfoot(0.1,0.75)level #(d)
}
```

Figure 4.6: An example of Benesh notation, the file format representation and the VBD posed inputed from the file.

4.4.1 Setting Joint Positions

Before calculating positions the VBD is loaded in a default standing pose. The height (z) values of the knee, waist, shoulder and head are calculated from the VBD's bone structure and set as the stave heights. For example, the waist height z_{waist} is stored as the third stave line height. The maximum width for positioning the hands and legs are taken from the sum of the bone lengths that make up the limbs for those extremities.

Positions are explicitly notated in terms of height (z), width (x), and depth (y). Figure 4.6 demonstrates the position of the extremities. The file format representation in this example specifies the position of each extremity as a tuple and a word, e.g. level, that defines the depth. The width parameter, though redundant and unused for calculating the position for extremities which are level, is however required in the calculation of the ballet rules. The right foot, in Figure 4.6, is notated half way between the second and third stave line. The application uses the height of the second stave (knee height of the VBD) and the third stave line (waist height) to calculate the height of the foot as:

$$z_{position} = z_{stave2} + p(z_{stave3} - z_{stave2}) \tag{4.1}$$

where p is the proportion value (0.5).

Given the value of the height, the position of the end effector can be calculated. When the appendage is in the body plane, this is a simple 2D problem using Pythagoras. Given the length of the limb (l), the height ($z_{position}$), and the rotation point of the extremity i.e. the hip or shoulder joint in absolute space ($c_{(x,y,z)}$; $c_{shoulder}$ or c_{hip} in Figure 4.6) the width position is calculated as:

$$x_{position} = \sqrt{l^2 - (z_{position} - \underline{c}_z)^2} + \underline{c}_x \tag{4.2}$$

The position of the extremity is set as $(x_{position}, c_{hip\_y}, z_{position})$ which in this example is the right ankle joint.

The above approach is easily extended into three-dimensional space for positioning the extremities in front or behind the body plane. The width (x) is calculated proportional to the length of the straight limb. For example if the arm span of the VBD is 1 metre, a notation width parameter 0.1 defines the hand to be 0.1m from the shoulder (see Figure 4.6, the raised arm above the head is notated with width 0.1 and height half way between the top of the head and a raised stretched arm (5.5)). Once the $x_{position}$ and the $z_{position}$ has been calculated (see above), the depth ($y_{position}$) is calculated using Pythagoras:

$$y = \pm\sqrt{l^2 - (x^2_{position} - \underline{c}_x) - (z^2 - \underline{c}_z)} + \underline{c}_y \tag{4.3}$$

where $y > c_y$ is in front of the coronal plane and $y < c_y$ is behind the coronal plane.

In the case of the arms, the length of the limb (l) can have two values. The straight arm length is calculated as:

$$l = l_{upperarm} + l_{lowerarm} \tag{4.4}$$

where $l_{upperarm}$ and $l_{lowerarm}$ is the length of the bone of the virtual skeleton. In the case of the rounded arm, the angle of rotation at the elbow joint depends on the ballet method style and the preference of the teacher. Future applications will be able to vary the amount of elbow bend however currently the rotation is 153°, the preference of the author. From the specified angle and the set length of the arm bones the reach of the rounded arm l is calculated using the cosine rule as:

$$l^2 = l_{upperarm}^2 + l_{lowerarm}^2 - 2l_{upperarm}l_{lowerarm}cos\theta \quad (4.5)$$

where θ is the degree of rotation measured from the inside of the arm i.e. 180° minus the amount of rotation by the elbow. The rounded arm of the VBD in this thesis was rotated to 27° and therefore $\theta = 153°$.

4.4.2 Rounded Arms and Elbow Positions

Like the Benesh notation, the VBD will assume the arms are rounded unless elbow joints are specified or the position is identified as one of the three *arabesque* positions where the elbow and wrist rotation is set to 0°. The rounded arm is produced by a slight bend of the elbow and wrist, examples are shown in Figure 4.7. The amount

(a) *secondé* position (b) *pirouette* position

Figure 4.7: (a) *a la secondé* position of the arms demonstrates rounded arms with the hand brought forward within the dancers line of sight. (b)the *pirouette* position of the arms demonstrating rounded arms with the elbow position on a plane continuing the line from the shoulder to the wrist.

of curvature varies depending on the ballet method and teachers preferences. The prototype therefore is designed for the user to specify the amount of curvature. Screenshots in this chapter with rounded arms were set at 154° based on the first authors professional opinion. The amount of rotation affects only the depth position of the wrist and the height and width values are obtained as described in §4.4.1 with the length l in Equations 4.1–4.3 calculated using trigonometry given the fixed length of the upper and lower limbs and the specified rounded angle. Once the wrist position is obtained, the vector u is the vector from the position of the shoulder joint to the position of the wrist joint, see Figure 4.8.

The position of the elbow in classical ballet is on a plane defined by the vector from the shoulder to the wrist u and a vector parallel to the floor w. The ballet rule states the elbow should not be dropped down or raised too high but continue the line of the slope to the hands. The position of the elbow joint is calculated using sphere intersection to obtain a point (p_{inner}) on the vector (u) and Pythagoras to translate the p_{inner} along a vector (v) which is on the plane and parallel to the floor from p_{inner} (see Figure 4.8)

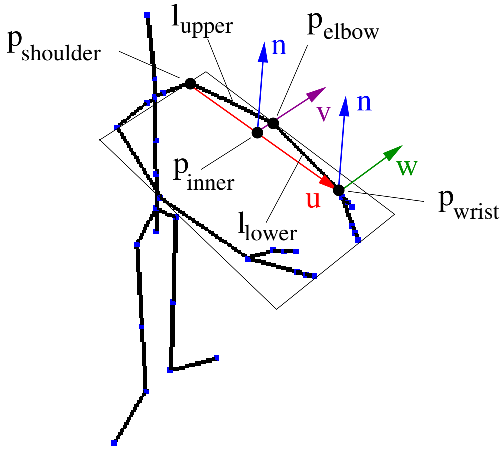


Figure 4.8: Vectors, points and limb lengths used to calculate the position of the elbow on a plane defined by the vector u (shoulder to wrist) and w (parallel to the floor).

$$p_{inner} = p_{shoulder} + \left(\frac{|u|^2 + l_{upper}^2 - l_{lower}^2}{2|u|^2}\right) u \tag{4.6}$$

The vectors are normalised to unit vectors and the cross product of w and u provides n and taking the cross product of n and u provides the vector v, assuming v and w are not parallel. The elbow position is calculated as:

$$\begin{aligned} d &= \sqrt{l_{upper}^2 - (p_{shoulder} - p_{inner})^2} \\ p_{elbow} &= p_{inner} + dv \end{aligned} \tag{4.7}$$

4.4.3 Specified Elbow Position and Rotation

Benesh notation can override the ballet rules by specifying the elbow and wrist positions individually. The elbow position is determined as described earlier (Equations 4.1–4.3), given the width and the height of the elbow, the depth is calculated in relation to the shoulder position. The notation also provides the width and height of the wrist position and the depth direction. Using the elbow as the rotation point the wrist positions coordinates are calculated and the amount of elbow rotation is calculated from the three coordinates, (S, E, and W) as:

$$\theta = \cos^{-1}\left(\frac{(u-v)\cdot(w-v)}{|u-v||w-v|}\right) \tag{4.8}$$

where S is the shoulder coordinate; E, the elbow coordinate; and W, the wrist coordinate.

4.4.4 Arm Orientation

For poses with bent arms, the z-axis of the shoulder and elbow is orientated perpendicular to the plane that contains the lower and upper arm. Vectors running along the length of the upper and lower arm are used to calculate the orientation of the shoulder. Arabesque poses have straight arms, and so require a slightly modified procedure (see Figure 4.9). Once calculated, the vectors are set in a rotation matrix

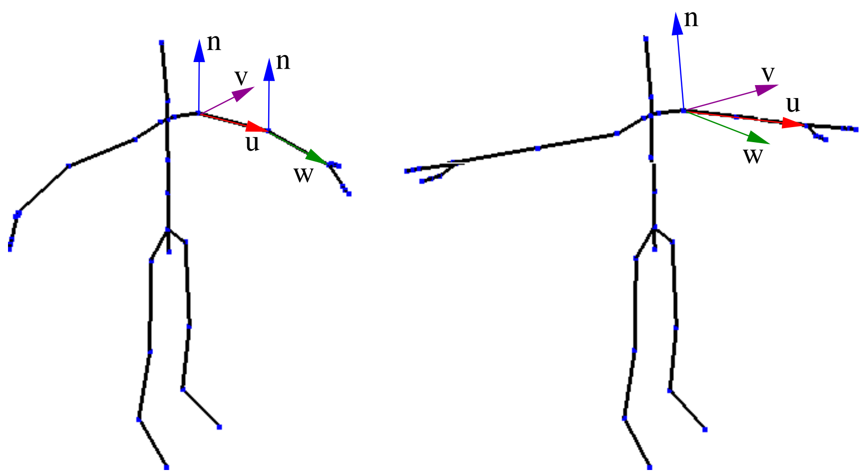


Figure 4.9: The left diagram demonstrates the orientation of the shoulder determined using the upper and lower arm vector. The cross product of w and u provides n where u is the x-axis and n is the z-axis. The y-axis v is obtained from the cross product of n and u. The right diagram demonstrates *arabesque* with straight arms where a vector (w) parallel to the floor and not parallel with u is substituted for the lower arm vector. All of the vectors are unit vector.

which for the model used with the Cal3D libraries in the VBD is:

$$r_{matrix} = \begin{pmatrix} u_x & u_y & u_z \\ v_x & v_y & v_z \\ n_x & n_y & n_z \end{pmatrix}$$

The matrix is converted to a quaternion to set the rotation.

The rotation of the wrist has been simplified and for rounded arms uses the same rotation angle calculated for the rounded elbow and rotated around its one DOF. The final rule for the orientation of the arms for classical ballet applies to the rounded arm where the palm of the hands are rotated ninety degrees. For example, when the arms are raised to the side, the lower arm is rotated at the elbow so the palm is facing the front. The final rotation is calculated by rotating the lower arm at the elbow joint around a vector specified by the lower arm bone. This does not apply to the arabesque pose where the wrist and elbow rotation are set as the identity quaternion.

4.4.5 Head, Body and Pelvis Rotations

The Benesh notation can be used to define rotations around three axes: *bend*, a *x-axis* rotation, *tilt* a *y-axis* rotation, and *turn*, a *z-axis* rotation where for the head bone of the VBD the x-axis is left to right; y-axis is front to back; and the z-axis is bottom to top. The VBD calculates the rotations to the limit for each DOF, where the limits have been selected based on the authors judgement within the range specified in (Grosso, Quach, Otani, Zhao, Wei, Ho, Lu & Badler, 1987) based upon the NASA Man–System Integration Standard Manual in *Occupational Biomechanics* by D. B. Chaffin (Chaffin, Andersson & Martin, 1999).

The rotations of the centre joints (neck, waist and pelvis) as discussed in §4.3 is simply achieved by using quaternion multiplication where the quaternion is calculated for each Euler angle. For example the head has five principal positions: erect; inclined; turned; raised; and lowered. For ballet the centre can also have a combination of any two rotations. The order of multiplication is important and the erect head is set as an identity quaternion. Table 4.1 shows the rotation required for balletic poses of the head, body and pelvis with references to example images.

Pose	Quaternion Rotation	Example Images
Erect	$q_{rotation} = q_{identity}$	4.7
Lowered	$q_{rotation} = q_{bend}$	4.3a,4.4d
Raised	$q_{rotation} = q_{bend}$	4.3b,4.4a
Turned	$q_{rotation} = q_{turn}$	4.3c
Inclined	$q_{rotation} = q_{tilt}$	4.3d,4.4b
Inclined and Turned	$q_{rotation} = q_{turn} \times q_{tilt}$	4.4c
Raised and Turned	$q_{rotation} = q_{turn} \times q_{bend}$	4.3e

Table 4.1: Quaternion Equations for Centre Rotation. The lowered, incline to the right and turn to the left has negative euler angle

4.4.6 Rules for the Lower Extremities

Positioning the legs follows the same rules as the arms replacing the rules for calculating rounded and straight arms with turnout and floor position. Turnout of the legs in the hip socket is one of the fundamental rules for classical ballet. The perfect dancer is aiming to have 90° rotation. However, few dancers have perfect turnout so the application allows for the user to specify the turnout for the VBD up to a maximum value of 90°. The rotation is around the axis of the thigh bone.

Benesh notation specifies the position of the feet on the floor. Using the width parameter in the depth direction (see §4.3) of the notation on the first stave, it is possible to determine if the feet are posed in one of the five basic feet positions, is a supporting foot, or a position not defined by the ballet rules. Ballet rules in the application set the position of the feet for the basic positions and if a supporting leg is specified (see Figure 4.6, left leg). The width position of the feet and the depth provided by the Benesh notation and using Equation 4.3, allows all other feet positions to be calculated using the vertical distance from the hip joint. Unless the foot position is in a line from the hip to the floor, and the calculation is taken from the hip joint, the height of the foot position will not be connected to the floor. A vertical translation of the parent node is calculated to reset the foot to the floor so the dancer remains grounded.

4.5 Evaluation 1: Text Book Comparison

4.5.1 General Methodology

The evaluation compared key poses of the VBD, as determined by combining machine-readable Benesh notation with the rules of ballet programmed into the VBD application, with corresponding poses described in *The Manual* (Beaumont & Idzikowski, 1977). The images from The Manual were used by permission of the Imperial Society of Teachers of Dance (ISTD). Images of each pose taken from the text book were set adjacent to the image screen grabbed from the VBD and only differences highlighted for comparison. The poses were selected to demonstrate the use of the different rules used by the VBD.

4.5.2 General Pose Discrepancies

The VBD uses the human model provided with the Cal3D libraries. Although this is an excellent starting point there are some discrepancies that need to be addressed. The most obvious is the shape and proportions of the Cal3D model in respect to the real-world ballet dancers used in this research. These include, most noticeably, the breast size and the shape of the legs. Figure 4.11 shows the VBD has noticeably curved thigh muscles and a ‘s’ shape to the leg, whereas ballet defines this shape as a straight leg. The three major classical ballet factors which are less obvious to non-professionals are the orientation of the head; the shape of the hands; and there being no toe joint.

Head Orientation

Blasis states *“Take especial care to acquire perpendicularity and an exact equilibrium”* (Blasis, 1830). Figure 4.10(a) shows the spine in the head is sloped slightly backward and is not perpendicular to the ground and the mesh is both forward and down . For a classical ballet stance as described by Blasis, the head should be perpendicular to the ground and the centre of the mesh aligned so there is a sense of equilibrium. Currently the VBD appears top heavy and forward.

(a) (b) (c)

Figure 4.10: (a) The VBD with skeleton and wire mesh surface display, with the head positioned in the default anatomical position. (b) A classical hand position as defined in *The Manual*, Plate IV Fig. 17 (left) and the open palmed VBD hand (right). (c) The pointed foot extended as much as possible with the instep forced well outwards and the *pointe* forced downwards taken from Plate III, Fig 11 (left) and the VBD without a toe joint showing the rigid foot with the *pointe* created with only the ankle rotation.

The Hands, Legs and Feet

The Manual describes the shape of the hands for classical ballet and provides variations in the positions of the fingers for different positions. These variations are minor and therefore for the VBD, a single classical shape would would suffice. However the Cal3D model currently used has an open hand which is incorrect for a classical dancer, as shown in Figure 4.10(b). This incorrect hand pose has been highlighted in both evaluated poses. See Figure 4.12, difference (c) and Figure 4.13, difference (c).

The pointed foot currently is an issue when the foot is lifted off the ground or defined touching the ground on full point (*sur la pointe*). This like the hands is a theme that will run through every pose when a pointed foot is required. To have every possible foot pose requires the toe joint to be added to the skeleton which is currently not part of the Cal3D model (see Figure 4.10(c)). Because the shape of the foot remains unchanged from flat to pointed, when a pointed foot is required the shape is noticeably rotated only at the ankle joint. See Figure 4.13, difference (e) on all images. The basic feet positions have minor errors as shown in Figure 4.11 for the *first* to *fourth* position and Figure 4.12 for the *fifth* position.

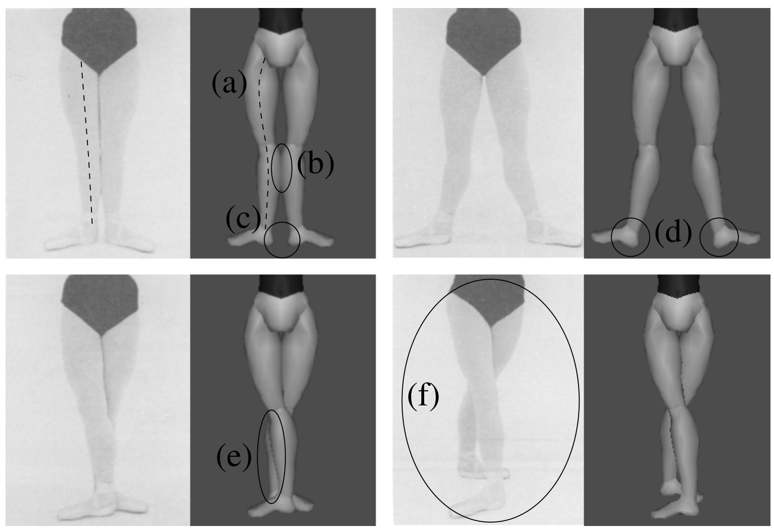


Figure 4.11: Positions of the feet from Plate I of The Manual (Beaumont & Idzikowski, 1977) and VBD in the same pose . The poses are from left to right: *first, second, third,* and *fourth croisé* position. Highlighted differences: (a) straight legs on the VBD appears 's' shaped (b) no mesh deformation resulting in intersecting mesh; (c) distance between heels due to leg shape of the VBD model; (d) ankle rotation is currently incorrect; (e) back leg can be viewed due to leg shape of the model; and (f) the real-world dancer has been photographed with the hip orientation off centre creating a slight twist in the shape.

Both the reshaping of the hands and skeletal change in the feet are required to add a greater level of fidelity to the classical pose. However, for this research, the fidelity of the dancer is high enough to demonstrate classical ballet poses that professionals and non-professional can recognise and/or compare to real-world examples.

4.5.3 Standard Poses in Fifth Position

The poses that were evaluated comprised the feet in *fifth* position (the corner stone of ballet) and a combination of different arm and body positions based on the five basic ballet positions and their derivatives that were outlined in §4.2.2. The example in Figure 4.12 is slightly lower than normal as the Manual is also describing the pose from the *First* Exercise on the *Port de Bras*, No. 2.

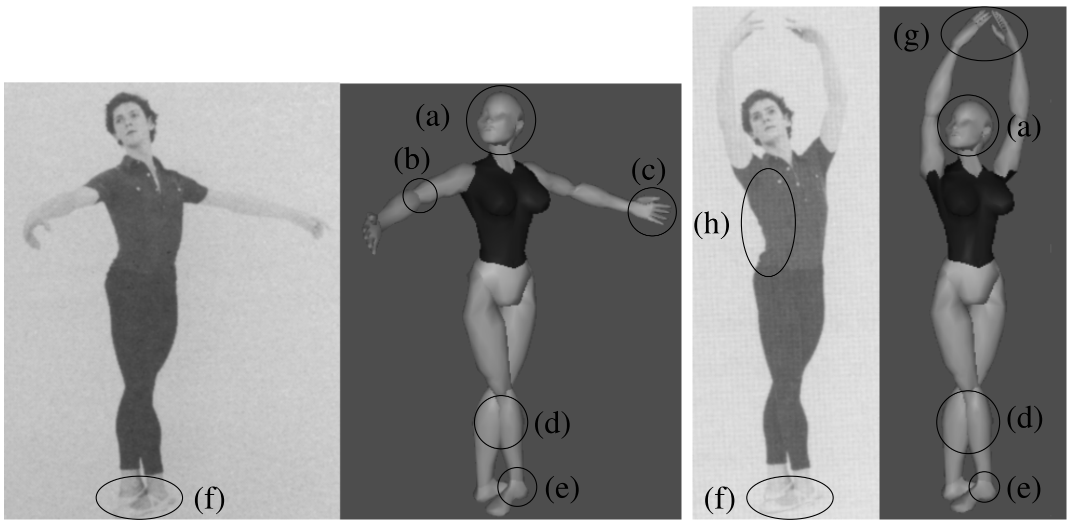


Figure 4.12: Pose from The Manual (Beaumont & Idzikowski, 1977) and VBD in the same pose . The poses are: *fifth position* with arms *a la seconde* (left) and *fifth position* with arms *fifth en haut* (right). Highlighted differences: (a) head turn and incline combination; (b) amount of elbow bend for rounded arms and orientation; (c) classical hand position; (d) collision detection and mesh deformation; (e) ankle rotation (toe position is slightly below floor level); (f) twisting of the joints to squeeze a better fifth position (common in posed photographs); and (g) width of hand placement.

Comparing the real-world pose with the VBD in Figure 4.12, the following differences were identified:

(a) Coding of the combination head rotations are currently incorrect. The assigned values for the rotations are set as a value not taking into consideration the arm positions and the author at the time of coding misunderstood the different variation in the Benesh notation and the effect the combinations have on the orientation of the head. The orientation therefore is currently only a close approximation.

(b) The current elbow bend and orientation specified by the author's professional opinion varies from the manual. The value for the bend is currently set from measurements taken from the author's own pose of the rounded arm as discussed earlier. The orientation is set to 90° around the bone axis. From Figure 4.12 we observe the VBD's lower arm orientation is greater than the real-world dancer. However the amount of rotation to orientate the lower arm varies between dance methods and the dancers themselves and other poses of the same arm position taken from The Manual demonstrate a greater rotation.

(c) The pose of the hands has been discussed earlier (see §4.5.2).

(d) The libraries used to create the VBD currently have no collision detection and therefore deformations of the mesh are only related to rotations around the joint. The real-world dancer's calf muscles have been compressed as we see that the legs are still straight (i.e. no bend at the knee joint). When the VBD is posed in the same position, the meshes intersect. Correcting this is beyond the scope of this research.

(e) The VBD is currently not being placed in a virtual environment and therefore no compensation of the ankle rotation has been coded to check if parts of the anatomy intersect the floor plane.

(f) The real-world dancer is using the pressure of the floor to have what is termed a tighter fifth position (toes are pressed against the heel of the other foot). This is noticeable on the real-world dancer as the direction of the hips (to the corner) do no match the direction of the feet (direction closer to facing the front). Current teaching tries to avoid this, however, when asked to pose for a still photo, most professional dancers will use floor pressure to rotate the ankle and knee joints incorrectly to create a tighter position. The Manual demonstrates the *fifth* position of the feet which the VBD maps accurately with respect to the defined turnout.

(g) The hands of the VBD are too close together. Increasing the separation will allow the elbow bend rotation to increase to visually make a more rounded shape.

(h) The hint of the back bend shown by the real world dancer is a level of fidelity that the VBD does not achieve. The slight bend is a part of the Cecchetti style and the image is a pose from the *Third* Exercise of *Port de Bras*. This variation in shape is hoped to be achieved from the movement algorithm discussed in the next chapter.

4.5.4 The *Arabesque* Poses

The *arabesque* pose is one of the most used in classical ballet choreography and therefore has been selected as our second evaluated pose. As in the earlier section the visually noticeable differences have been highlighted:

(a) This is a recurring theme and was discussed in the previous evaluated pose. An extension to the problem can be seen in the bottom pose of Figure 4.13 where the head line (direction of the head) is slightly raised to look at the top hand. Whether a choreologist would define a head back position as seen in the VBD of the same pose or leave it undefined is at this stage unsure. If undefined, a new level of fidelity to the ballet rules would need to be added to compensate 'looking at the raised front hand'.

(b) Most classical dancers place a slight break in the wrist to create the illusion of a softer position. The amount of break varies from dancer to dancer and therefore the VBD was coded without. When compared with the real-world pose however, the VBD's arms appear very rigid and stiff and would be corrected by a dance teacher.

(c) The pose of the hands has been discussed earlier, see §4.5.2.

(d) The rotation of the hips by the real-world dancer is used to provide the required turnout of the raised leg. Depending on the dancer's body this can vary a great deal. Dancers spend years of training to minimise the amount of twist required. The VBD is therefore in a technically correct but unrealistic pose in the sense that most professional dancers will use some amount of hip rotation to create a better leg line.

(e) We see that the bottom half of the foot does not match the real-world pose. This is due to the toes of the VBD not having the functionality to be pointed. See §4.5.2 for the discussion on the pose of the feet.

(f) The real-world dancer has rotated the shoulder. Though, technically, students are trained to be in what is classified as a square position (both shoulders facing the direction and not a corner), many professionals rotate the shoulders to create a better arm line and to make it easier to raise the hips to create better turnout of the legs. Because of the different teaching methods and the technical description of an *arabesque* pose the VBD will keep its shoulders square.

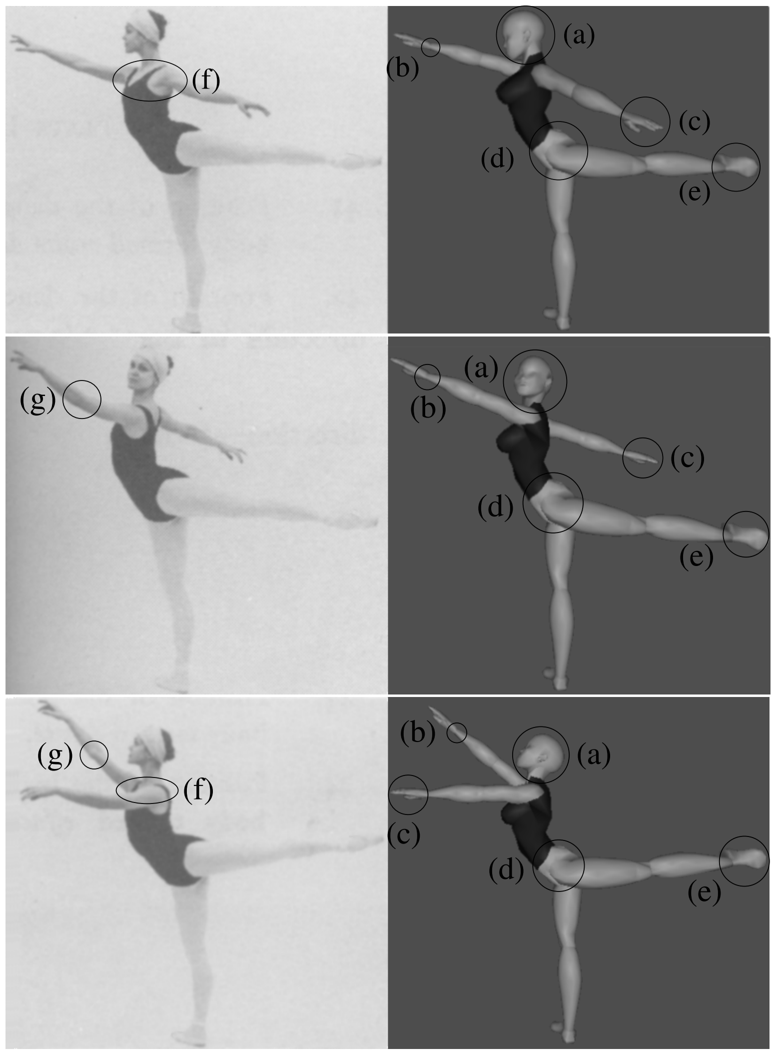


Figure 4.13: Poses from The Manual (Beaumont & Idzikowski, 1977) (left) and VBD in the same pose (right). The poses are: *first arabesque* from Plate VIII, Fig. 36 (top); *second arabesque*, Plate VIII, Fig. 37 (middle); and *third arabesque*, Plate VIII, Fig. 38 (bottom). Highlighted differences are: (a) head discrepancies; (b) break in the wrist joint; (c) classical hand position; (d) pelvis compensation for turnout; (e) classical foot shape; (f) rotation of the shoulders; and (g) slight break in the elbow to create a softer appearance (common with the female dancer).

(g) The real-world dancer in this pose, arguably, has too much bend in the elbow joint. It is of the authors professional opinion that the arabesque pose has straight or nearly straight (if creating a softer appearance) arms. The amount of bend is difficult to assign and varies between dancers and therefore the VBD currently sets the arabesque pose with straight arms.

4.6 Changes Resulting From Evaluation 1

4.6.1 Head Orientation

From evaluation 1, the rotation of the head was reassessed. The order of rotation was found to be incorrect and was limited to posing the basic balletic head positions. Combination orientations such as 'bend and turn' and 'tilt and turn' were originally developed to be the same head or body orientation . Benesh notation considers a greater number of possible orientations including using all three rotations 'turn, bend and tilt'. The 'bend and turn' orientation also differs from a 'bend and tilt'. The code was therefore simplified where the orientation of the centre joints were set using quaternion multiplication. As specified in §4.4.5, the quaternions are calculated for each Euler angle. Again the order of multiplication is important and the orientation of the three centre joints in the correct order is calculated as:

$$q_{rotation} = q_{turn} \times q_{tilt} \times q_{bend} \tag{4.9}$$

4.6.2 Ankle Orientation to Place a Flat Foot

The Ballet Rule

The rotation of the ankle is considered up to now as a 1DOF rotation for pointed and flexed feet. However, from the first evaluation, the placement of the foot was incorrect when placed flat on the ground. In ballet the foot is placed flat on the ground with the weight equally distributed at the three extreme pressure points on the foot: heel; big toe; and little toe making a supporting triangle. If the foot is not completely flat (e.g. one of the triangle points is not in contact with the ground such the little toe being raised), this is called 'rolling' and is classified as bad technique.

Key Pose for the Flat Foot

To set the foot on the floor plane requires 3DOF instead of the original 1DOF due to the turn out rule and the foot being placed flat in front and behind the coronal plane as demonstrated in Figure 4.14. The foot placed flat on the ground is always aligned in the plane coming directly forward from the front of the shin bone and a plane of $z = 0$ in the local coordinate geometry for the lower leg (see Figure 4.14). The orientation of the foot is calculated from the position of two critical points. The

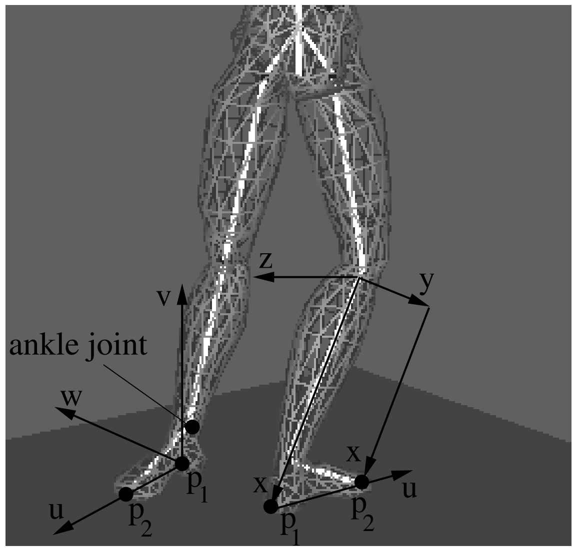


Figure 4.14: Placing the foot flat on the ground. Vectors x, y and z is the coordinate system for the lower leg in global space and vectors u, v and w is the coordinate system for the foot in global space. p_1 is where the vector of the lower leg intersects the floor plane and p_2 is where the same vector extrapolated along the y axis intersects the floor plane.

first is the intersection of the lower bone vector to the floor p_1 and the second point p_2 is the intersection of the lower bone vector extrapolated along the y-axis. The points p_1 and p_2 give the vector u which is normalised. For the foot to be flat the second vector v is always vertically upwards and given the vectors u and v we can calculate the third vector w as the cross product $v \times u$. This provides the two global orientation matrices:

$$r_{lowerleg\_matrix} = \begin{pmatrix} x_x & x_y & x_z \\ y_x & y_y & y_z \\ z_x & z_y & z_z \end{pmatrix} \qquad r_{foot\_matrix} = \begin{pmatrix} v_x & v_y & v_z \\ u_x & u_y & u_z \\ w_x & w_y & w_z \end{pmatrix}$$

which are converted to quaternions q_l and q_f. The orientation rotation at the ankle joint in the local coordinate system for the lower leg was calculated as:

$$\begin{aligned} \text{ankle} &= \frac{\text{global orientation of the foot}}{\text{global orientation of the lower leg}} \\ q_r &= q_l^{-1} \times q_f \end{aligned} \tag{4.10}$$

where q_r is the quaternion rotation at the ankle joint, q_l is the global orientation of the lower leg, and q_f is the global orientation of the foot.

4.7 Evaluation 2: Judged by Ballet Professionals

Evaluation 2 investigated the accuracy of the poses displayed by the VBD from the machine-readable file format representing Benesh notation. Displaying a series of poses by the VBD two groups were provided the task to either name the pose or notate the pose and in a structured interview ascertain differences between the VBD pose and the real-world. The structured interviews hoped to provide answers to the following questions: is the VBD in a balletic pose; if not, what is wrong with the pose and how would you correct the pose?

4.7.1 Method

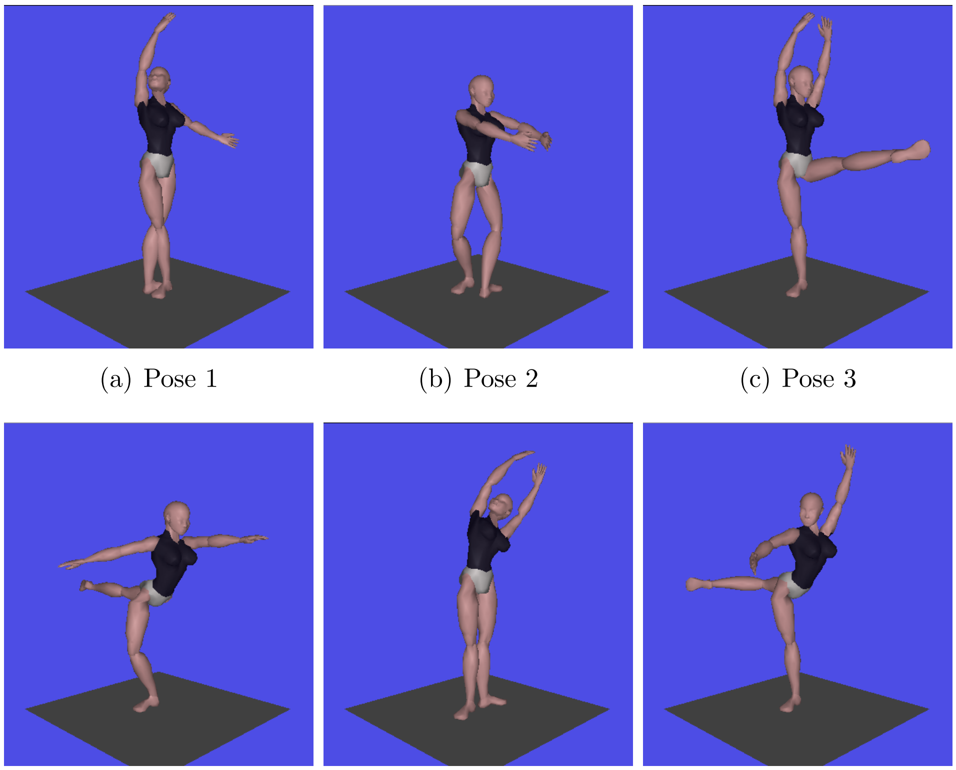
Participants

The participants were split into two groups. The first group included two professional ballet teachers currently teaching at a professional level and the second group included two dance notators (choreologists) trained to notate ballet using Benesh notation.

Materials and Procedure

The prototype bespoke application developed for demonstrating the VBD was used in keyframe mode. The application was run on a Dell Latitude C600 Intel Pentium III 1000MHz with 512M RAM and an ATI Radeon Mobility M6 video card (8M). The 14.1" XGA Color TFT display had a resolution set at 1024 x 768 x 16.7 million colours. The system ran Red Hat Linux release 9, Kernel 2.4.20-20.9.

Each of the participants were presented with six trials of a balletic pose with nameable positions of the body and limbs input into the VBD prototype application on startup. Five of the trials were poses used during the exercises for the real-world experiments. The final pose assessed was an attitude position commonly used in ballet. Figure 4.15 shows the six poses participants were required to evaluate. The application was set to keyframe mode and the participants displayed the next



(a) Pose 1 (b) Pose 2 (c) Pose 3

(d) Pose 4 (e) Pose 5 (f) Pose 6

Figure 4.15: The six poses used for evaluation by professional teachers and choreologists

pose using the '+' key. For each trial, the participants were provided the functionality to navigate around the VBD using a mouse and were asked to name the pose using Cecchetti ballet terminology or notate using Benesh notation. A structured interview was instigated after all positions were named or notated. This method is the most appropriate means of conducting a primary investigation for assessing the keyframe poses for the VBD because (a) interviewing professional teachers should determine the quality of the pose in relation to classical ballet technique and how the VBD may be corrected to improve the overall shape of the pose, and (b) interviewing choreologists will determine the accuracy of the pose taken by the VBD in relation to the Benesh notation represented in the machine-readable file format and what changes are required to be made.

The teachers were allocated as the first group and the choreologists as the second group. It is worth noting that the choreologists were also professional ballet teachers. The structured interview for the first group was to determine if the VBD pose represented a ballet pose using the balletic rules the overall quality of the pose. The procedure for the first group was:

1. Start application and set keyframe mode where first pose is automatically displayed.
2. Asked to name and write down the pose by the experimenter.
3. Participants have unlimited time to navigate around the VBD in the pose. Experimenter notes the directions of the VBD viewed by the participants.
4. Participants selects next trial using '+' key.
5. Repeat from 2 to 4 for each trial.
6. Instigate discussion after comparing experimenters description of the pose with the participants. Question: is the experimenter's description the same and if not is it a description of the same pose?
7. Question: what is not correct about the ballet pose?
   (a) is it a fault in the ballet rules?
   (b) does the description difference apply to a style?
   (c) how would you correct the pose?
8. Repeat 6 and 7 for each trial.

The structured interview for the second group was to determine the accuracy of the VBD pose using the file-format input of Benesh notation and the use of the ballet rules. To compare the participants notation with the notation inputed to the VBD, the procedure for the second group was:

1. Start application and set keyframe mode where first pose is automatically displayed.
2. Participants asked to notate the pose on the five line stave at the top of the question form.
3. Participants have unlimited time to navigate around the VBD in the pose.
4. Participants selects next trial using '+' key.
5. Repeat from 2 to 4 for each trial.

6. Instigate discussion after comparing differences comparing the experimenter's notation with the participants notation for the pose. Question: are the any differences and if so what is incorrect?

7. Question: what is not correct about the ballet pose?

   (a) is it a positional fault? if so, is it an interpretation issue?

   (b) is it a fault in the ballet rules?

   (c) how would you correct the pose?

8. Repeat 6 and 7 for each trial.

4.7.2 Results

The first set of participants' (dance teachers) description of the six poses had some variation. This is understandable as similar positions have different terminology relative to the front of the stage and this direction was not stipulated as generic answers were required. In some cases the pose was described as if the dancer was facing the front or the front corner of the stage (i.e. a more specific description of the pose) and in other cases a generic description was provided. This direction calculation for the front of the stage based on the pose is intuitive of teachers when recognising balletic poses to speed up the teaching process. For example, *"stand in attitude croisé but face the back"*. Table 4.2 provides the descriptions of each pose using Cecchetti terminology by the experimenter and the two participants. Differences are mapped in the final column.

The following section describes the differences in the descriptions of each pose and the possible reasons:

(a) Participant 1 reasoned that because of the *ecarte* line of the head, each arm required its own description. In fact, the participant by individually describing each arm has described the fourth position.

(b) Examples of different description of the same pose. In pose 1, the alignment of the head is open to interpretation and the same orientation can have different names depending where the front is. By describing the head as *ecarte*, the participant has assumed the VBD was facing the front while the original description and participant 2 has provided a more generic description. All descriptions will position a dancer with a similar head pose. In pose 3 *a la quatrieme devant* and fourth *devant* translates as fourth front.

Pose 1	Experimenter	Feet *fifth* with right foot front; arms *fourth en haut*; and head turned and raised to look in the top arm.
	Participant 1	Feet 5^{th}; **R arm – 5th *en haut* and L arm – *a la seconde*** (a) ; and Head – ***ecarte*** (b).
	Participant 2	Feet in 5^{th}; Arms 4^{th} *en haut*; and Head **looking through elbow**. (b)
Pose 2	Experimenter	Feet *fourth croisé* with right foot front on a demi plie; and Arms *fifth en avant.*
	Participant 1	Feet 4^{th}**{. . . }** (c); and Arms 5^{th} *en avant*
	Participant 2	Feet 4^{th} ***plie*** (c); Arms 5^{th} *en avant*; and Head straight
Pose 3	Experimenter	Right foot raised *fourth devant*; and Arms *fifth en haut.*
	Participant 1	Arms 5^{th} *en haut*; Legs ***a la quatrieme devant*** (b)
	Participant 2	Leg 4^{th} *devant* at 90°; and Arms 5^{th} *en haut*
Pose 4	Experimenter	*Fourth arabesque*
	Participant 1	**1st** (d) *arabesque*
	Participant 2	4^{th} *arabesque*
Pose 5	Experimenter	Feet *first*; Arms *fifth en haut*; Body tilted to the dancers left; and Head turned and tilted to look at raised hand.
	Participant 1	Feet 1^{st}; Arms 5^{th}*en haut*; Head ecarte; and **Mid way through 3rd *port de bras*** (e).
	Participant 2	Feet 1^{st}; Arms 5^{th}*en haut*; and **Body inclined** (f).
Pose 6	Experimenter	*Attitude* position looking at the side arm.
	Participant 1	Legs *attitude*; **Left arm 5th *en haut*; and R arm 2nd** (a). If on different alignment, would've called it ***croisé*** (f)
	Participant 2	*Attitude derrière*; Arms 4^{th} *en haut*; and Head turned toward the side arm.

Table 4.2: Results of pose description for evaluation two using Cecchetti terminology. The highlighted differences are: (a) separating arm pose to describing each arm; (b) varying descriptions for defining the same pose; (c) inferred the knees were bent in a *demi plie*; (d) wrong description; (e) used a moment in time during a Cecchetti exercise to describe the pose; and (f) inferred the head pose from the body angle (inclined) or direction (*croisé*).

(c) Both participants inferred that the position of the feet is *croisé*. This is because *fourth croisé* is more commonly used than *fourth ouvert*. This position is also mainly used as a preparatory or transitional pose and therefore usually in a *demi-plié* and therefore one participant did not even describe the bent knees and the second gave a shortened description that could be misinterpreted as a full-*plié*.

(d) Participant 1 described the *arabesque* pose incorrectly. However the first *arabesque* and fourth *arabesque* are identical with the exception that fourth *arabesque* is on a bent supporting leg. The participant admitting to completely not seeing the bent supporting leg and could give no reason for why when looking at the pose again.

(e) The participant felt unsure how to describe the pose of the head and body in terms of the Cecchetti terminology and describe the pose as midway through the third *port de bra*. The pose was taken from the third *port de bra* used in the original real-world experiments.

(f) Examples of inferring the pose of the head based on the pose or direction of the body. Participant 2 in pose 5 inferred that the head would be an extension of the body line. This is common in ballet teaching and therefore did not consider describing the pose of the head. For pose 6, participant 1 inferred that the head was turned to face the front and the complete pose was in the *croisé* direction i.e. facing the corner. This would infer the head is turned to the side hand.

The second set of participants (choreologists) notated the VBD poses extremely closely to the original as shown in Figure 4.16 with some minor discrepancies which have been highlighted and discussed during the formal discussion. The following section describes the discrepancies, the reason for the discrepancy and the results from the following discussion:

(a) The participant notated the top arm fairly wide of the centre, however this is the result of their not needing a great deal of accuracy to recognise the *fourth* position of the arms. When asked to recreate the pose the participant could demonstrate the correct arm positions. This is the result of choreologists using inferred rules recreating balletic poses and therefore less accuracy within the notation i.e. it can only be fourth position.

(b) The second participant interpreted the head position as a tilt and turn while a turn and raise was the pose demonstrated by the VBD. The participant felt that this position can depend on interpretation. However it is worth noting that when looking at the head again from a different angle after the experiment position, the choreologist agreed that the head was actually a turn and raise as read by the VBD.

(c) Both participants positioned the raised foot higher than the third stave line. Though the notation stipulates that the third stave represents waist height, it appears in practice choreologists notate the legs when the knee is straight on the third line as being ninety degrees or horizontal to the ground which appears very logical for visualisation of the pose by the choreologists. This equates to positioning the VBD with the leg at the same height as the hip in an anatomical position.

(d) The degree of the height of the arm can vary according to pelvis tilt and different choreologists will have a different approach. We see participant 1 posed the arm after the body tilt and therefore it is lower than the actual position while participant 2 took the same approach by notating the arm and then the body. Because of the angle of the body it is difficult to visually see exactly where the arm is when compared to a vertical position of the body and therefore the notated posed arm varies slightly. Both participants understood this problem and agreed that the VBD posed the arms correctly from the notation.

(e) This is an alternative way for writing the same pose of the head and the body

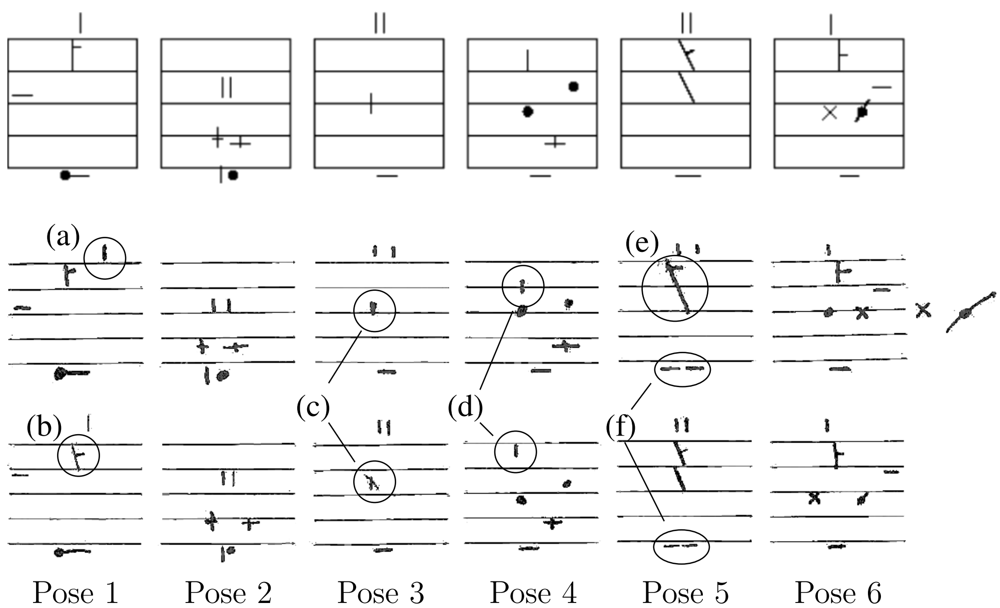


Figure 4.16: The Benesh notation pose evaluation results. The top line is the notation of the input file used by the VBD prototype, the middle line is the first participant and the bottom line is the third participant. Highlighted differences are: (a) notated wide; (b) notated as tilt and turn instead of turn and raise; (c) posed leg position as above ninety degrees instead of opposite waist; (d) positioned of the height of the arm varies due to the body tilt of the VBD; (e) alternative notation for the same body and head pose; and (f) notated heal separation in *first* position

as shown by the experimenter and participant 2 and both are understood by choreologists.

(f) Both participants notated the heel separation of the VBD. A general discrepancy described in §4.5.2 and shown in Figure 4.11(c). Interestingly, both the teachers and choreologists describe the pose of the feet as *first* position. Participant 2 stated the discrepancy between the notation and named description as: *"feet in first position usually assumed as touching each other – depending on the shape of the legs"*. Given the models leg design, the pose was acceptable as a *first* position.

4.7.3 Discussion

From the second evaluation, the two main observations were the placement of the heels in the *first* position and the position of the raised leg when specified by the third line of the Benesh stave being related to a horizontal position parallel to the floor and not mapping to the waist height. From the ensuing formal discussions with the choreologists, it was decided that both the VBD poses and the differences noted in the evaluation two results were acceptable ballet positions. Even though the first position was not raised as being incorrect by the dance teachers, but recognisably different when notated by the choreologists it was decided to implement the changes to place the heels together when the notation specifies a *first* position and to map the third stave line height as hip height instead of the original waist height to create a horizontal raised leg.

From evaluation 2, both the teachers and the choreologists did not have a problem with the design of the model when evaluating the poses. However, from the formal discussions, when asked about correcting the VBD, the main issues were as expected and discussed in evaluation 1. The issues were:

Breasts size The model design provided with the Cal3D is not a typical ballet body and the most obvious difference that sticks out is the size of the breasts. Though noted as not being an aesthetic design for ballet, they did not hinder the recognition and notation of the posed ballet positions.

Shape of the hands While the breasts can be put down to personal preference, this is not the case with the shape of the hands which are incorrect for a ballet dancer as described in §4.5.2 and evaluation 1. Again, they did not affect the participants judgement on the poses, however when asked what they would correct, the hands were always mentioned.

Squareness of the hips One factor that was consistently mentioned by both sets of participants was the lack of rotation in the hips with the raised leg. This equates to a perfect dancer though lacking in realism as professional dancers aim to have square hips however very few achieve this and therefore rotate to achieve the positions. Because this varies depending on the facility of the dancer, the VBD will be kept as a dancer with square hips with a raised back leg i.e. the perfect dancer.

Pose of the head The pose of the head has been greatly improved from the first evaluation, however the position of the head can vary depending on the pose of the arms. This is shown with one of the participants selecting a turn and raise instead of a turn and tilt for pose 1. However, the pose of the head can be interpreted slightly differently and therefore we will for this research keep the orientation as the maximum turn with no compensations based on the arm pose and assign this as possible future research and development. It is worth noting that the model has not been changed and therefore the head mesh has the chin and nose pointing slightly downwards instead of straight as would be required by a model of a dancer as discussed in §4.5.2. Though this had some effect on the participants describing the pose of the head both as descriptions and notation, the results showed they could assess the pose and pointed out that the position of the head required correction in the same way as students are corrected during a class.

4.8 Summary

This chapter shows that setting balletic poses from a file format relating to Benesh notation can define positions for classical ballet. Ballet professionals could name the pose of the VBD using ballet terminology and also annotate the VBD pose that matched the input from the file format. Though there were some minor discrepancies on some of the VBD poses, the overall shape of each pose as defined by the rules of classical ballet and inferred in Benesh posed the VBD correctly. Using each pose as a keyframe, a combination of these poses can be used as the basis for setting an exercise or dance on a VBD.

The main criticism of the pose on the VBD is the appearance of rigidity. This is not a criticism of the VBD but a reflection on the design of classical ballet. Many positions are at the limit of personal physical capabilities and therefore to achieve some balletic positions, the real-world dancers make small alterations as shown with the twisting of the hips in Figure 4.13(d). Though not technically correct in terms of the ballet rules, it is a common feature of dance. The VBD is able to be positioned in a technically 'correct' position as described by the classical ballet rules due to the fact there are no physical constraints. The real-world dancers make compensations known in the ballet world as 'cheats'. The decision for setting the foundations towards simulating ballet was to pose the VBD in a technically correct ballet pose as defined by the ballet rules, even given the difficulty for the real-world dancer to imitate the exact same pose.

Chapter 5

Expressive Interpolation

5.1 Introduction

Classical ballet performers mainly utilise expressive gestures of the arms and legs, together with facial expression to convey emotional intent to the audience. There are various pieces of ongoing research in simulating human expressions (Camurri & Trocca, 2000; Byun & Badler, 2002; Cassell, Vilhjálmsson & Bickmore, 2001), but the VBD research focuses on expression performed by the limbs.

The expressive VBD system can be defined in two stages, (1) the setting of the key poses required to define a dance movement, as presented in Chapter 4, and (2) a set of algorithms and methods to interpolate movement between the key poses. Classical ballet provides enough freedom in the ballet rules for arm movement for dancers to add expressive qualities which can be distinguished by the audience. The VBD system provides a set of parameters that allows dancers, teachers and choreographers to manipulate the quality of the motion to their own preferences.

This chapter describes the development and evaluation of techniques that interpolate the movement of a VBD using movement rules for classical ballet, and movement specified by the Benesh notation and the emotion being performed. The following sections explain and define the rules for movement, the interpolation methods (calculation of intermediate poses from one key pose to the next) used by the VBD to perform expressive movement and then evaluates these methods used by making comparison between the movies used for the real-world experiments in Chapter 3 and the VBD performing the same ballet sequence.

5.2 Background

To aid understanding of methods used for interpolation between the key poses, a basic understanding of ballet rules for movement and the Benesh notation rules notated and inferred by choreologists are explained.

5.2.1 Benesh Notation and Movement

The previous chapter demonstrated how Benesh notation was used to define the poses of a dancer using classical ballet dance rules. In many disciplines, complex tasks can be divided into a set of simpler tasks to aid learning and understanding. In classical ballet, teaching complicated movement and steps is accomplished by segmenting the movement to a series of recognisable poses and a description of the movement required from pose to pose. Many dance notations, and in particular Benesh, take the same approach. The process can be clearly demonstrated where the notation for a *grand jete en tournant* are shown in Figure 5.1. The step is a combination of five frames (key poses) with movement lines to describe the path of the extremities (requirement 7 as described in Chapter 3).

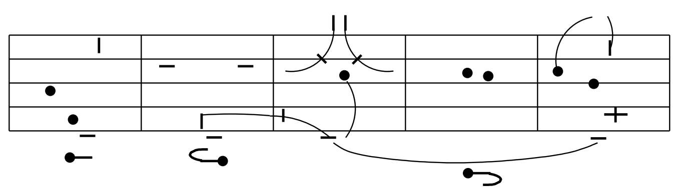
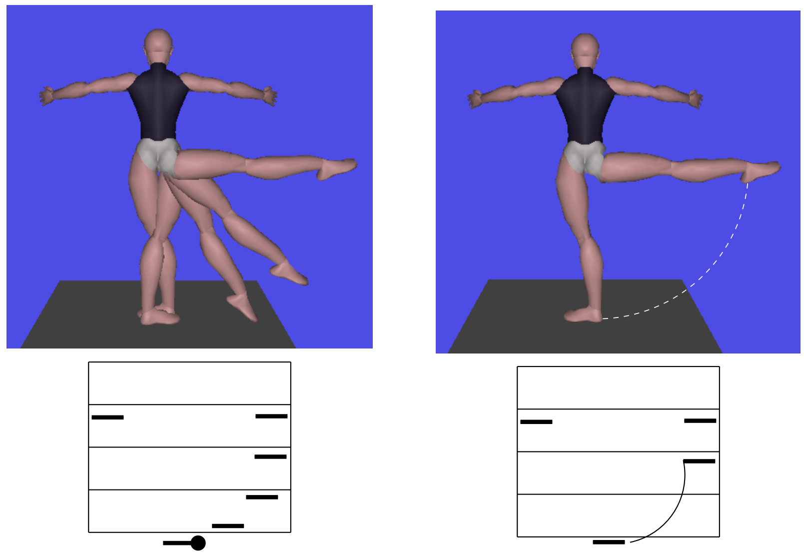


Figure 5.1: Example of annotating, using Benesh notation, a *grande jete en tournant* using a combination of extremity positions and movement path lines.

The alternative to movement lines would be the explicit notation of a large number of key poses, which is cumbersome and impractical (Benesh & Benesh, 1983) (see Figure 5.2).

Benesh notation was originally devised for classical ballet and assumes movement mostly takes place along the shortest path. For example, if the first pose has the arm out to the side and the second pose has the arm above the head the shortest path is a circular arc up the side. If a variation in the path is required, for example, via a pose with the arm out in front of the body, then further intermediary information is



(a) Intermediate poses (b) Movement lines

Figure 5.2: *Grand battement à la seconde* demonstrated by the VBD with (a) intermediate positions and (b) connecting the commencing and final positions with a movement line

provided. An example is shown in the third frame of Figure 5.1 where the movement is required to go in front of the body from the side pose of the arms to a pose above the head by annotating a short perpendicular line to the middle of the movement path. Further details on Benesh movement descriptors can be found at page 138 –142 in *Dance Notation for Beginners* (Brown & Parker, 1984) and pages 31–38 in *Reading Dance* (Benesh & Benesh, 1983).

Movement lines do not determine intermediate joint angles, as discussed in Chapter 4. Also, while Benesh notation can provide a movement path using the inferred ballet rules, the design of the notation means that other inputs can be used on top of the path description. This can include techniques for expressive movement in ballet described by Blasis (Blasis, 1830) and other methods such as Laban's Effort-Shape theory used to describe the qualities of motion.

5.2.2 Laban's Effort-Shape Theory

Laban Movement Analysis is a method for observing, describing, notating and interpreting human movement. It provides a comprehensive vocabulary and analytic framework describing human movement and the way we move (LIMS, 2004). Composed of five major components (Body, Space, Effort, Shape, and Relationship), it incorporates a textual and symbolic language for describing movement. This chapter is concerned with the dynamic qualities of the movement between the key poses which is characterised and parameterised in Laban's Effort-Shape theory (requirement 8 as described in Chapter 3). Ballet rules provide a description of the shape of the movement and therefore the parameters of interest in the present research are associated with the Effort component. In particular we are interested in the factors space, weight, and time. In EMOTE (Chi, Costa, Zhao & Badler, 2000) and Synthesis and Acquisition of Laban Movement Analysis Qualitative Parameters for Communicative Gestures (Zhao, 2001), Chi and Zhao gave the following descriptions and examples:

Weight: sense of impact of the movement and exertion required.

- *light* buoyant, weightless and delicate. e.g. dabbing paint on canvas, describing the movement of a feather
- *heavy* powerful with impact e.g. pushing or punching

Time: describes the qualities of sustainment and quickness i.e. sense of urgency.

- *sustained* lingering and indulging in time e.g. stretching to yawn, stroking a pet
- *sudden* agitated, jerky movements e.g. swatting a fly, making a snap move.

Space: is spatial focus and attention to surroundings.

- *indirect* multi-focused e.g. waving away bugs.
- *direct* pinpointed and single focused. e.g. undeviating from a path, threading a needle.

The Laban factors in the present research are used as control parameters that vary the movement path and interpolation along the path to distinguish differences in expressiveness.

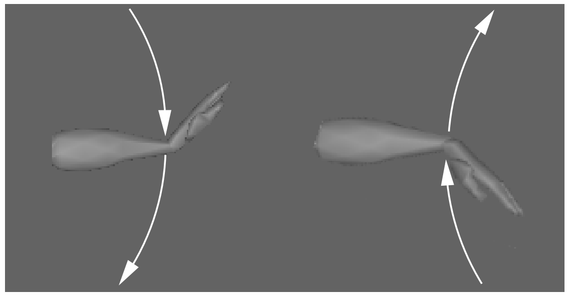
5.2.3 Ballet Rules for Movement

The rules for classical ballet described in Section §4.2.2 for setting the key poses can also apply during the movement e.g. the rounded arm shape (requirement 9 as described in Chapter 3). This research concentrates on the arm and hand movement and inflections where the expression can be readily assessed.

Study of the Arms

In *"The Code of Terpsichore"* (Blasis, 1830), a complete chapter is dedicated to the study of the arms. The following issues are a combination of the rules for dance movement stated in the book that are used for expressive motion.

Movement in the wrist and the orientation of the hand depends on the movement direction of the arms as depicted in Figure 5.3.



(a) Wrist down (b) Wrist up

Figure 5.3: The two directions of the wrist for classical ballet movement, where the wrist leads the direction of movement.

According to Blasis, the elbow, as well as the wrist, has its movement downwards and upwards. The modern classical dancer uses inflections of the elbow, wrist and, depending on the ballet method, different degrees of shoulder rotation to express. The Cecchetti method, which are fundamentally the ballet rules used in this research, specifies the downward movement at the side is led by the lower part of the hand and not the wrist though the same amount of wrist up or down is still applied.

5.3 Motion Capture of Dance Movement

To better understand the inflections and variations that take place when real-world dancers move, three dimensional motion data were captured from two classically trained dancers performing a *first port de bras* from the Cecchetti method. Analysis was performed with respect to Laban's weight, time and space parameters.

The data was captured in the University of Leeds Interdisciplinary Centre for Scientific Research in Music (ICSRiM) using a nine camera VICON infra-red motion capture system (as shown in Figure 5.4).

Vicon retro-reflective markers were positioned on the upper body of the dancers as specified in the user manual. The marker positions were: four markers on the head (two front and two back); the left and right shoulder; upper arm, elbow, lower arm, inside wrist, outside wrist and middle finger for both arms; left and right pelvis bone at the side; the sternum and clavier for the front of the body; and three markers

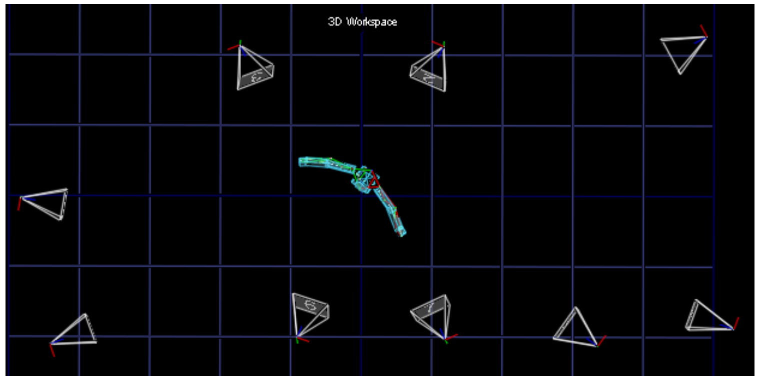


Figure 5.4: Motion capture layout visualised by the Vicon Ia software showing the positions of the nine cameras and the model of the upper body and head fitted to the captured dancer for post processing.

at the back, two on the spine (C7 and T10) and the third on the right shoulder blade to form a triangle.

VICON iQ reconstructs the multiple camera images into a single set of 3D co-ordinates. The coordinates for each marker are linked together to form trajectories which are labelled for identification. Using the labelled trajectories information on the relative marker positions, kinematic and kinetic calculations were performed to calculate the joint centres and joint angles. The VICON system capture frequency was set at 200 Hz.

5.3.1 Choreography for Dance Movement Set Capture

The *first port de bras* is the most basic of all the arm movements and is the first taught to students learning the Cecchetti method. The movement entails the three fundamental arm movements. Upward movement in front of the body, the sideways movement, and downward movement at the side. Figure 5.5 shows the Benesh notation and the path of the wrist (in this case, the right wrist) highlighting the position of the extremity at the key poses.

The dancers were required to perform the *first port de bra* in 3/4 time for each emotion of natural, happy, sad, angry, and afraid. Each emotion was repeated four times, with a break between each emotion. This was necessary for the dancers to compose their emotional state for the next move. The capture of the arm movements were split into two sessions lasting a total of three hours.

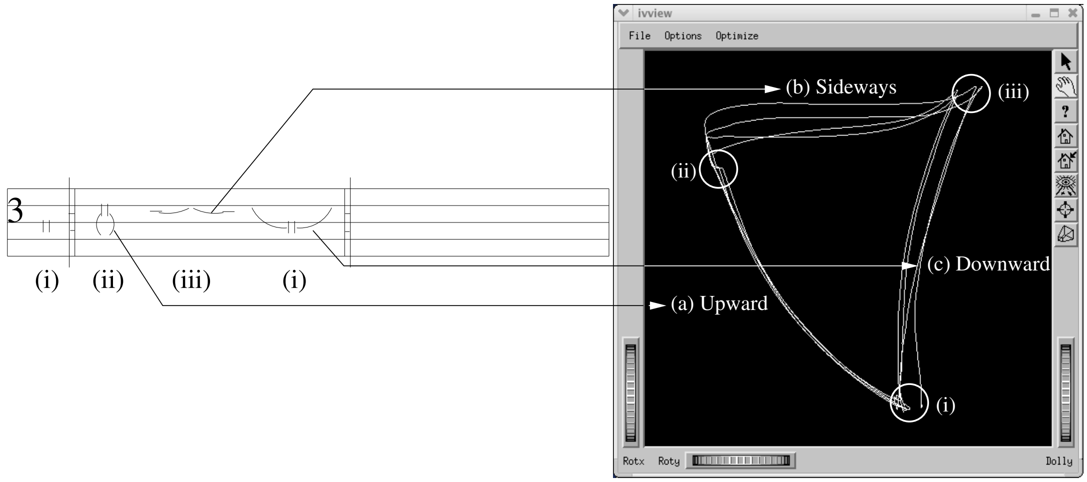


Figure 5.5: Benesh notation and movement paths for the *first port de bras* of the right wrist performed with emotion 'natural'. The key poses are: (i) *fifth en bas*; (ii)*fifth en avant*; and (iii)*a la seconde*.

5.4 Motion Data Analysis

The motion capture system software VICON iQ saved the data files in a CVS format of the 6D motion trajectory of the wrist (orientation and position). These data were used to obtain an understanding of ballet movement made with different emotions. Analysis of the wrist was used because Benesh notation specifies the actual path to be taken by the wrist (Benesh & Benesh, 1983) and classical dancers while executing the movement of the arms will be considering the pose of the arms and the shape of the movement (i.e. the position of the wrist relating to the body during the movement). The analysis is divided into three parts.

Analysis 1 looks into finding a difference in the tempo of the movement being performed.

Analysis 2 looks into the profile of the speed and distance travelled along a motion path with respect to Laban's Weight and Time parameters.

Analysis 3 has been segmented into two sections. (3a) provides an initial investigation into specifying a motion path using simple parameters for different emotions based on Laban's Space parameter, and (3b) specifies the use of dance and notation rules to stipulate the path of the wrists.

The analysis focuses on happy, sad, and angry emotions, in which participants distinguished significant differences (see §3.3.3). The data files were segmented manually using iQ software into three sets of data, upward, sideways, and downward.

5.4.1 Analysis 1: Emotion Tempo

Results from the real-world experiments showed that participants could distinguish between different emotions, even with the same tempo (see §3.3.3). However, one of the strongest clues to distinguishing the emotions was the tempo of the movement.

The results from the motion captures show a distinct difference between the time taken to perform each emotion, and between the three stages of the movement (see Figure 5.6). The variations in the tempo between the directions of movement

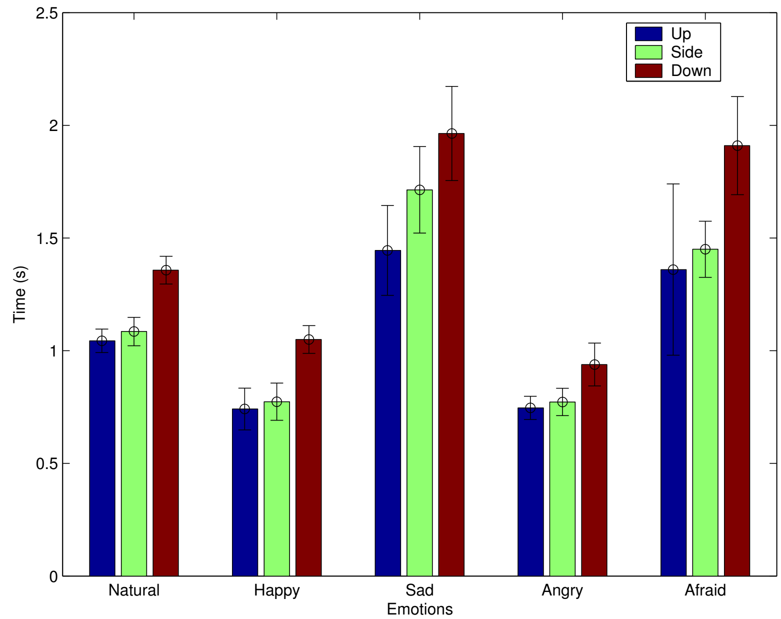


Figure 5.6: Average time taken between key poses for each emotion in an upward, sideways and downward movement as shown in Figure 5.5. Error bars show the standard deviation

may have been caused by: (1) the length of the movement between the key poses where the up movement is the shortest and the down movement is the longest path, and/or (2) the phrasing of the whole movement where the start of the phrase (up movement in this example) has an initial acceleration and the end of the phrase (down movement) is performed with a deceleration. The phrasing of movement requires the understanding of how each movement affects the next and is beyond the scope of this research.

The most noticeable difference is the consistently fast tempo for the happy and angry emotions and the large difference in tempo used to express a sad emotion. From Table 5.1, the tempo for sad is approximately half that of happy and angry. For the VBD to simulate expressive movement, the user interface is therefore provided with a tempo controller that can vary the speed of the movement. For the evaluation described later in this chapter, the tempi used were derived from the real-world videos, and both the happy and angry emotions were performed with the same tempo. Slight variations in the evaluation between the VBD and the real-world

	Up		Side		Down	
	Time (s)	Tempo	Time (s)	Tempo	Time (s)	Tempo
Natural	1.04	57	1.09	55	1.36	44
Happy	0.74	81	0.77	78	1.05	57
Sad	1.45	42	1.71	35	1.96	30
Angry	0.75	80	0.77	78	0.94	64
Afraid	1.36	44	1.45	41	1.91	31

Table 5.1: Average time and metronome tempo for movement between key poses taken from the *first port de bra* segregated into the three direction of movement.

dancers can be expected to occur based on the phrasing, the emotion being portrayed and the direction of movement. With these factors, the real-world dancers do not keep an exact tempo with slight variation in speed during the performance of the sequence and a slowing down at the end of the sequence. This needs to be considered when comparing the intermediate poses of the VBD and the real-world dancers.

5.4.2 Analysis 2: Motion Dynamics of the Wrist

The task for calculating points between key poses (animation key-frames) is called inbetweening or interpolation of key-frames. This, however, typically specifies the animation path, not its dynamics. The two common methods for specifying how the speed of movement varies along a given path are: (1) the P-curve system, which specifies the path and the dynamics of the motion, and (2) expressing the path as a parameterised spline with an associated curve specifying speed. Classical ballet dancers expressing emotions may use the same path with different dynamics i.e. no variation in Laban's space parameter but variations in the other parameters, therefore an understanding of the dynamics irrespective of the path was required (i.e. method 2).

The approach in this PhD has been to match variations in the motion dynamics to Laban's weight and time parameters. The paths were split into upward (Up), sideways (Side) and downward (Down) motions. Figure 5.7 presents profiles for the relative distance travelled and speed. The distance travelled was normalised so the relative time to perform the motion was equal to one and the relative distance travelled to complete the motion was also equal to one. The speed profile was normalised so that the maximum speed achieved by all the emotions was equal to one as shown to occur during the down motion while expressing anger.

By looking at the shape of the speed graphs, there is a noticeable difference between angry (sudden/accented heavy motion) and happy or sad (sustained light motion). This section focused on fitting a sigmoidal curve to the distance versus time data to specify the dynamics of the motion.

5.4.2.1 Fitting a Curve to the Distance Profile

The objective was to find a straightforward way to define the dynamics along a given path. The general shape of the distance profile corresponds to a sigmoidal curve. These have the main parameters shown in Figure 5.8.

The curve fitting was performed using SigmaPlot 2001 for Windows from SYSTAT (SYSTAT, 2004). SigmaPlot 2001 offers a variety of sigmoid functions for non-linear regression. Functions include Weibull (4 or 5 parameter), Gompertz (3 or 4 parameter), Hill (3 or 4 parameter) and Chapman (3 or 4 parameter) which were discounted as being either the incorrect shape of sigmoid or having too many parameters. The two curves that did appear suitable were the 3 parameter Sigmoid:

$$y = \frac{a}{1 + e^{\left(\frac{-x - x_o}{b}\right)}} \tag{5.1}$$

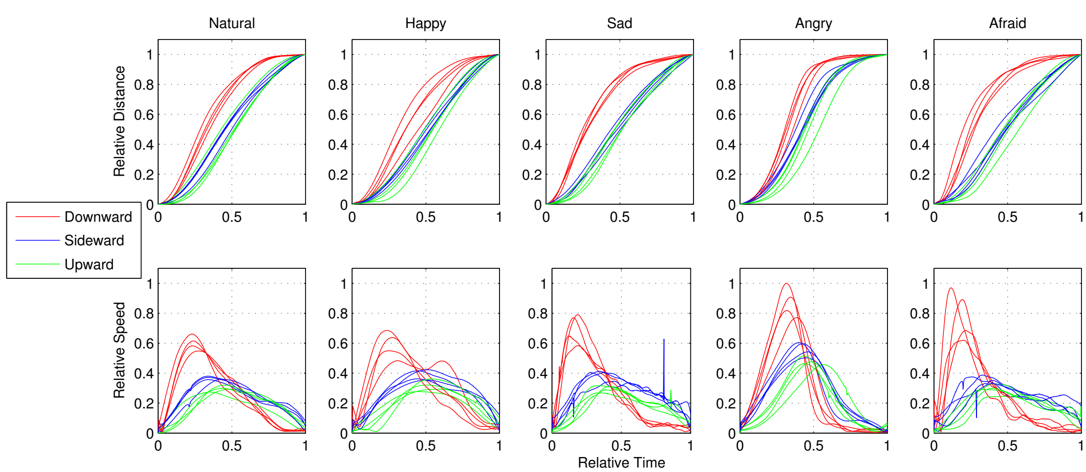


Figure 5.7: Relative distance travelled and speed during the up, side and down movements performed with each emotion

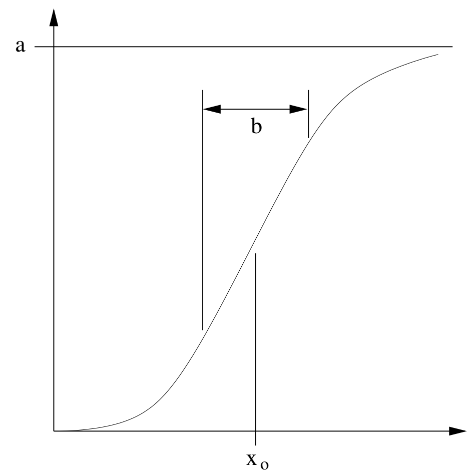


Figure 5.8: The Logistic sigmoidal curve where a is the max distance travelled, b is the maximum gradient of the curve and x_o is the centroid of the curve.

Logistic		Sigmoidal	
Angry	0.9996	Angry	0.9926
Afraid	0.9973	Afraid	0.9994
Happy	0.9994	Happy	0.9962
Natural	0.9996	Natural	0.9951
Angry	0.9996	Angry	0.9934

Table 5.2: The Average RMS for the Logistic and Sigmoid Fitting for Each Emotion

and the 3 parameter Logistic fitted curve:

$$y = \frac{a}{1 + \left(\frac{x}{x_o}\right)^b} \tag{5.2}$$

Each individual profile was fitted to provide a set of parameters to specify a sigmoidal curve relating to the emotions and the direction of movement. From the parameters obtained from each fitted curve, the objective was to find a correlation between the sigmoidal parameters and the emotions being performed.

From the Interpreting Regression Reports provided by SigmaPlot 2001, the closeness of the fit using the Root Mean Square (RMS) was compared and found the Logistic function was a better fit than the Sigmoid function by approximately half a percent. The average RMS for the Logistic curve for all emotions was 0.9991, where 1.0 is a perfect fit and for the Sigmoid curve was 0.9953. Breaking it down into emotions the average RMS for each emotion is shown in Table 5.2:

5.4.2.2 Analysis of Sigmoidal Distance Curve

While the two dancers analysed had distinct different styles, it can be seen in Figure 5.9 the angry motion has a steeper gradient which occurs earlier in the movement.

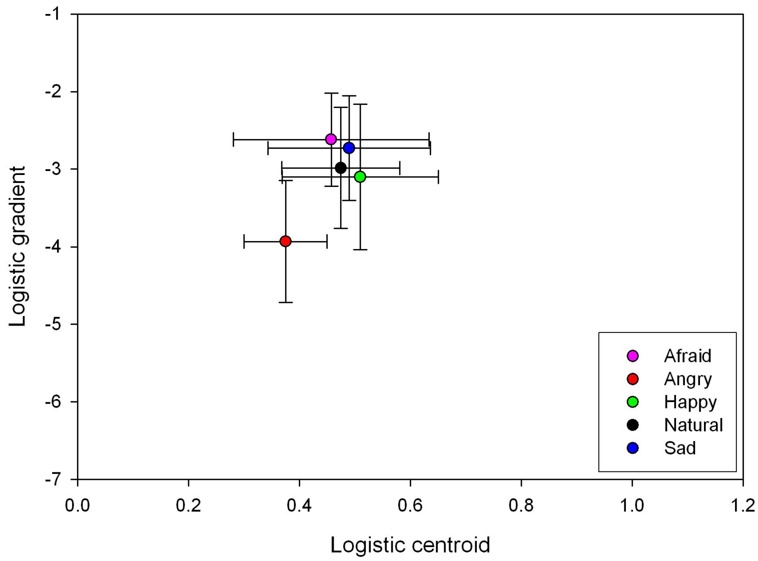


Figure 5.9: Graph showing the mean sigmoidal logistic gradient and weight values for each emotion. Error bars show the standard deviation

By separating the dancers, the difference between the emotions can be more easily distinguished. Interestingly the styles of the dancers affect how each emotion is performed. For both dancers, it can be seen in Figure 5.10, the angry motion is

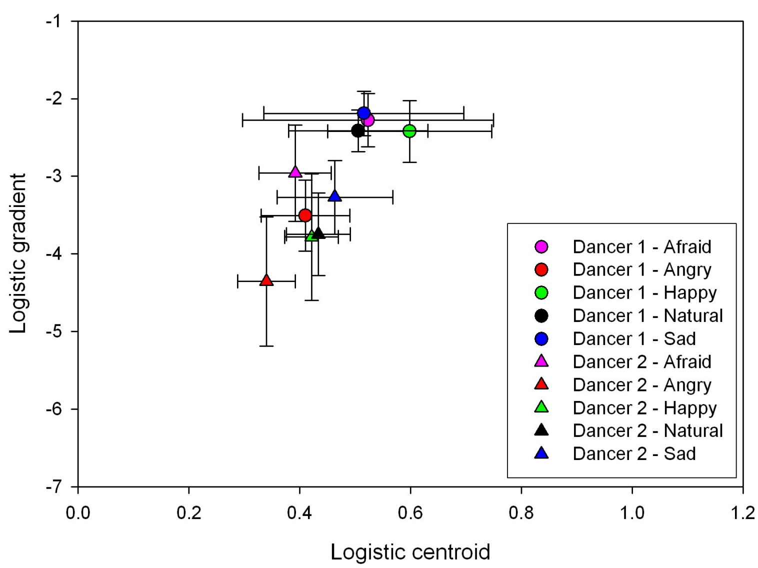


Figure 5.10: Graph showing the mean sigmoidal logistic gradient and weight values for each emotion. Error bars show the standard deviation

separated from the other emotions, i.e. the red triangle is distinctly separate from the other triangles and the red circle is separate from the other circles. However, the first dancer (circles) has a more lyrical quality while the second dancer has a strong style and this can be seen where the data has a similar pattern for the emotions where the triangle data is offset from the circle data downwards and to the left.

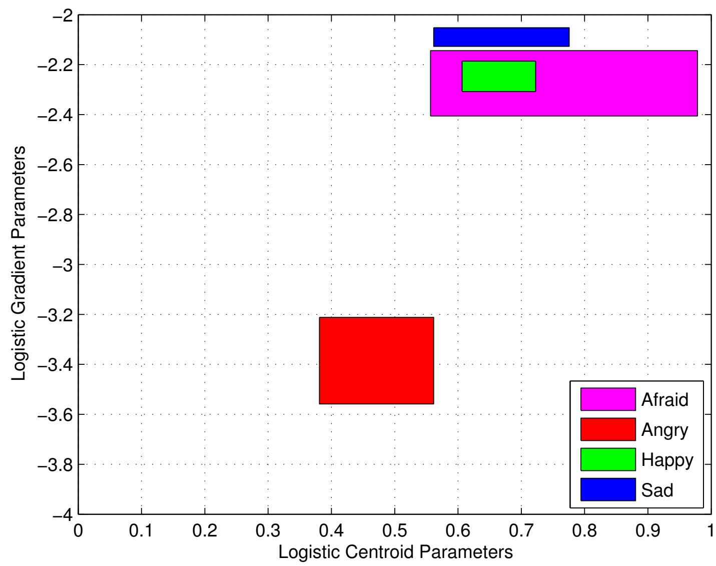


Figure 5.11: Graph showing the area taken by the different emotions derived from the maximum and minimum parameters for the centroid and gradient for a logistic sigmoidal curve for the distant interpolation between key poses for each combination of emotions for Dancer 1.

From the analysed data, Figure 5.10 shows a distinct difference from the angry motion and the other emotions and this is emphasised for a single dancer in Figure 5.11. There are two aspects about the angry motion that can be assumed in relation to Laban's weight and time parameters. The angry motion was performed with more accent than the other emotions (higher peak velocity; this can also be seen in the real-world videos), and angry motion is usually described as being heavier in movement.

There is a noticeable difference between the angry sudden movements and the other emotions. From the logistic regression for angry, the average gradient coefficient was $B_1 = (-3.51 \pm 0.06)$ with the maximum gradient coefficient $B_1 = (-4.07 \pm 0.07)$. The sad emotion was more sustained movement between key poses and its average gradient coefficients were $B_1 = (-2.19 \pm 0.01)$ with the minimum gradient coefficient $B_1 = (-1.90 \pm 0.00)$. From this data, it was decided to work between the range −2.0 to −4.0 for the gradient of the sigmoidal curve used to interpolate the distance travelled for demonstrating the expressive emotion on the VBD.

Analysing the affect of the weight parameter, using the ballet rules for movement, the inflections of the wrist is the main cue for assessing the emotive movement as being heavy or light. Heavy weight has been described as pushing or pushing an heavy object where the maximum speed of the motion is earlier in the movement than with lighter motions such as a flicking action where the maximum speed can be seen later in the movement. With the sigmoidal curve, a comparison between the emotions was looked at to see if there was any correlation between the weight factor of the movement and the centroid x_o of the sigmoidal curve which defines where the maximum gradient occurs in the curve.

From the captured data, in Figure 5.10, it maybe noted that: (1) the movement for the heavier angry weight is attacked earlier in normalised time and the other other lighter emotions are attacked later in time, and (2) due to the phrasing structure, the down motion (at the end of the phrase) was typically in rallentando (slowing down), Hence, the average time for attack appears earlier in time. The emotion at the end of the phrase can not be considered since it relies on the individual style of the dancer.

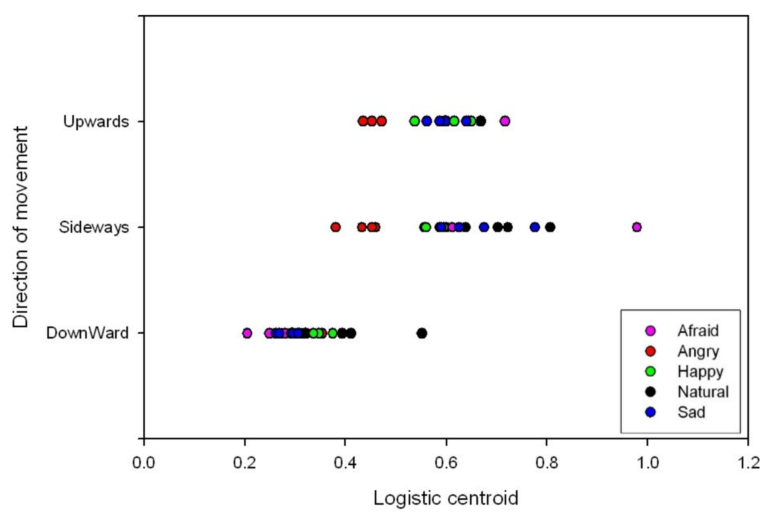


Figure 5.12: Graph showing the sigmoidal logistic centroid values for emotive movement for the upward, downward and sideward directions.

It was concluded the greater increase in the rate of acceleration occurs later for lighter motion but earlier for heavier motion. The average centroid coefficient for happy was $X_o = (0.60 \pm 0.00)$ with the maximum centroid coefficient $X_o =$

(0.81 ± 0.01). For the angry heavier movement, the average centroid coefficient was (0.41 ± 0.00) with the minimum centroid coefficient $X_o = (0.38 \pm 0.00)$ not including the ending of phrase down movement. This phrasing was not analysed with the current captured data. The way in which the end of a phrase (slow down) maps to emotive movement is outside the scope of this research.

5.4.3 Deriving Parameters for Weight and Time

From the above, it can be concluded that motion dynamics during ballet movement can be represented as a sigmoidal curve. Using SigmaPlot 2001, the simplest and best fitted equations was the Logistic curve. The range of the gradient used in the VBD demo is approximated to be between -2.0 (sustained) to -4.0 (sudden). The centroid defines when the maximum speed occurs in the movement and is approximated to be between 0.3 (heavy) to 0.8 (light). The same parameters are used to define the amount of wrist bend where light is the maximum of wrist bend during the movement and heavy has the minimum amount of wrist bend. Drawing together data from analysis 1 and 2, different parameters for weight (dynamics and time (tempo) can be used to distinguish between motive themes (see table 5.3).

	Happy	Sad	Angry	Afraid
Time	-2.4	-2.2	-4.1	-2.3
Weight	0.60	0.51	0.41	0.52
Tempo	80	37	79	43

Table 5.3: The average captured data Laban weight and tempo parameters and tempo parameters for the happy, sad, angry and afraid emotions.

From the real-world experiments discussed in Chapter 3, the participants were able to distinguish between the emotions but found it more difficult to distinguish between motions with a similar tempo, weight and time i.e. sad and afraid (see Table 5.3 showing the average parameter values). Participants were more accurate distinguishing between emotions with a large difference in one or more of the particular parameters, for example, between happy and angry (time) and between happy and sad (tempo). From this, it is assumed that other factors, such as Laban's shape parameters, were used by participants to distinguish emotion close together on the current parameters used. To increase the participants ability to distinguish emotions, more factors are required to be analysed, however, for this research, the current parameters were used to characterise the inbetween motion used in classical ballet for happy, sad, and angry, and to a lesser degree, afraid.

5.4.4 Analysis 3: Ballet Movement Path

Variations in the movement between different emotions are small. For the untrained eye, it is often difficult to distinguish where this variation occurs. However, general appreciation of the quality of movement is perceived as presented in the real-world experiments (see Chapter 3). In this section there are two stages of analysis, the first was to define the path based on the emotion being portrayed, i.e. can the space parameter define a distinct path that is generic to all movement in different directions? , and the second section was defining the path based on the dance movement rules, Benesh rules and from observations noted from the real-world videos.

5.4.4.1 3a: Lagrangian Motion Analysis

This analysis defines the motion path between key poses using a trajectory curve, the Lagrangian description of motion. In this section, the analysis concentrated on the right wrist path captured using the VICON data and path fitting techniques. The wrist is critical for defining the overall path for two reasons: (1) Benesh notation specifies the position and orientation of the arms by specifying the movement path of the wrist, (2) the dancer visualises the arm movement as a path defined by the wrist where the position of the wrist during the movement invokes ballet rules for posing and using the arms. From the rules for ballet and the Benesh notation description for movement, the path between key poses are simple curves as shown in Figure 5.5 and therefore the objective is to find a simple polynomial of the lowest order.

The spline is a piecewise polynomial function that can have a locally very simple form and at the same time be globally flexible and smooth. Splines are used for modelling arbitrary functions and are commonly used in computer graphics. There are many different types of splines, however because of the simplicity of the curve to be fitted, it is deemed the extra control by changing weights towards control points, i.e.Rational Curves and NURBS (Non-Uniform Rational B-Splines), is not necessary for this analysis. The movement to be fitted is known to start and end at particular points in space. A Bezier curve or B-spline with knots defined to fix the end points was selected as the most appropriate means for fitting a spline to the captured data.

5.4.4.2 Curve Fitting

Curve fitting is a process of modelling a trend of outcomes while overcoming any noise that is present in the raw data. Data is often accompanied by noise. The curve fitting process minimises an error component such as the RMS deviation from the raw data. Least squares problems of large size are now routinely solved (Bjorck, 1996). There are a number of different methods for multi-dimensional non-linear minimisation which fall into two categories. The conjugate gradient method (including the Fletcher-Reeves or Polak-Ribiere version) is suitable for very large problems. The variable metric methods (Gauss-Newton) which has two main algorithms: the Davidon-Fletcher-Powell (DFP), and the Broydon-Fletcher-Goldfarb-Shanno (BFGS) and Dixon has shown that most of them generated the same sequence of points and any differences are attributed to numerical accuracy (Lootsma, 1972).

The method of least squares assumes that the best-fit curve of a given type is the curve that has the minimal sum of the deviations squared (least square error) from a given set of data. Suppose that the data points are $(x_1, y_1), (x_2, y_2), ..., (x_n, y_n)$ where x is the independent variable and y is the dependent variable. The fitting curve $f(x)$ has the deviation (error) d from each data point, i.e., $d_1 = y_1 - f(x_1), d_2 = y_2 - f(x_2), ..., d_n = y_n - f(x_n)$. The property for least squares is therefore:

$$\prod = \sum_{i=1}^{n} [y_i - f(x_i)]^2 = \text{minimum}$$

There are varying methods for fitting Bezier curves and B-splines, for example, Borges and Pasta consider the problem of fitting a single Bezier curve segment to a set of ordered data by applying the Gauss-Newton method (Borges & Pastva, 2002). They also demonstrate a simple extension of their algorithm to B-spline curves. Matlab's (MathWorks, Inc., 2004a) Spline toolbox (MathWorks, Inc., 2004b) provides fitting algorithms for the B-spline curve in the weighted mean sense.

$$\prod = \sum_{i=1}^{n} w_i [y_i - f(x_i)]^2$$

Their algorithm is the least-squares approximant to the data x, y, by cubic splines with two continuous derivatives, basic interval $[a..b]$, and interior breaks x_i, provided x_i has all its entries in $(a..b)$. In that case, the approximant consists of $n + 1$ polynomial pieces where n is the number of interior breaks.

5.4.4.3 Path Fitting Analysis

The ballet movement path defined by the Benesh notation means the path is required to start and end at a key pose position. As described earlier, elegant ballet movements also follow simple curves. Therefore given these facts, the fitted curve that can be best used to describe the trajectory is either the Bezier curve or a Bspline curve with end knots specified to lock the curve to the start and end points. To fit a curve to the data, Matlab 7 was used using the Spline Toolbox (MathWorks, Inc., 2004a) using the least-squares spline approximation, `SPAP2`, and curves of the second, third and fourth order were analysed. Given that it is possible to use the Eulerian description of motion, the purpose for this section is to find a simple trajectory description encapsulating the path and the expressive emotions. Because no two movements are identical, a close approximation would satisfy an interpolation path between key poses.

`SPAP2(1,k,x,y,w)` with a 1 positive integer as the first parameter returns the B- spline form of a least-squares spline approximant with the knot sequence, k, chosen within Matlab. Though it is possible to select a knot sequence for better distribution, it was felt unnecessary given that simple curves were being fitted. The w allows the specification of weights in the error measure, where w must be a vector of the same size as x, with nonnegative entries. For example, `spap2(1,2,x,y);` provides the least-squares straight line fit to data x,y, while

```
w = ones(size(x)); w([1 end]) = 100; spap2(1,2,x,y,w);
```

forces that fit to come very close to the first and last data point i.e. the start and end of the trajectory.

Using the above method, the x, y and z values for the control points values of a Bezier curve were obtained for a third, fourth and fifth order curve. The coordinates on the curve were recalculated using the control points and the Bezier function. The higher the order the better the fit to the captured path as shown in Figure 5.13.

The results were subject to a three stage transform before comparison. The first stage was to translate the points so all start points were at $(0, 0, 0)$. Based on knowledge of ballet, movement from key pose to key pose should be planar. Therefore, the second stage involved projecting the points onto a plane. This was calculated by taking the average of the cross products of the vector of all points, P, from the start point, S, with the vector connecting the start point and the end point, E, $\overrightarrow{SE}$. Taking the average vector $(\overrightarrow{SP_1}, \overrightarrow{SP_2}, ..., \overrightarrow{SP_n})$ as the y-axis and $\overrightarrow{SE}$ as the x-axis, the cross product was used to calculate the plane normal. The final stage was to scale the results so the final point was located at $(1, 0, 0)$ (see Figure 5.14).

The quadratic curve is distorted due to the noise and inflection performed by the captured dancers around the key poses. Depending on the amount of noise, the

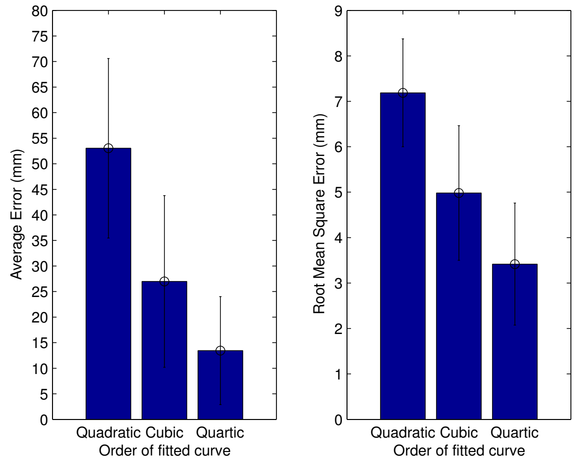


Figure 5.13: Average error and root mean square error for a Quadratic, Cubic and Quartic Bezier curve fit

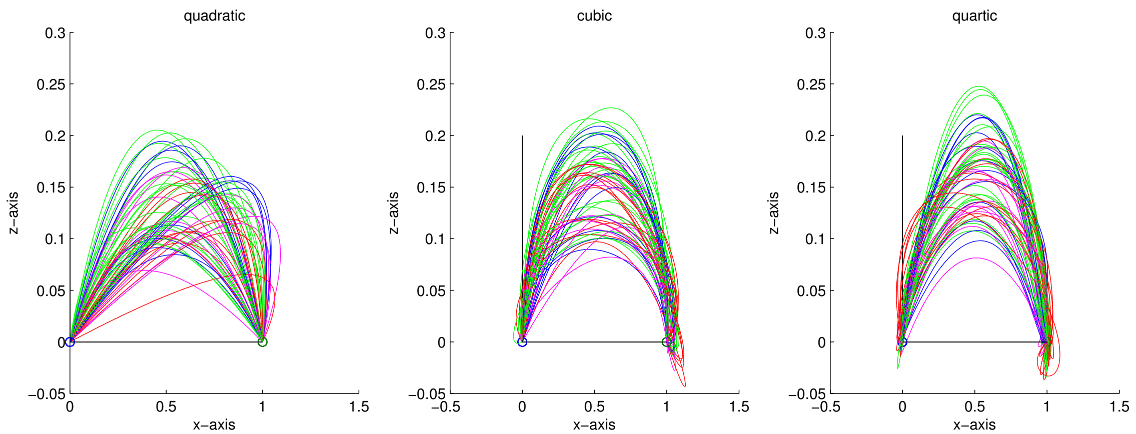


Figure 5.14: Resulting curves for each emotion from Bezier curve fitting calculations where green is happy, blue is sad, red is angry and magenta is afraid

curve was pulled to the right. As the order increases, the curve appears as expected, a simple curve of varying heights. However, at the end points in the quartic fitted curve and higher order curves, the control points include the inflections and noise linking one movement to the next movement. From these results, it can be concluded the a cubic curve is sufficient to represent the captured trajectories of the wrist movement.

5.4.4.4 Mapping Paths to Laban's Space Parameter

Laban's space parameter defines whether the movement is direct or indirect. Personal knowledge of ballet means happy and sad movement can be classified as indirect and the angry movement as direct. Inspection of the control points taken from the curve fitting in Figure 5.15 shows some similarities for the upward and sideward movements but this is lost in the downward movement. It is difficult to see a consistent relationship between the control points and the emotions. Therefore, it seems that the phrasing and direction of the movement affects the shape of the curve to a greater degree than the emotion expressed in the movement. Further analysis with a much larger set of captured data sets would be required to define paths based on Laban's space parameters.

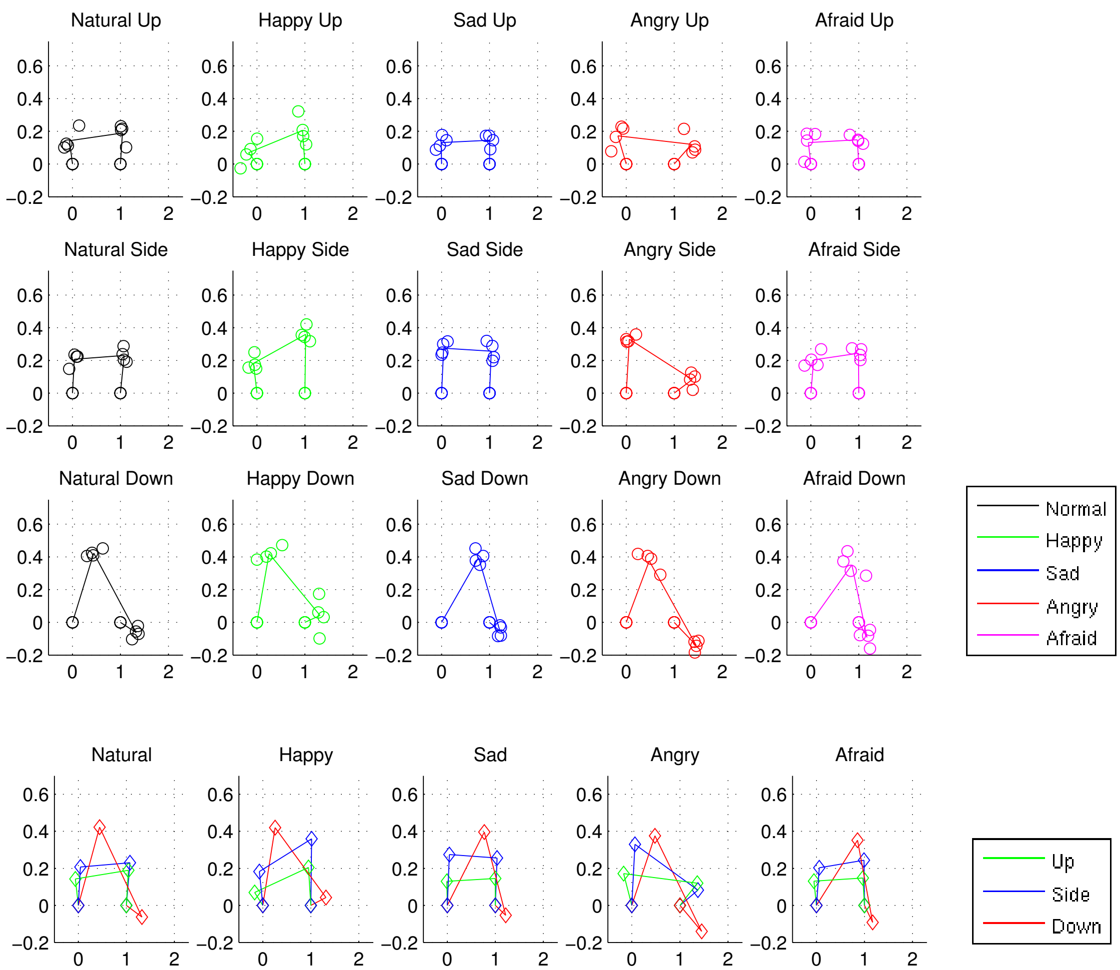


Figure 5.15: Normalised Control points for fitted cubic curves. First three rows include the four captured runs for the four emotions and the natural emotion where the top row is the upward movement, the second row is the side movement and the third row is the down movement. The fourth row shows the average for each emotion.

5.4.4.5 3b: Rule Based Movement Paths

This analysis focused on the original real-world videos using the author's judgement as a professional dancer and teacher. From the videos, two distinct variations in the motion can be seen. The wrist movement either moves away from the body or towards the body (the upward direction in front of the body). The emotion being performed dictates the amount of variation towards or away from the body between the key poses. Not much variation is seen in the angry performances (direct movement) while for the happy and sad performance's (indirect movement) there is a much greater amount of wrist and elbow movement during the movement. This is the same with both dancers and for all runs of the emotion for all exercises.

From the visual findings and the authors professional background, two variations in the path can be described: (1) for the upward movement in front of the body, the path starts and ends with the pose radius and during the movement the radius for the movement gradually shortens for the first half of the movement and then lengthens for the second half to arrive at the end pose radius length. (2) for the other movements, the same applies for the start and end however the radius lengths for the first half of the movement and shortens for the second half. The amount of variation for the radius half way during the motion is dictated by the space parameter and the maximum amount was defined so the rules for ballet were not broken i.e. the elbow does not straighten for the outward direction and the amount of bend for the inward direction is still classified as a balletic rounded arm.

5.4.5 Conclusion

From the first analysis (3a) of the movement path, it was inconclusive whether the trajectories could be defined using Laban's space parameters. Though the movement is fundamentally circular in nature, other factors affected the trajectory of the performed movement including phrasing, the direction of movement, and instances where different ballet rules were applied as discussed in the second analysis (3b). To define a generic trajectory would require a deeper analysis to understand (1) the basic trajectory for all the various directions and phrasing of movement, (2) how the various space parameters affect the different trajectories specified by the ballet rules for movement and (3) how the phrasing of movement by the real-world dancers is affected by the various space parameters.

Using Benesh notation and the inferred ballet rules for the movement between the key poses, it is possible to specify the trajectory of the motion. Using this trajectory, applying spatial parameters to the ballet rules for movement defines the variations that can be performed. This research therefore focused on using the inferred path specified by the Benesh notation and the ballet rules (analysis 3b) to define the trajectory of the arms for expressive interpolation.

5.5 Mathematical Methods for Expressive Interpolation of the Arms

The interpolation methods can be segmented into three parts: the shape of the movement, i.e. the overall tempo of the movement (analysis 1); the dynamics, i.e. speed profile (analysis 2); and the path the wrist follows between key poses (analysis 3b). A simple interface was devised to control the tempo parameter and the Laban parameters for time, weight and space and is shown in Figure 5.16.

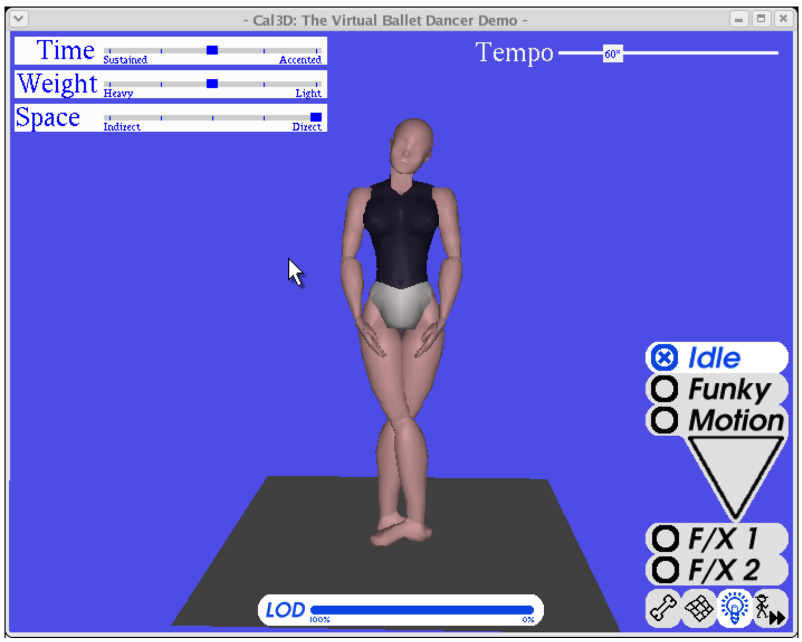


Figure 5.16: The screen capture of the VBD interface demonstrating the Tempo slider (top right) and the Laban parameter slider bars (top left). Other functionalities (bottom right) includes changing the model to show the skeleton structure, the model's mesh and changing the lighting. Also setting the 'Idle' position, 'Funky' using the expressive model derived in this research and 'Motion' using the original Cal3D interpolation model.

5.5.1 Setting Tempo and Elapsed Time

To cover the necessary range of metronome and dance tempos, the tempo slider could vary from 1 to 250 beats per minute. The tempo is used to set the elapsed time of the animation. Cal3D stores and tracks the duration of the complete animation set by the key frames and the time for each key pose during the animation sequence in seconds. Changing the movement speed requires the calculation to update the pose of the model to be based not on the elapsed time of the animation but on the elapsed time for the movement. Using the elapsed time (time tick) and tempo required, the next pose was calculated using the updated elapsed movement time and is calculated as:

$$t_{\text{elapsed}} = \frac{\text{tempo}}{60} * (t_{\text{new}} - t_{\text{last}}); \tag{5.3}$$

where t_{new} (micro seconds) is the current time, t_{last} was the time at the last interpolation drawing for the animation.

5.5.2 Laban's Time and Weight

From §5.4.2.2, the sigmoidal curve is used to calculate the distance interpolated with respect to time between key poses. The logistic curve is calculated using the Equation 5.2. The shape of the curve is changed by altering the: (1) time parameter to change the steepness of the curve, (values range from -4.0 to -2.0); (2) and the weight parameter defining the position of the centroid (0.3 to 0.8).

The distance interpolated between key poses is normalised where 0 is the start of the movement (i.e. first key pose) and 1 is the end of the movement (i.e. the next key pose). The asymptote is calculated using the time and weight parameter to make sure that at time equal to 1, the distance interpolated is also equal to 1. The asymptote is calculated as follows:

$$a = 1 + \left(\frac{1}{x_o}\right)^b \tag{5.4}$$

Figure 5.17 demonstrates the extreme Laban time changes where the centroid $x_o = 0.5$ for both examples. In Figure 5.18, the same observation can be found when the gradient is kept constant ($b = -3$, the median value from the gradient range) and the centroid value is controlled from heavier movement ($x_o = 0.35$) to lighter movement ($x_o = 0.75$).

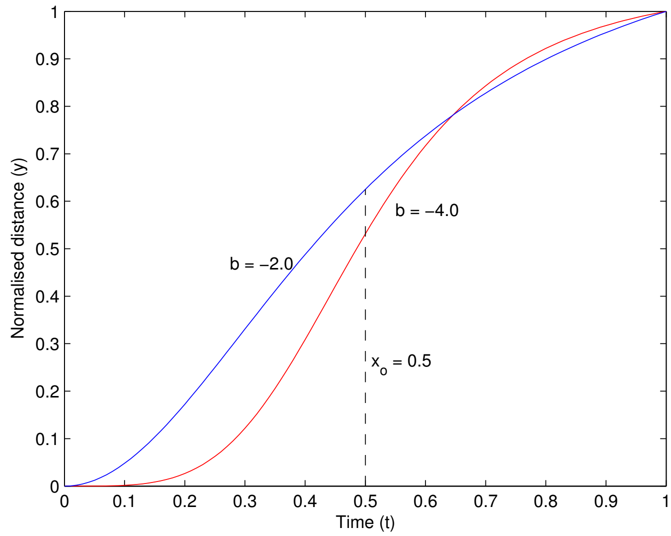


Figure 5.17: Sigmoidal graph showing the effect of changes in Laban's time parameter, where the blue plot produces sustained movement and the red plot produces sudden movement (e.g. angry).

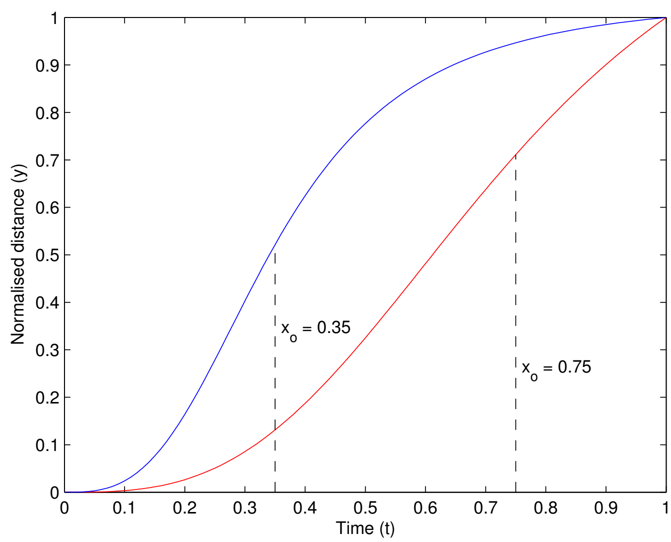


Figure 5.18: Sigmoidal graph showing the effect of changes in Laban's weight parameter, where the blue plot produces (earlier centroid) gives the appearance of heavier movement, and the red plot produces light movement. Note the speed of the movement (gradient) at the end of the light movement which has little deceleration giving a higher speed entering the transition from one movement (the end of the current movement) to the next (beginning of the next movement).

5.5.3 Laban's Space – Spatial Arm Movement

For this research the differences in the space parameter were devised to be simple in order to demonstrate the variations in the movement and how it compares to the real-world movements captured on video. From analysis 3b, the distance of the wrist from the body varied according to the ballet rules and the emotion being portrayed. The Benesh notation specifies the path to be taken with an inference on the depth of the movement. This in turn introduces variation in the circular movement. Cal3d defines keyframes, i.e. orientation and position for the key poses. To demonstrate variations in the space parameter, it was necessary to define intermediate keyframes i.e. orientation and position of the elbow and shoulder along the path that follows the ballet key pose, movement rules and the constraints of the Benesh notation used to define the path.

In §5.2.3, rules for position in the wrist along a movement path described by the Benesh notation were defined. Intermediate key poses are calculated using the same rules as the main key poses as described in Chapter 4. Two equations were used to calculate the distance, (1) for movement within Laban's kinesphere, i.e. extra bend of the elbow, and (2) extension outside a balletic rounded arm reach.

Expressive spatial movement towards the body such as the upward front movement was calculated as:

$$l = r - (1 - S)(0.1r)sin(\frac{k}{n-1}\pi) \tag{5.5}$$

where l is the new length from the shoulder to the wrist and r the length between the shoulder and the wrist for the rounded arm. Rounded arms are defined by the Benesh rules and calculated in §4.4.2. S is the space parameter [0 1] where 0 is indirect and 1 is direct. k is the intermediate key pose being calculated, and n is the number of intermediate key poses required for the path. The most spatial bend as seen in Equation 5.5 is $0.1r$ or 10% of the amount of normal rounded arm bend. This value was heuristically observed by the author as a professional dancer and teacher. A greater amount of bend would result in a different pose as specified by the notation.

Outward expansive movement on the edge of Laban's kinesphere (the sphere of reach) is calculated using the following equation:

$$l = r + (1 - S)(L - r); \tag{5.6}$$

where l, r and S are as described earlier. L is the maximum length the wrist can be from the shoulder when the elbow is straight. Variations to the intermediary key poses for this research are linear segments. In reality, the movement would be a smooth curve, however, for this demonstration it was found unnecessary as the perception of the visual movement appeared smooth when seven intermediate iterations or more were specified.

5.5.4 Implementation of the Expressive Model

The key poses for the VBD are determined using the methods described in the previous chapter. The key poses define the keyframes in the Cal3D animation methods where the animation has a track for each bone and the keyframe position and orientation for each bone is set at a specific time on the appropriate track. The Expressive Interpolation Model (Expressive model) used two stages. The first was to calculate the path based on the spatial parameters set using the GUI. The second stage was to interpolate along the path using the weight and time parameters (also set using the GUI) to specify the movement dynamics on the distance travelled along the defined path.

For the first stage, the setting of the path, the Expressive model defines intermediary key poses using the rules for ballet. For this research, there were seven intermediary poses calculated using the methods described earlier. If less than five intermediate key poses are defined, visual changes in movement direction were noticed and therefore seven made a visually smooth motion. Once the path has been defined, the length of the path was calculated. The length was calculated using the vector from one intermediate point to the next.

For the second stage, the distance travelled by the wrist along the movement path at a given time was calculated using the dynamics specified by the Logistic curve. From the calculated distance travelled, the amount of rotation elbow and shoulder rotation was calculated to place the wrist on the path at the correct distance travelled incorporating the ballet rules.

5.6 Evaluation of Expressive Interpolation

Evaluation of the expressive algorithm was achieved by comparing the arm position and orientation of the VBD performances and the real-world videos, using the *third port de bras* (Easy Exercise 1 from Chapter 3). The VBD animation was captured using Kino, release 0.7.5 (Linux DV, 2004). All captured movies were imported into Adobe Premiere® Pro 1.5 (Adobe, 2004) and trimmed to align the first frame as the start of the arm movement. The emotions captured were Angry, Happy and Sad. Each movie was trimmed so the first frame was the start of the motion. The images of every fourth frame of the fast tempo motion and every eighth frame of the slow tempo motion were exported for comparison of which one example is presented in the next sections

Easy Exercise 1 was evaluated in Chapter 3 with three separate runs of each emotion and there was no significant difference between pairs of same exercises and different exercises. Though the tempo varies marginally between different runs of the same emotions, angry for example was performed with a tempo between 59 and 64, the emotions of the same type can be recognised. From Figure 5.11, an overlap in the range of weight and time parameters with the afraid and happy demonstrates that tempo is used to distinguish the difference in these emotions. The difference between sad and afraid is a lot closer and though there is no overlap in the parameters it would take an excellent teaching eye and understanding of dance movement to distinguish the difference. However, from the real-world experiments in Chapter 3, participants could distinguish differences though the results were not as high as with pairs of emotions with different tempos. It was hypothesised that participants consider different factors such as Laban's shape parameters which describe the shape of the body both during the motion and at the key poses. For this evaluation looking at the inbetween movement, the afraid and sad emotions will be almost identical without the implementation of other factors such as variation in the key pose shape. For this section, the evaluation of motion between key poses therefore focuses on the emotions with distinct inbetween motion differences (i.e. happy, sad, and angry). A comparison was made with all runs of the three emotions evaluated and the results from the evaluation of the different runs were found to be the same. This section will present the motion capture process for all evaluations and discuss the evaluation using one run arbitrarily selected from each emotion.

5.6.1 VBD Configuration and Movie Capture of VBD Animation

The VBD can be executed in two modes: (1) the default Cal3D interpolation model (Cal3D model), and (2) with the expressive interpolation model (Expressive model) proposed in his chapter. This section compares these performances with the real-world video performances of the same emotions. To set up the comparative study, VBD was configured to perform with similar main parameters for each emotion including tempo and Laban's effort factors.

The first step was setting the VBD to perform to a similar tempo to the dancers in the real-time video. From the runs selected for presenting the evaluation in this chapter, Table 5.4 presents the tempos used for each emotion evaluated where the calculation was based on the first and also frame number of the movies captured at 25Hz. There were nine key poses in the *third port de bras* performed, i.e. a start and end linked by eight motions. From the time taken to perform the exercise for a run, the tempo can be calculated as:

$$\text{(int)tempo} = \text{n/t} * 60 \tag{5.7}$$

where t is the time to perform the exercise and n is the number of motions performed.

	First Frame	Last Frame	Frames (n)	Time (n/25Hz)	Tempo
Angry Dancer 1	101	289	188	7.52sec	64
Angry Dancer 2	094	283	189	7.56sec	63
Happy Dancer 1	105	293	188	7.52sec	64
Happy Dancer 2	106	293	187	7.48sec	64
Sad Dancer 1	982	1284	302	12.08sec	40
Sad Dancer 2	978	1269	291	11.64sec	41

Table 5.4: Average tempos of the *third port de bras* calculated from the first and last frame of the arm movement.

The second step was to set Laban's Effort parameters. In terms of the Laban's space, it was noticeable from the real-world dancers that the spatial movement for happy and sad was in-direct, but direct for angry. For angry the VBD was configured with space set to 1 (direct) and for happy and sad, the VBD was configured with space set to 0 (in-direct).

The comparison was made with both real-world dancers at the same time so differences could be more easily compared during the evaluation. As no two dancers perform the same emotions exactly the same, it was necessary to set the weight and time parameters for the VBD to the averages obtained for each emotion in §5.4.2.2. The space, weight and time parameters configured for the VBD for evaluation are shown in Table 5.5.

	Space	Weight	Time
Angry	1	0.41	-3.51
Happy	0	0.60	-2.42
Sad	0	0.52	-2.19

Table 5.5: Laban's Effort parameters used in the evaluation

5.6.2 Common Faults and Differences

Initial evaluation highlighted three general differences between the Cal3D model and Expressive model. The first and most obvious differences was the distance between the VBD's wrists. Ballet rules specify this should be approximately the width of the face. The Expressive model adheres to this rule but Cal3D model does not (see Figure 5.19).

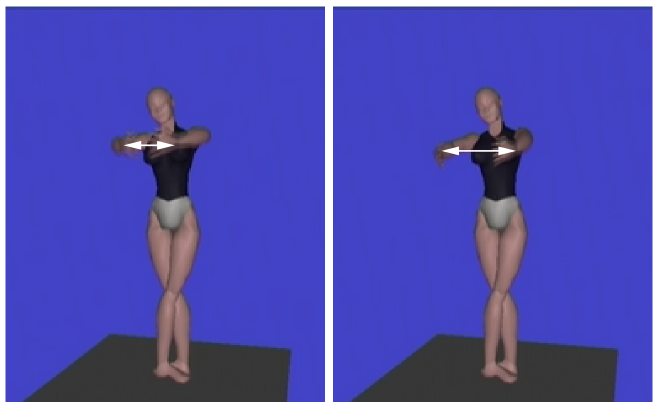


Figure 5.19: The image on the left is the expressive interpolation and the image on the right is the linear interpolation. While the left image keeps the ballet pose rules during interpolation the shortest quaternion breaks the rules by separating the wrist to a greater degree.

The second difference is the position of the head and body at a key pose. Though the time and weight parameters affect the speed of the rotation when changing from one head or body pose to another, Laban's Shape parameters also affect the orientation of the head at the key pose. For example, 'retreating' rotates the head at the key pose away from an audience creating a greater rotation than with a direct pose while 'advancing' hardly rotates the head at all to face the direction of the body. This research focused on the in-between interpolation, so the way the head moved between the key poses was compared but not whether the beginning and end pose of the movement was in the same pose as the real-world dancers. This extra rotation has obviously been captured by the dancers' real-world performances where extra rotation can be seen at the key poses during the phrasing of the exercise. This can be seen in Figure 5.20(a) where the real-world dancers are focusing away from the facing direction of the body while in Figure 5.20(b) the direction of the head is more aligned with the body or the front of the stage.

(a) Retreating (b) Advancing

Figure 5.20: Comparison of key pose with different shape parameters.

The third difference is the varying styles of different dancers. One of the major style variations can be seen in the wrist rotation of the dancers in Figure 5.21, 5.23 and 5.24. Dancer 2 expresses excessively with her arms, and particularly the wrist. For all emotions portrayed, this dancer rotated the wrist, usually ninety degrees, so a distinct angle can be seen. This is known as breaking the wrist. It is a distinct style of this particular dancer and usually occurs in the beginning of each movement.

The expressive interpolation for the VBD cannot take into consideration styles and nuances of all dancers, only those defined by the general ballet rules. Therefore, the VBD performs the movement between key poses using the ballet rules described in Chapter 4 for the arm poses and §5.2.3 for the movement rules.

The main parts to focus on for the following evaluations are the position of the wrist (how far it moves along the path during intermediate poses) and the amount of inflection of the wrist and elbows. It was decided that the VBD would adhere to the Cecchetti ballet rules during the movement between key poses. This was chosen because the intermediate poses during the movement hold the same rules as the key poses.

5.6.3 Evaluation of Portraying Angry Motions

Figures 5.21, 5.23, and 5.24 present comparisons between the real-world dancers (columns (a) and (b)), the VBD using the Expressive model (column (c)), and the VBD using the Cal3D model (column (d)). The Laban parameter was set to direct space and heavy weight (limited inflection) and therefore the differences in the shape of the arms (rotations of the wrist and elbow) is relative to the individual style of the real-world dancers as explained in §5.6.2. This comparison focuses mainly on the distance travelled by the wrist along the path between key poses. The shape of the arms was compared in the evaluation of the happy and sad movement where the space and weight parameters have a more profound effect.

5.6.3.1 Evaluation of the Upward Direction of Movement

The first evaluation compared movement in the upward direction, see Figure 5.21. The movement is evaluated from the top image, (1) to the bottom image, (6), and the points to note are:

i. The sudden time motion of the real-world dancers and VBD using Expressive model (c) compared to the VBD using Cal3D model, (d).

ii. The amount of distance the wrist travels in the last two iterations.

iii. Variations in the elbow and wrist bend of the real-world dancers compared to the VBDs.

iv. The tension and stress in the posing of the hands.

In (i), the sudden expressive movement of the real-world dancers and the Expressive model, (c) achieves a faster speed than Cal3D model, (d). Dancer 2, (b), and the Expressive model are very similarly posed at each frame. Dancer 1, (a), accented the movement to a greater degree and later in time e.g. frame 3 and 4. The Expressive model approximately match the arm poses of Dancer 2 and to match Dancer 1, the VBD weight parameter could be lessened.

In (ii), the sudden movement causes the end of the up movement to almost come to a halt by the end of frame 5 with the real-world dancers and the Expressive model. The Cal3D model is still moving along the path when compared to the distance travelled for sudden movement (even the delayed sudden movement of Dancer 1). The equal distance travelled for each frame using the Cal3D model gives the illusion of dragging behind in the movement.

In (iii), there is minimal change in the shape of the arms with the Cal3D model and the Expressive model with space set to direct whereas there will be differences with real dancers. For example, in Figure 5.22 where the arms are slightly more bent at the elbows for the angry movement in Dancer 2 (middle image) when compared to Dancer 1 (left image) due to a softer style more suited lyrical characters in ballet (e.g. Juliet from Romeo and Juliet and White Swan from Swan Lake) as

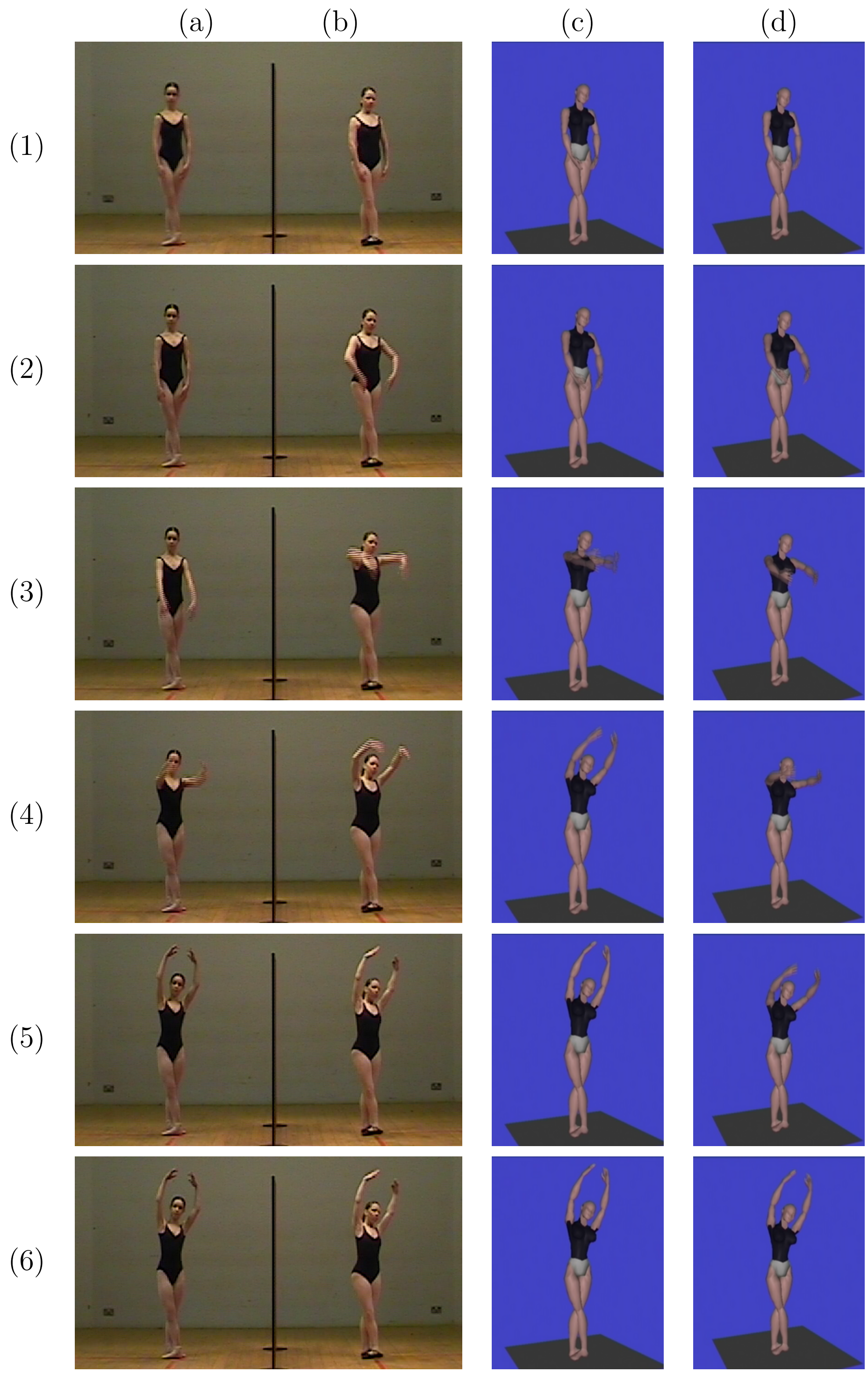


Figure 5.21: Upward movement of the *third port de bras* performed "angrily". (a) and (b) are real-world Dancer 1 and Dancer 2; (c) VBD set with time = −3.508, weight = 0.410 and space set at 1 (direct); and (d) VBD using Cal3Ds default interpolation. Both VBD captures were set with a tempo of 64 to match the real-world dancers.

opposed to stronger characters (e.g. Kitri from Don Quixote and Black Swan from Swan Lake). Though there is a softer quality to the movement, it can be seen in Figure 5.22 that when the same dancer performs the happy emotion (right image) the amount of inflection increases with more bend at both the elbows and the wrists.

(a) Dancer 1: Angry (b) Dancer 2: Angry (c) Dancer 2: Happy

Figure 5.22: Comparison of arm bend: (a) Dancer 1 performing angry with the arms holding the original key pose (Figure 5.21, 2a). (b) Dancer 2 performing angry with the arms bent to a greater degree (Figure 5.21, 2b); and (c) Dancer 2 performing happy with the greatest degree of bend in the elbow and break in the wrist (Figure 5.26, 2b).

In (iv), though not a part of this research, tension and stress can usually be found in the arms and closer inspection of Dancer 2 in the right image of Figure 5.22 reveals the dancer's fingers are more spiked to accentuate this extra inflection for the happy emotions. It is common for dancers to use the hands to either aid in the expressiveness or hold unwanted tension during movement and therefore breaking the ballet rules for the shape of the hand. This evaluation will ignore any other changes in the shape of the hands.

The previous comparisons were made using the average parameters defined earlier. Closer approximations of each dancer's motions can be made by further refining Laban's parameters. For example, to obtain the softer motion of Dancer 2, the space parameter could be lowered from the 1 setting until the elbow and wrist inflections are a closer match. To create the delayed sudden movement of Dancer 1, the weight and time parameters could be manipulated to a lighter and more sudden motion to simulate a closer match.

5.6.3.2 Evaluation of the downward direction of movement

The second evaluation compares the downward movement for the angry motion. Figures 5.23 and 5.24. The points highlighted in the previous section also apply to downward movement with the exception of the elbow. In this case, the elbow bend during the interpolation straightens and extends away from the body as discussed earlier in §5.2.3. An exaggeration of this can be seen from Dancer 2, and to a lesser degree from Dancer 1, in Figure 5.25b.

Similar degrees of elbow bend are demonstrated by Dancer 2 in the downward movements of both the happy and sad emotion. This is another stylistic example of individual dancers. It is worth noting that by changing the spatial parameters for the expressive VBD, the same downward movement style of Dancer 2 can be achieved.

Assessing the pose of the arms in each frame for the downward movement in Figures 5.23 and 5.24, the arm poses of the VBD with expressive interpolation closely matches the wrist position of Dancer 1, (a). The downward rotation of the arm with the palm facing the floor (highlighted in Figure 5.24 frame 2 by both dancers is a common arm orientation in classical ballet performed by many dancers to express the movement and mention by Blasis in *"The Code of Terpsichore"* (Blasis, 1830). However, the rules of the Cecchetti method specifies the fifth digit (little finger) should lead the direction of the hand in a downward movement (keeping the classical ballet orientation of the arms specified in the key pose during the movement) and this was simulated in the Expressive model.

5.6.4 Evaluation of Portraying Happy and Sad Motions

For emotions with a more sustained motion such as happy and sad, the position of the wrist in the intermediate poses was similar to the original Cal3D model. Laban's time parameter was set to sustained and although the Expressive model has a slow in and slow out and the maximum speed occurs is respective of the weight setting, the shape of the distance profile is close to linear. This equates to only small differences in the position of the wrist when comparing frame by frame in Figures 5.26, 5.27, 5.30, 5.31, 5.32, and 5.33. There are two reasons for the position differences: (1) the average Laban parameters and tempo used for the evaluation do not map exactly to what the real-world dancer performed on the captured videos, and (2) the real-world dancers while expressing the movement (particularly the slow sad movement) have variations in the tempo between key poses. The main aspect for comparison in both

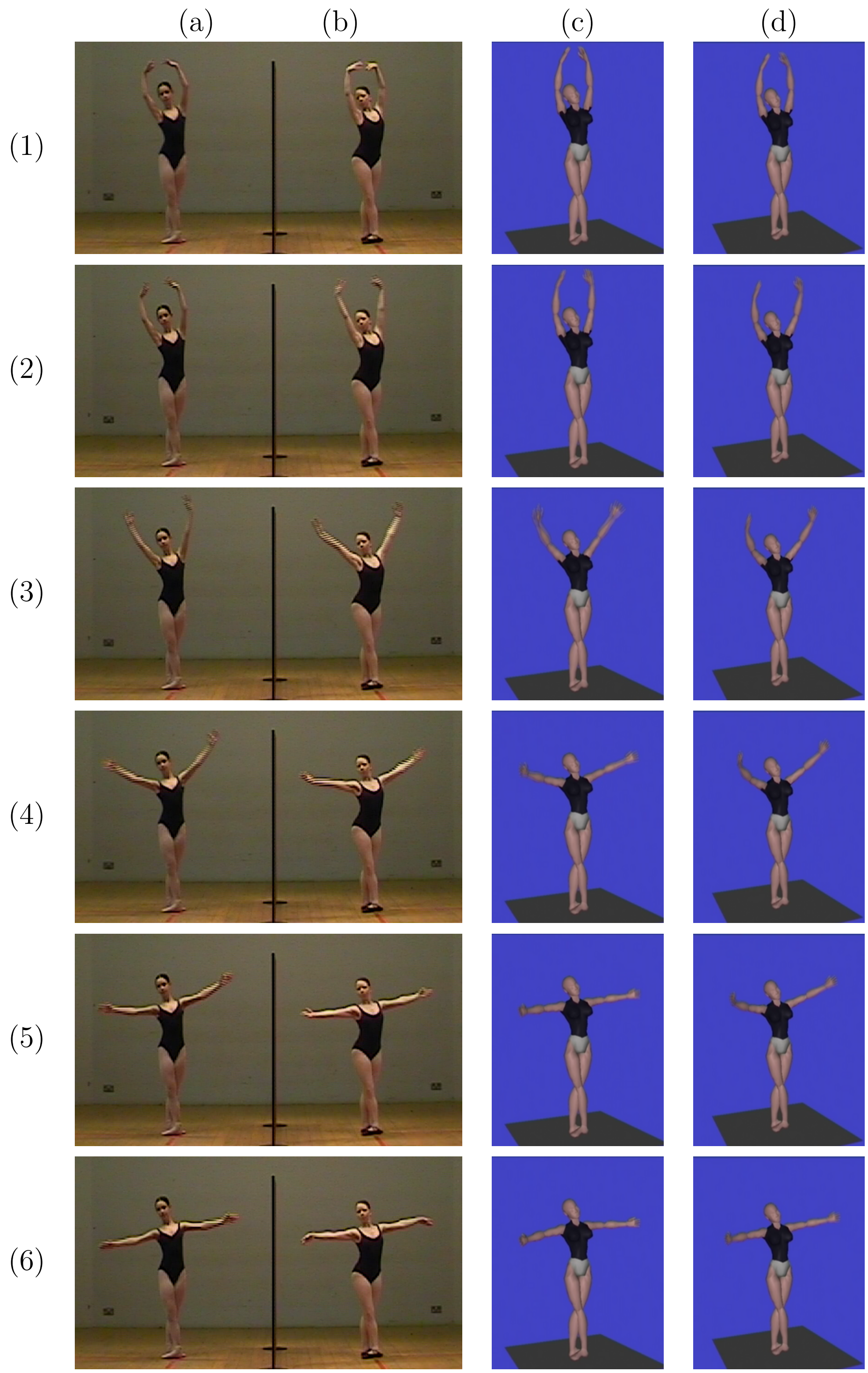


Figure 5.23: Downward movement of the *third port de bras* performed “angrily”. (a) and (b) are real-world Dancer 1 and Dancer 2; (c) VBD set with time = −3.508, weight = 0.410 and space set at 1 (direct); and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 64 to match the real-world dancers.

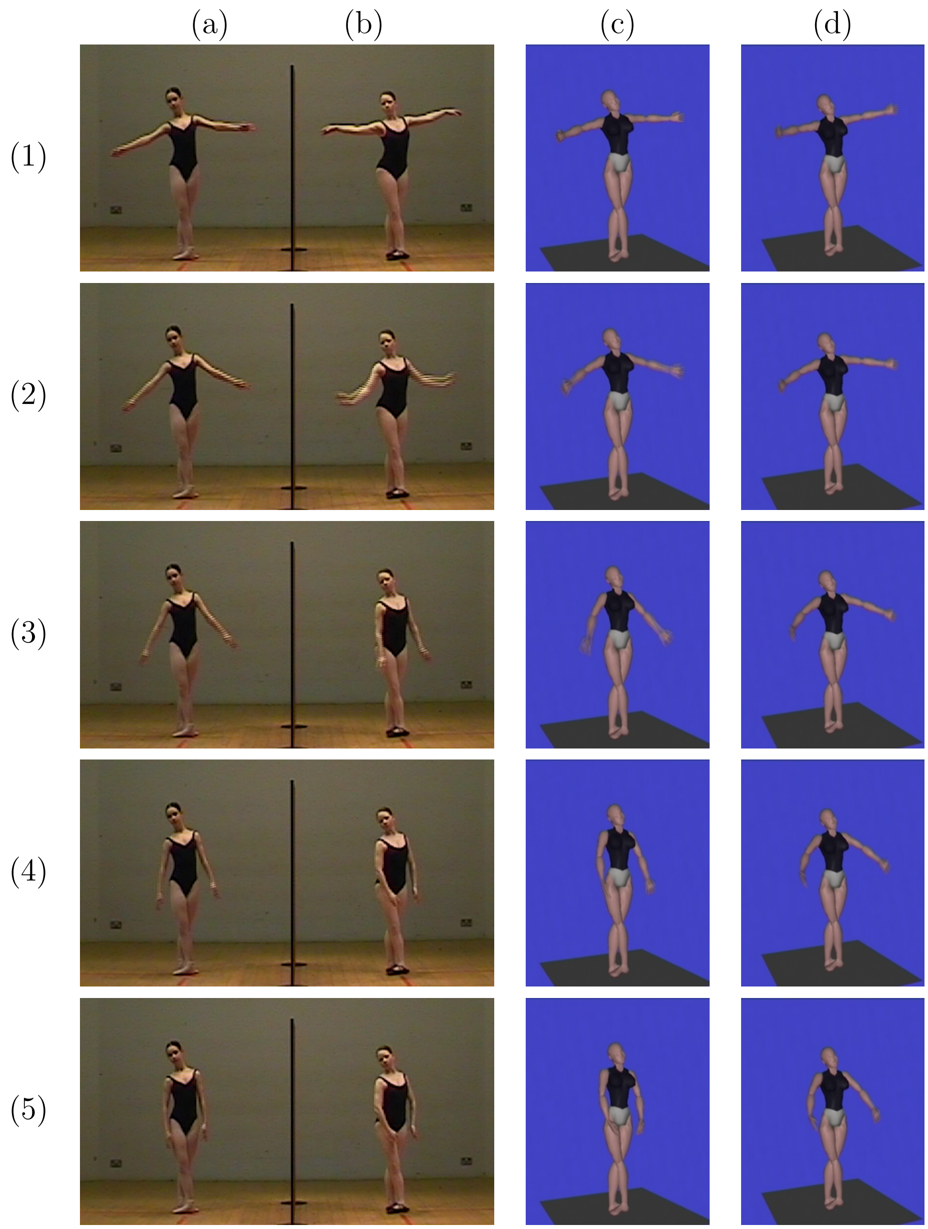


Figure 5.24: Continuation of downward movement of the *third port de bras* performed “angrily”. (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time = −3.508, weight = 0.410 and space set at 1 (direct); and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 64 to match the real-world dancers.

the happy and sad evaluation section is the amount of bend in the elbow and the wrist and how the movement of the arms compares to the real-world dancers.


(a) Key pose *fifth en haut*


(b) Extended arms during movement

Figure 5.25: (a) shows the pose of the arms at the key pose by both dancers and the orientation of the elbows and wrists. (b) shows the extension of the elbow and the degree of rotation performed by both dancers performing and angry downward movement.

5.6.4.1 Evaluation of the upward direction of movement

The spatial movement of the arms in the upward direction in front of the body can be seen in Figure 5.26 and 5.27, where the position of the wrist is drawn towards the body preserving the ballet rules for the arms. Figure 5.28 demonstrates the use of the elbow and wrist by the real-world dancer and the VBD using the Expressive model with light indirect motion (middle image) which is lacking these inflections using the Cal3D model(image on the right).

In comparison of the upward direction as indicated in Figure 5.28:

(a) shows the real-world dancer has altered the movement path to be closer to the body based on the movement rules for the upward direction of the arm movement. The Expressive model has also posed the arms in a similar shape but the Cal3D modelholds the curved arm shape defined by the key pose.

(b) shows the real-world dancer performing lighter motion leading the movement by the wrist with a greater degree of bending. This has been simulated by the Expressive model. The lack of this characteristic can be seen in the Cal3D model.

(c) shows the amount of tilt set by the real-world dancer was not excessive and followed the rules of ballet and therefore matched closely to both VBDs. It is noted that on a different run, the tilt for the body derived from the expression on the real-world dancer at a key pose can be larger with indirect movement.

(d) shows the real-world dancer has added a turn to the head during the phrasing

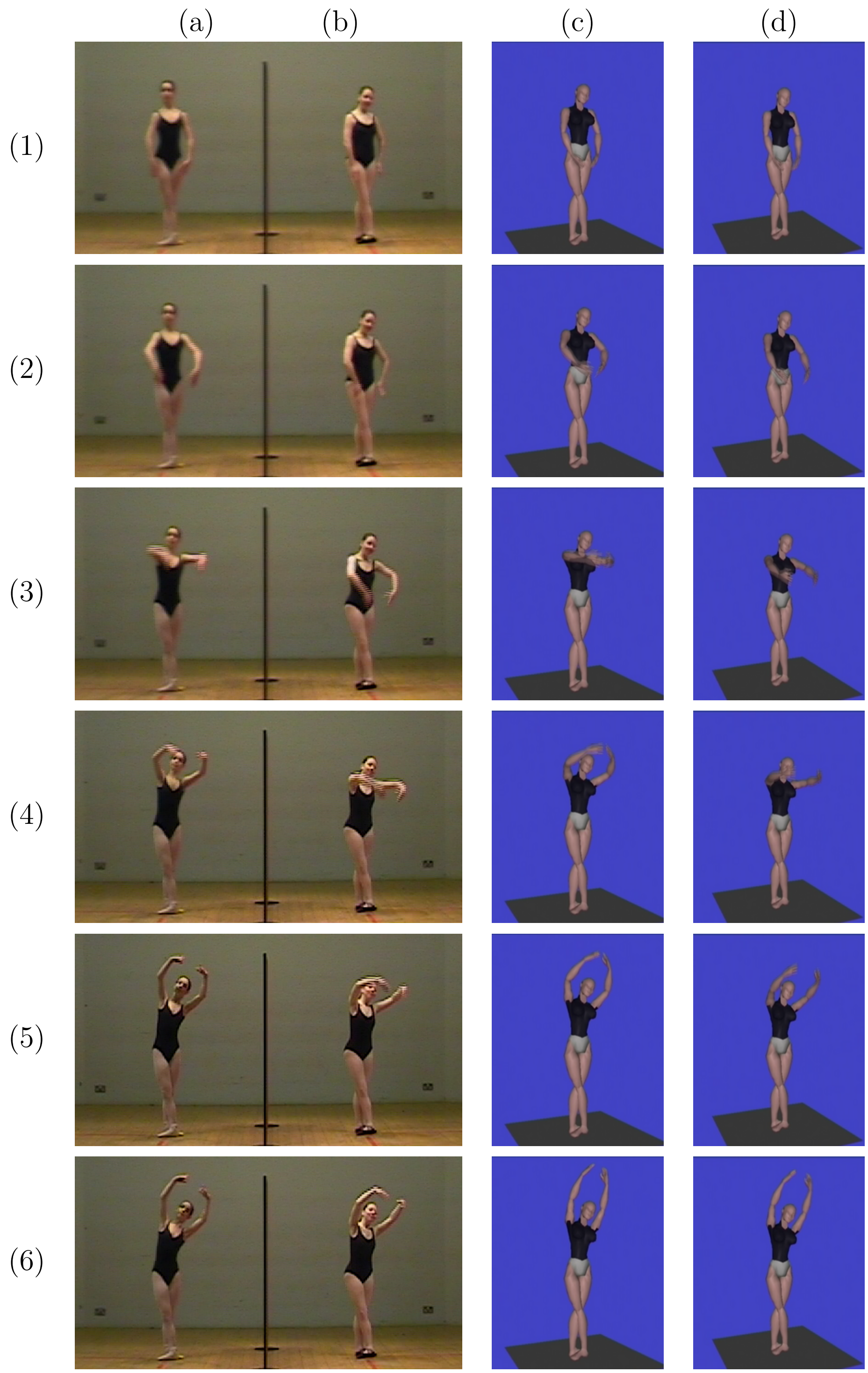


Figure 5.26: Upward movement of the *third port de bras* performed "happily". (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time $= -2.421$; weight $= 0.598$ and space set at 0 (indirect)and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 64 to match the real-world dancers.

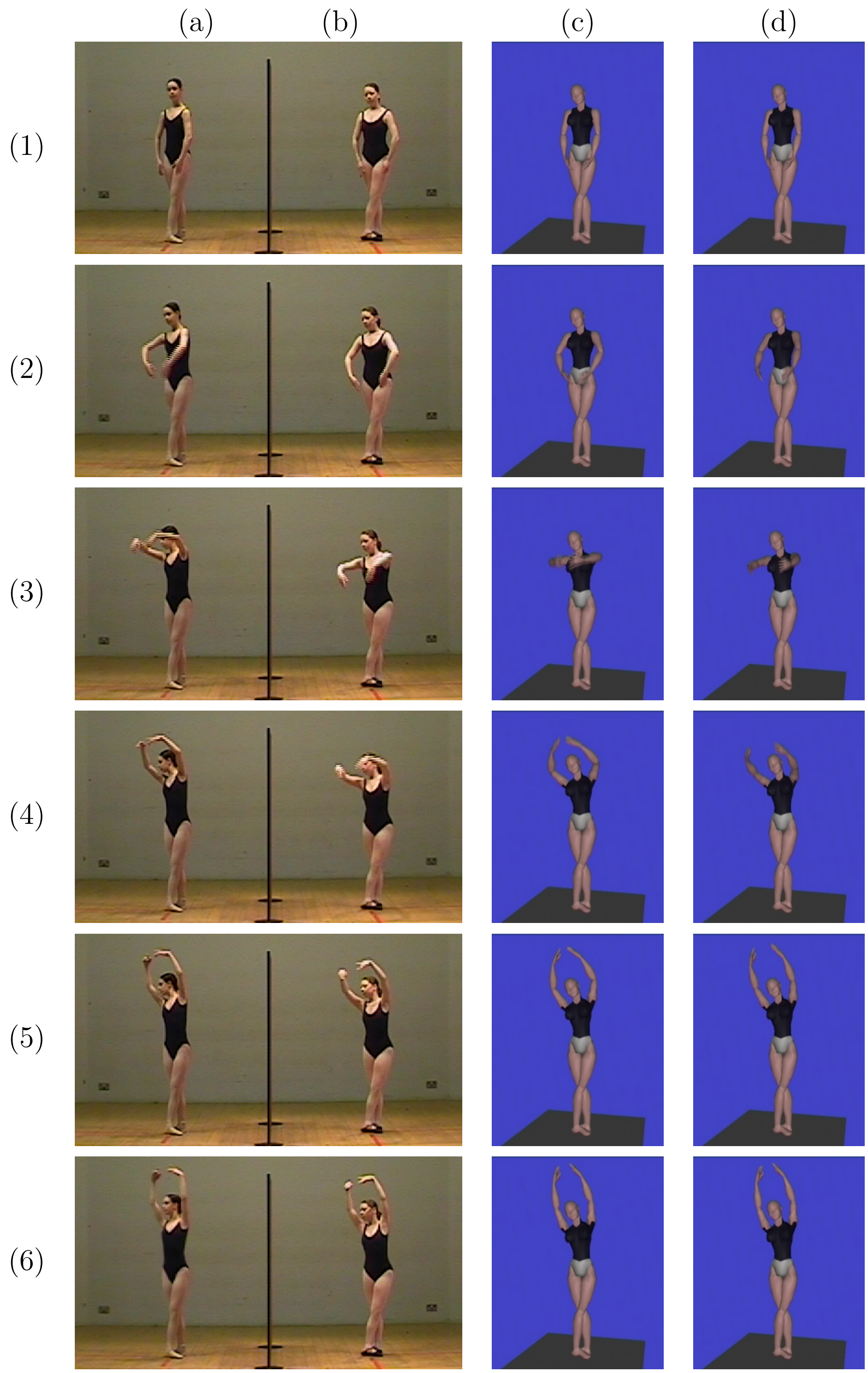


Figure 5.27: Upward movement of the *third port de bras* performed "sadly". (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time = −2.421; weight = 0.598 and space set at 0 (indirect); and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 40 to match the real-world dancers.

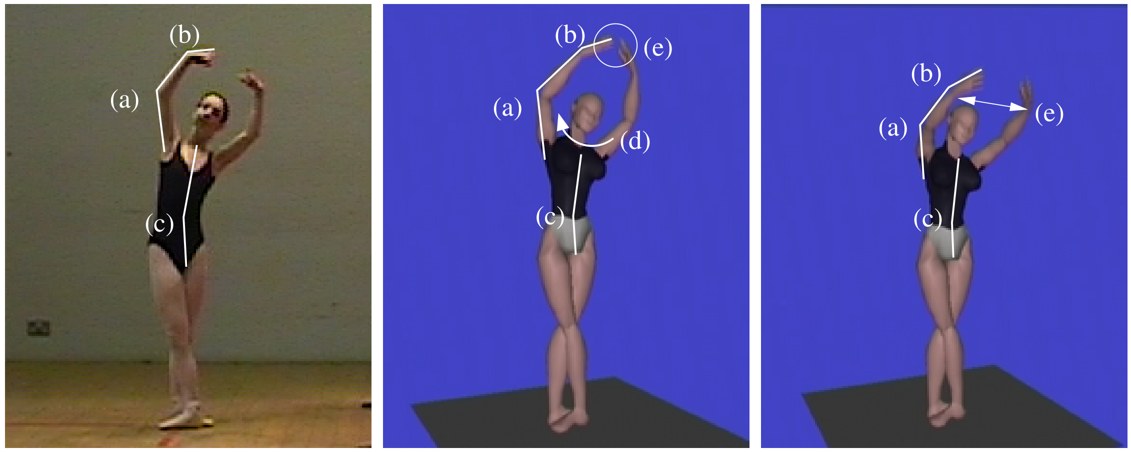


Figure 5.28: Comparison of the spatially indirect upward movement taken from the frames for the happy expression in the upward direction in Figure 5.26. Highlighted differences identified are: (a) the rotation of the elbow joint; (b) the rotation of the wrist joint; (c) the amount of tilt and twist of the body; (d) the amount of tilt and turn of the head; and (e) the position of the wrists in relation to each other.

of the movement at the key poses. This cannot be captured by either VBD.

(e) shows the distance between the hands using the Cal3D model as discussed earlier in §5.6.2. The expressive algorithm rectifies the breaking of this ballet rule. However, the hands of the 3Dmodel of the VBD are slightly disproportionate and when the wrists are correctly positioned in accordance to the ballet rules, the hand size makes the fingertips too close together. This could be corrected by altering the model.

The shape and orientation of the arms was closely matched in the real-world dancer and the Expressive model. The wrist inflection was not as great as the real-world dancer, but this is merely a parameter change in the Expressive model to specify the maximum amount of rotation in the ballet rules for the wrist. Despite this, the rotation is still a closer match to the real-world dancer than the held pose of the VBD using the linear interpolation.

5.6.4.2 Evaluation of the downward direction of movement

The following section describes the downward movement for happy and sad, where the weight is light and the movement is more indirect downward movement. The screenshots were taken at an interval of every four frames for happy and every eight frames for sad. This is because the tempo of the sad movement was slower than the happy interval. A comparison between the emotions was not being made so their frames do not need to match. The downward movements are captured in Figures 5.29, 5.30, 5.31, 5.32, and 5.33.

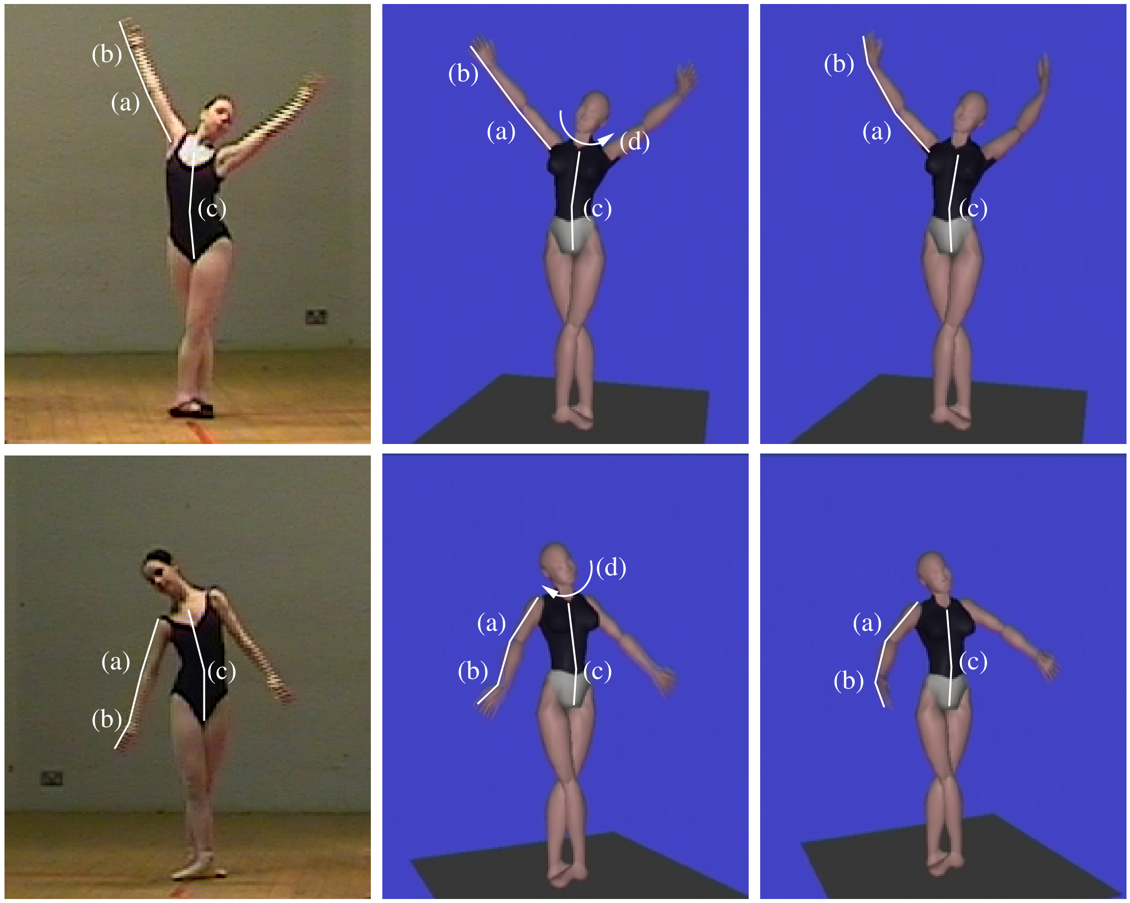


Figure 5.29: Comparison of the spatial indirect downward movement. The top row is a snapshot of indirect down movement from above the head to the side from Figure 5.32 and the bottom row is a snapshot taken of the indirect movement lowering from the side taken from Figure 5.31. Highlighted differences identified are: (a) the rotation of the elbow joint; (b) the rotation of the wrist joint; (c) the amount of tilt and twist of the body; and (d) the amount of tilt and turn of the head.

In comparison of the downward direction as indicated in Figure 5.29:

(a) shows the real-world dancer has extended the elbow to make maximum use of arm extension during the downward movement. The Expressive model shows how the VBD emulates the same action, creating a straighter line from the shoulder to the wrist. The Cal3D model holds the original key pose and loses this change in the shape of the movement.

(b) shows the orientation of the wrist differs in the downward movement from above the head to the side, and lowering from the side. As with the elbow, the

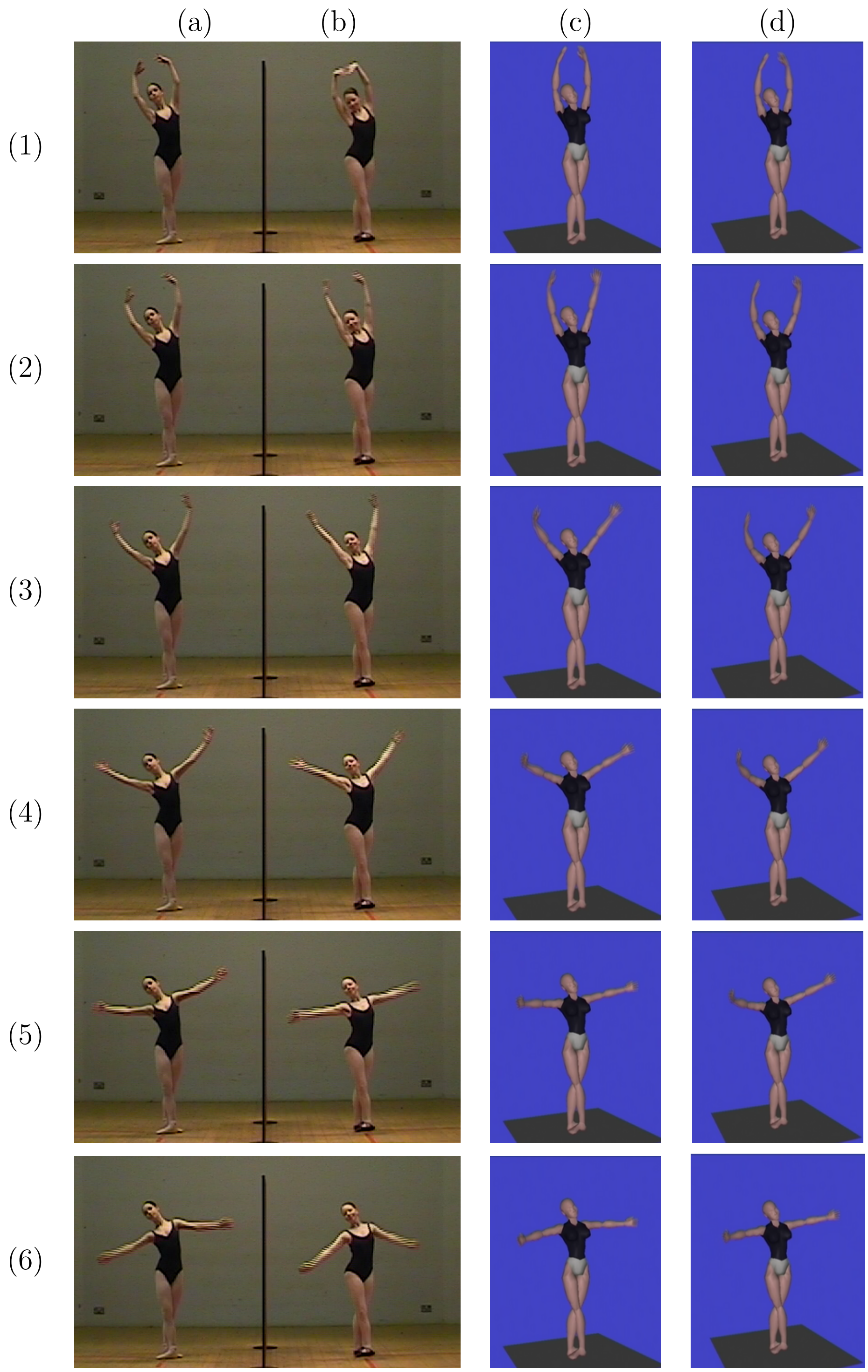


Figure 5.30: Downward movement of the *third port de bras* performed "happily". (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time = −2.421; weight = 0.598 and space set at 0 (indirect)and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 64 to match the real-world dancers.

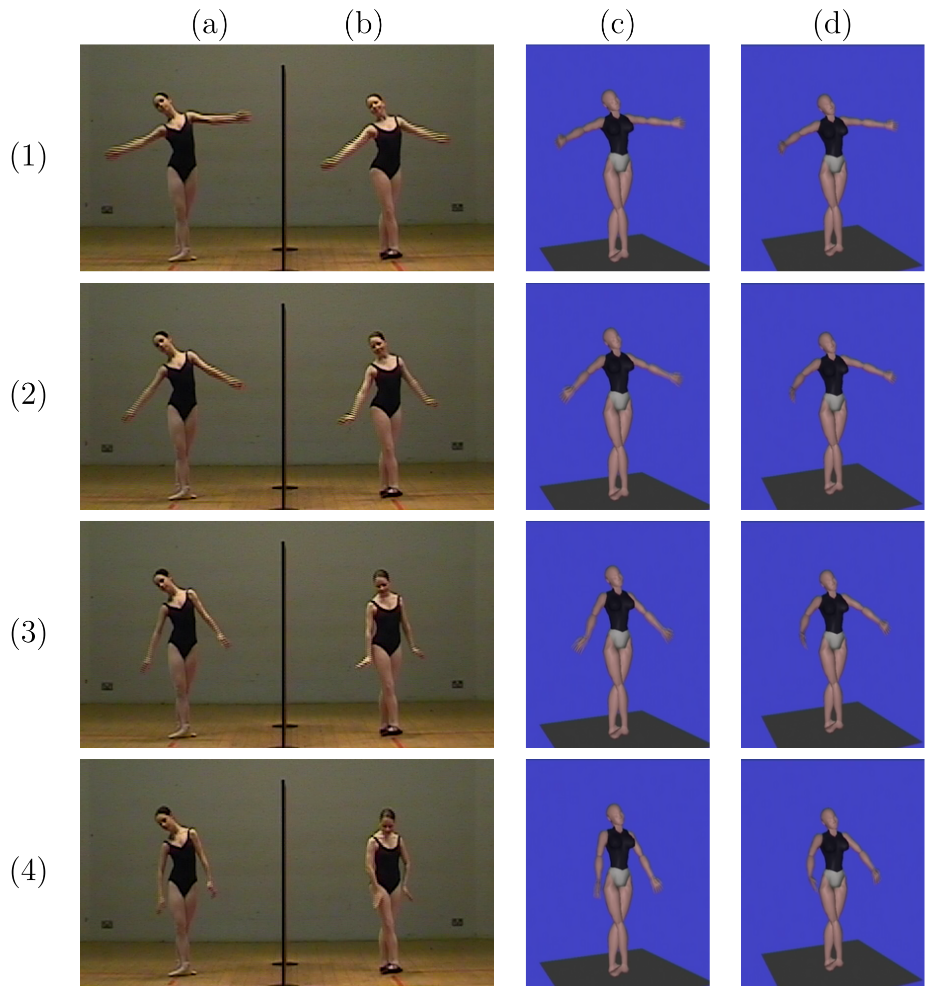


Figure 5.31: Continuation of downward movement of the *third port de bras* performed "happily". (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time $= -2.421$; weight $= 0.598$ and space set at 0 (indirect)and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 64 to match the real-world dancers.

real-world dancer rotates the wrist joint following the ballet rules for movement and in both cases, it can be seen that the VBD using the Expressive model captures a similar shape while the Cal3D model does not. This is especially noticeable in the bottom example where the wrist rotation is in the opposite direction.

(c) shows during the phrasing of the *port de bras*, the real-world dancers exaggerated the amount of tilt in the body and turn of the head. The amount of tilt and turn is derived from the key poses while expressing the emotions. These variations in the key pose are exaggerated and outside the Benesh definition

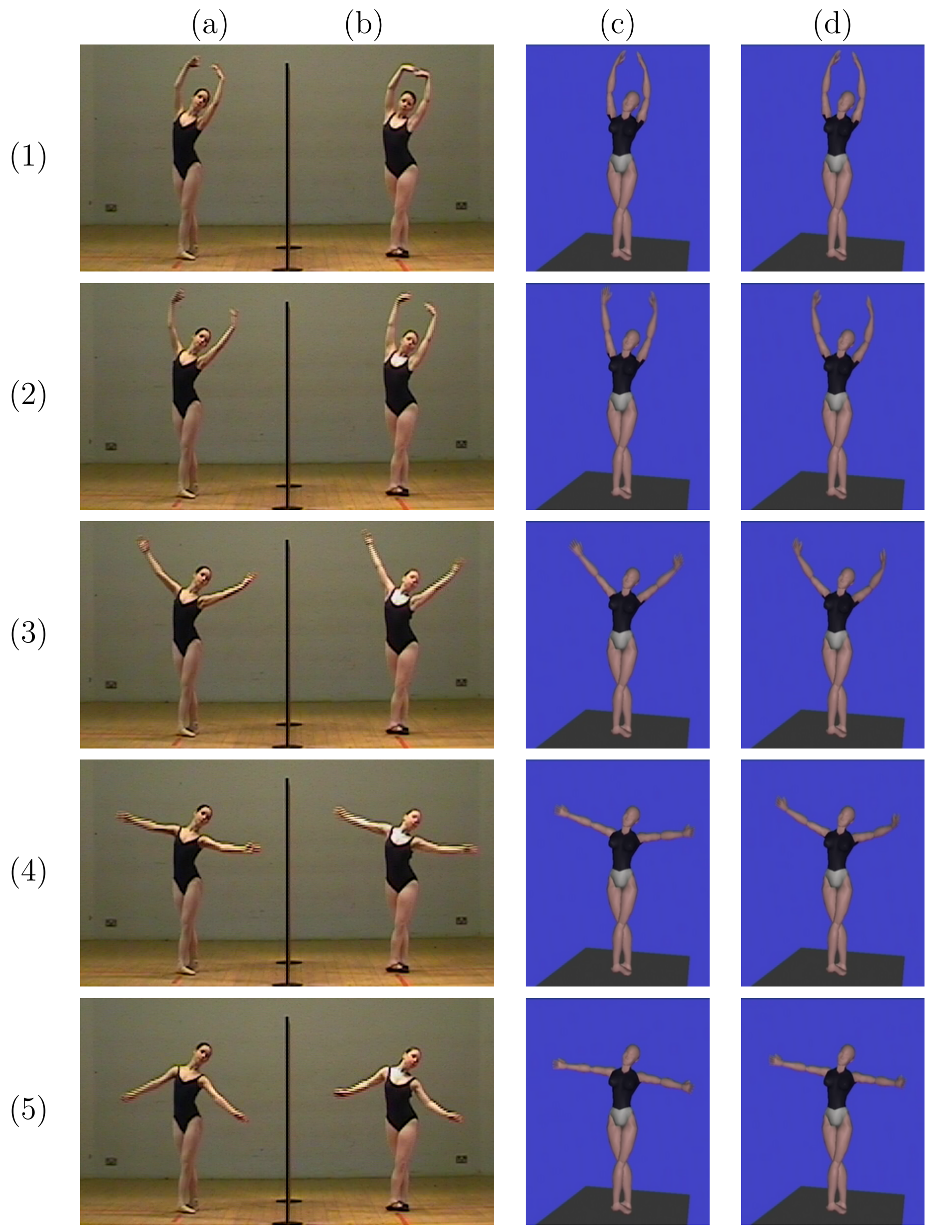


Figure 5.32: Downward movement of the *third port de bras* performed “sadly”. (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time = −2.421; weight = 0.598 and space set at 0 (indirect); and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 40 to match the real-world dancers.

of the pose. Variations in the key pose are not in the scope of this research and therefore, the extra degree of rotation is not simulated.

(d) shows the same evaluation applies to the head as it does with he body (c) where he extra amount of rotation is added to the body.

(a) (b) (c) (d)

(1)

(2)

(3)

(4)

(5)

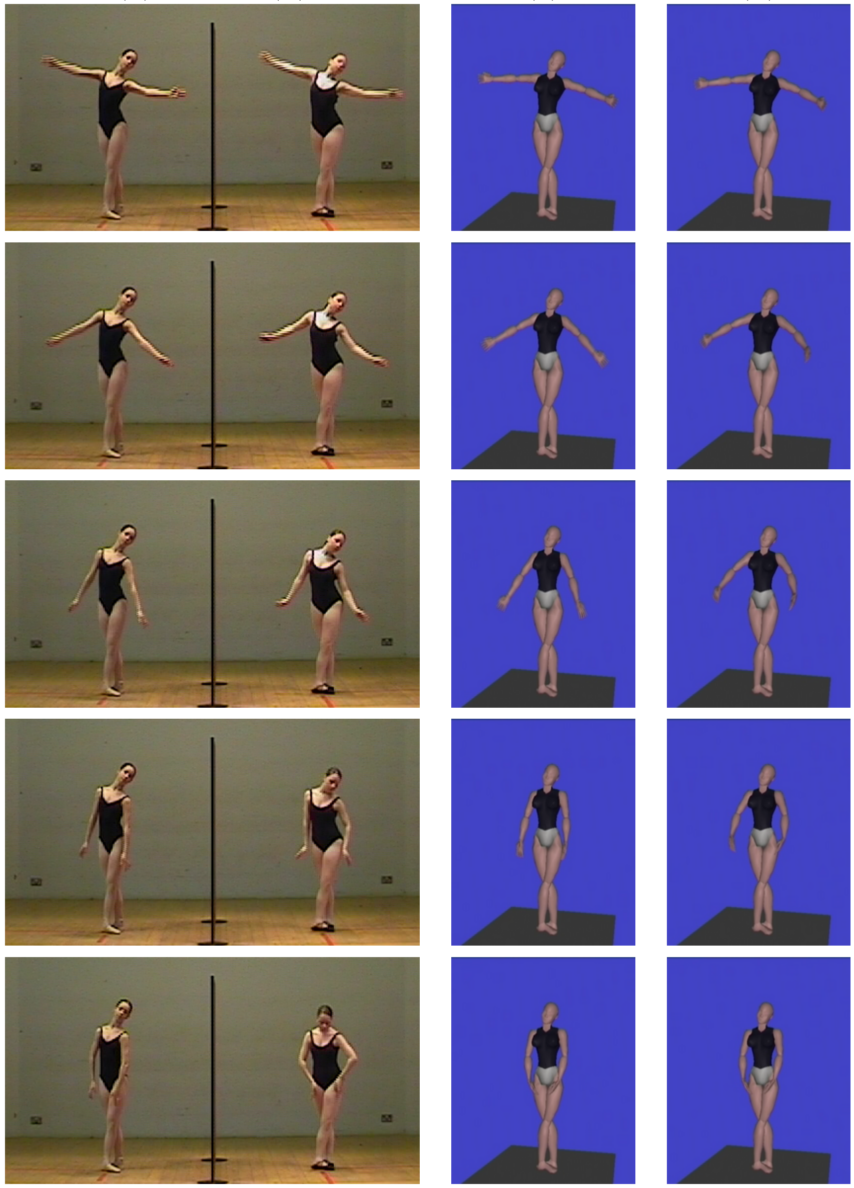


Figure 5.33: Continuation of Downward movement of the *third port de bras* performed "sadly". (a) and (b) are real-world dancer 1 and dancer 2; (c) VBD set with time = −2.421; weight = 0.598 and space set at 0 (indirect); and (d) VBD using Cal3Ds slerp algorithm. Both VBD captures were set with a tempo of 40 to match the real-world dancers.

An interesting observation when comparing the body and head movement between the key poses on the real-world dancers are the extra rotations at the key pose do not change during the interpolation. The interpolation algorithm developed can therefore still be applied and further research to posing the key poses including methods based on expression can be applied without affecting the current algorithm.

5.7 Discussion

This evaluation section presented examples of the *third port de bras* used in the real-world experiments in Chapter 3. The rules for motion in classical ballet also hold through the different arm motions and this is shown where the analysis of the captured motion of the *first port de bras* were applied to the *third port de bras*. The VBD using the expressive algorithm derived in this research could simulate the motions of both dancers by manipulating the parameters for tempo and Laban's weight, time and space.

The differences from the real-world dancers and the Expressive model were from variations in the key poses by the dancers performing emotions, the individual phrasing of the complete motion, and the different distinct styles of the real-world dancers. In terms of the in-between motions, the match with the real-world dancers was extremely close and, by the manipulation of parameters based on Laban's weight, time and space, can simulate expressive motions between key poses.

5.8 Summary

The motion profile of real-world dancers captured using VICON and iQ were analysed and mathematical rules were devised to simulate the in-between motion between balletic key poses. The in-between motion simulated the real-world dancers by manipulating parameters based on Laban's weight, time, space. The manipulation of these parameters altered the interpolation to visually match the weight, time and space movement in the real-world videos analysed in Chapter 3. The VBD tempo was also manipulated to match the timing of the movement being performed by the real-world dancers.

The evaluation showed that the new emotive mathematical methods were capable of matching the real-world videos. The main variations in the comparison were because: (1) parameter selection for the VBD was not the perfect match to the real-world dancers, and (2) each dancer also performs to their own distinct style which is impossible to capture based on the ballet rules for key posing and movement. Future research on these variations would heighten a viewer's perception of the expressive gestures being performed and generate a better match with the real-world dancers.

The distinct style and phrasing of individual dancers is extremely hard to quantify. In this research, real-world dancers were used with their own distinct styles and nuances. These nuances are particular to each dancer and distinguishes one dancer from another. An example of this is the excessive use of the wrists by one of the real-world dancers, as discussed earlier.

This chapter has shown specific aspects of the motion can be parameterised based on Laban's effort descriptors. The closeness of the match between the real-world dancers and the VBD using the expressive mathematical methods infers that by changing these parameters, a user can allow specific expressive motions performed by the VBD.

Chapter 6

Conclusion and Future Work

In this thesis, the research was separated into three sections: (1) to understand the applied problem for achieving a VBD capable of displaying expressive movement, (2) the devising and development of the rules and mathematical equations to orientate the skeleton joints of the VBD into each key pose using a machine-readable format of Benesh notation, and (3) the analysis of balletic movement to develop interpolation algorithms with respect to the Laban Effort parameters.

The first section analysed certain fidelity requirements of a VBD and looked into how these issues of fidelity affect the user's judgement to distinguish emotions. Videos of real-world dancers showed that different emotions can be distinguished from each other, even when presented via video on a small two dimensional screen. Experiment 2 assessed the use of different frame rates to assess levels of interpolation required for a VBD. The high percentage accuracy overall showed different frame rates had only a marginal effect on the participants. This highlighted that interpolation between keyframes equivalent to 5-25Hz is capable of providing enough visual clues for the user to distinguish differences in emotions from the animated movement of a VBD.

The second section described a machine-readable format for dance notation with keyframe rendering. The prototype parsed the data using built-in domain knowledge and conventions to render the VBD in key poses. This includes default position settings and the use of classical ballet rules such as turnout and straight legs. Ballet professionals could name the pose of the VBD using ballet terminology and also annotate the VBD pose that matched the input from the file format. Though there were some minor discrepancies on some of the VBD poses, the overall shape of each pose as defined by the rules of classical ballet and inferred in Benesh posed the VBD correctly. Using each pose as a keyframe, a combination of these poses can be used as the basis for setting an exercise or dance for a VBD.

In the third section, motion profiles of captured real-world dancer's were analysed and mathematical rules were devised to simulate the in-between motion between balletic key poses. The in-between motion simulated the real-world dancers by manipulating parameters based on Laban's weight, time, space. The manipulation of these parameters and the manipulation of the tempo altered the interpolation to visually match the weight, time and space movement in the real-world videos analysed in the earlier real-world experiments.

6.1 Future Work

Future research is required to extend the emotive model and algorithm for expressive movement and create a comprehensive VBD driven by dance notation. The full development of a software animation system to represent and simulate dance would be beneficial to historians, choreographers and choreologists to: (a) evaluate ballet choreography with expressive styles, and (b) aid professionals to visualise the movement required for resurrecting ballet scores. In classical ballet, the main mode of knowledge transfer is the live demonstration process. The comprehensive VBD would fill a gap in the learning process of choreography and dance using VE technologies.

This thesis is an initial step towards developing such a VBD. There are still many areas of further research and development to creating a complete VBD. One aspect is the further development of the file format and its parsing for the VBD. This research has not included any of the below stave notation which includes stage position and specifies the dancers movement around the stage. This research has looked at the basic ballet poses, and testing of more complex poses needs to be evaluated with the currently implemented dance rules. Also, defining balletic poses in the future requires analysis of the degree of orientation for the head and body related to arm poses and emotions being portrayed. This is currently calculated to a set values specified by the author professional opinion, and variations in the key poses depending on the quality of the movement being performed.

This thesis presented expressive motion of the arms. As ballet is based on coordination and the methods and algorithms devised with some adjustment can be applied to the legs, head, body and pelvis. Before this can be accomplished, movement rules based on ballet conventions need to be devised for:

- the legs including the use of the foot on the floor, turnout applied using basic biomechanical constraints and the centre of balance

- transition of the pelvis as the root node to allow the VBD too travel around the stage based on the notation. Contact with the stage (usually the feet) will need to be considered.

- Use of the foot on the floor due to the fact there are strict rules in ballet on the use of the foot which is inferred in the Benesh notation.

With regards to further development related to synthesising expressive motion, future analysis is required on the variation in the key pose shapes taken by the VBD based on Laban's shape parameters related to the emotion portrayed. Laban discusses the connection between the Effort and Shape parameters where Shape characterises movements as being towards or away from the centre of the body. Shape includes parameters for the three directional axes: vertical (rising and sinking); saggital (advancing and retreating) and horizontal (widening or narrowing) (Dell, 1977). Interestingly, dance teachers and choreographers would use the same or similar descriptions to inform the dancer if the dance pose during a movement needs to be adapted. It is therefore highly feasible that using these parameters, the pose of the dancer can be varied at each key pose with respect to the expression being performed.

The final aspect for future research is the transition between segmented movements and the phrasing of the combined segments. Though the learning process and understanding of dance is usually simplified by breaking it down to manageable sequences, the dance is viewed as a whole. This is particularly true with less structured dance as in contemporary, neo-classical and modern dance where the shape of the complete movement is as important as the nuance of each individual motion. It is necessary to identify the phrasing of the motions with regards to the emotions and defined by the Benesh notation including understanding the effect portraying an emotion has on the transition between each segmented motion.

Despite the need for continued development, the VBD is useful in its current form. It demonstrates that the rules of ballet can be coded in software to allow balletic poses to be visualised, and shows how weight, time and space can be used to convey different emotions in a virtual performance.

Bibliography

Abouaf, J. (1999a). Biped: A Dance with Virtual and Company Dancers. Part 1. *IEEE Multimedia Journal*, *6(3)*, 4–7.

Abouaf, J. (1999b). Biped: A Dance with Virtual and Company Dancers. Part 2. *IEEE Multimedia Journal*, *6(4)*, 5–7.

Adobe (2004). Adobe Premiere Pro 1.5. `http://www.adobe.com/products/premiere/main.html`. Last accessed November 2004.

Ahmad, K., Salway, A. & Lansdale, J. (1998). (An)notating Dance: Multimedia Storage and Retrieval. In *International Conference on Computational Intelligence and Multimedia Applications (ICCIMA'98)* (pp. 788–793). Singapore: World Scientific.

Amaya, K., Bruderlin, A. & Calvert, T. (1996). Emotion from Motion. In *Graphics Interface* (pp. 222–229).

Badler, N. (1989). *A Computational Alternative to Effort Notation*, chapter 3, (pp. 23–44). National Dance Association.

Badler, N. (1997). Virtual Humans for Animation, Ergonomics, and Simulation. In *NAM '97: Proceedings of the 1997 IEEE Workshop on Motion of Non-Rigid and Articulated Objects (NAM '97)* (pp. 28–36). Washington, DC, USA: IEEE Computer Society Press.

Badler, N., Bindiganavale, R., Allbeck, J., Schuler, W., Zhao, L. & Palmer, M. (2000a). Parameterized Action Representation for Virtual Human Agents. *Embodied Conversational Agents* (pp. 256–284).

Badler, N., Chi, D. & Chopra-Khullar, S. (1999a). Virtual Human Animation based on Movement Observation and Cognitive Behavior Models. In *CA '99: Pro-*

ceedings of the Computer Animation (pp. 128–137). IEEE Computer Society Press.

Badler, N., Costa, M., Zhao, L. & Chi, D. (2000b). To Gesture or Not to Gesture: What is the Question? In *Computer Graphics International* (pp. 3–10). IEEE Computer Society's Conference Publishing Service (CPS).

Badler, N., O'Rourke, J. & Kaufman, B. (1980). Special Problems in Human Movement Simulation. In *SIGGRAPH '80: Proceedings of the 7th annual conference on Computer graphics and interactive techniques* (pp. 189–197). ACM Press.

Badler, N., Phillips, C. & Webber, B. (1999b). *Simulating Humans: Computer Graphics, Animation and Control*. Oxford University Press.

Badler, N. & Smoliar, S. (1979). Digital Representations of Human Movement. *ACM Computer Survey*, *11(1)*, 19–38.

Ballin, D., Aylett, R. & Delgado, C. (2002). Towards Autonomous Characters for Interactive Media. *Intelligent Agents for Mobile and Virtual Media* (pp. 55–76).

Bates, J. (1997). The Role of Emotion in Believable Agents. *Communications of the ACM*, *37(7)*, 122–125.

Beaumont, C. & Idzikowski, S. (1977). *A Manual of The Theory and Practice of Classical Theatrical Dancing* (Revised Ed.). Beaumont Publication. Manual for the Cecchetti Method of Classical Ballet, Preface by Maestro Cav. Enrico Cecchetti.

Benesh, R. & Benesh, J. (1983). *Reading Dance: The Birth of Choreology* (First Ed.). McGraw-Hill Book Company Ltd.

University of Birmingham (2004). CALABAN: Computer Aided Labanotation. `http://www.bham.ac.uk/calaban/`. Last accessed December 2004.

Bjorck, A. (1996). *Numerical Methods for Least Squares Problems*. Society for Industrial and Applied Mathematics.

Blasis, C. (1830). *The Code of Terpsichore*. London, E. Bull. The Code of Terpsichore. The art of dancing, comprising its theory and practice, and a history of its rise and progress, from the earliest times by C. Blasis. Translated under the author's immediate inspection by R. Barton.

Borges, C. & Pastva, T. (2002). Total Least Squares Fitting of Bezier and B-spline Curves to Ordered Data. *Comput. Aided Geom. Des.*, *19(4)*, 275–289.

Brand, M. & Hertzmann, A. (2000). Style Machines. In Akeley, K. (Ed.), *Siggraph 2000, Computer Graphics Proceedings* (pp. 183–192). ACM Press / ACM SIGGRAPH / Addison Wesley Longman.

Brown, A. K. & Parker, M. (1984). *Dance Notation for Beginners*. Dance Books Ltd.

Byun, M. & Badler, N. (2002). FacEMOTE: qualitative parametric modifiers for facial animations. In *Proceedings of the 2002 ACM SIGGRAPH/Eurographics symposium on Computer animation* (pp. 65–71). ACM Press.

Calvert, T., Wilke, L., Ryman, R. & Fox, I. (2005). Applications of Computers to Dance. *Computer Graphics and Applications*, *25(2)*, 6–12.

Campbell, L. W. & Bobick, A. F. (1995). Recognition of Human Body Motion Using Phase Space Constraints. In *Proceedings of teh Fifth International Conference on Computer Vision (ICCV 95)* (pp. 624–630). IEEE Computer Society Press.

Camurri, A. & Coglio, A. (1998). An Architecture for Emotional Agents. *IEEE Multimedia Journal*, *5(4)*, 24–33.

Camurri, A., Hashimoto, S., Suzuki, K. & Trocca, R. (1999). KANSEI Analysis of Dance Performance. In *Proc. Systems Man and Cybernetics*, Volume 4 (pp. 327–332). IEEE Computer Society Press.

Camurri, A., Mazzarino, B., Trocca, R. & Volpe, G. (2001). Real-Time Analysis of Expressive Cues in Human Movement. In *Conference on Artistic, Cultural and Scierntific Aspects of Experimental Media Spaces (CAST01)* (pp. 63–68). FhG - Institut Medienkommunikation (IMK).

Camurri, A., Mazzarino, B. & Volpe, G. (2003). *Analysis of Expressive Gesture: The EyesWeb Expressive Gesture Processing Library* (pp. 460–467). Springer.

Camurri, A. & Trocca, R. (2000). Analysis of Expressivity in Movement and Dance. In *Colloquium on Musical Informatics Proceedings*.

Camurri, A., Volpe, G., Poli, G. D. & Leman, M. (2005). Communicating Expressiveness and Affect in Multimodal Interactive Systems. *Multimedia, IEEE*, *12(1)*, 43–53.

Carion, S., Sannier, G. & Magnenat-Thalmann, N. (1998). Virtual Humans in CyberDance. In *Computer Graphics International Proceedings* (pp. 142–153). IEEE Computer Society Press.

Cassell, J., Pelachaud, C., Badler, N., Steedman, M., Achorn, B., Becket, T., Douville, B., Prevost, S. & Stone, M. (1994). Animated Conversation: Rule-Based Generation of Facial Expression, Gesture & Spoken Intonation for Multiple Conversational Agents. *Computer Graphics*, *28(Annual Conference Series)*, 413–420.

Cassell, J., Vilhjálmsson, H. & Bickmore, T. (2001). BEAT: The Behavior Expression Animation Toolkit. In Fiume, E. (Ed.), *SIGGRAPH 2001, Computer Graphics Proceedings* (pp. 477–486). ACM Press / ACM SIGGRAPH.

Chaffin, D., Andersson, G. & Martin, B. (1999). *Occupational Biomechanics* (Third Ed.). John Wiley and Sons, Inc.

Chi, D. (1999a). A Motion Control Scheme for Animating Expressive Arm Movements. IRCS technical report 99-06, CIS, University of Pennsylvania.

Chi, D. (1999b). A Motion Control System for Animating Expressive Arm Movements. PhD thesis, University of Pennsylvania, `http://portal.acm.org/citation.cfm?id=929276`. Last accessed April 2005.

Chi, D., Costa, M., Zhao, L. & Badler, N. (2000). The EMOTE Model for Effort and Shape. In *Proceedings of the 27th Annual Conference on Computer Graphics and Interactive Techniques* (pp. 173–182). ACM Press/Addison-Wesley Publishing Co.

Costa, P. & McCrae, R. (1992). Normal Personality Assessment in Clinical Practice: The NEO Personality Inventory. *Psychological Assessmentg* (pp. 5–13).

Credo Interactive Inc. (2005a). DanceForms 1.0: Choreography software. `http://www.credo-interactive.com/danceforms/`. Last accessed April 2005.

Credo Interactive Inc. (2005b). LifeForms. `http://www.credo-interactive.com/products/index.html`. Last accessed April 2005.

DanceWrite (1995). MacBenesh. `http://members.rogers.com/dancewrite/`. Last accessed December 2004.

Delgado-Mata, C. & Aylett, R. (2004). Emotion and Action Selection: Regulating the Collective Behaviour of Agents in Virtual Environments. In *AAMAS '04: Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems* (pp. 1304–1305). Washington, DC, USA: IEEE Computer Society.

Dell, C. (1977). *A Primer for Movement Description* (Fourth Ed.). Dance Notation Bureau, Inc.

Edward, F., Hunt, S., Politis, G. & Herbison-Evans, D. (2004). The Design Of LED: An X-Windows Mini-Editor for Labanotation. Technical Report TR343, University of Technology, Sydney.

Egges, A., Kshirsagar, S. & Magnenat-Thalmann, N. (2002a). A Model for Personality and Emotion Simulation. In *Knowledge-based Intelligent Information & Engineering Systems (KES2003)* (pp. 201–208). Springer-Verlag.

Egges, A., Kshirsagar, S. & Magnenat-Thalmann, N. (2002b). Imparting Individuality to Virtual Humans. In *First International Workshop on Virtual Reality Rehabilitation (Mental Health, Neurological, Physical, Vocational)* (pp. 201–208).

Eshkol, N. & Wachmann, A. (1958). *Movement Notation* (First Ed.). Weidenfeld and Nicolson.

Fox, I., Ryman, R. & Calvert, T. (2001). Documenting Dance for the 21st Century: A Translation Interface between LabanWriter and Life Forms. In *Processings of the International Council of Kinetography Laban/Labanotation (ICKL2001)*. ICKL Publication.

Granieri, J., Crabtree, J. & Badler, N. (1995). Production and Playback of Human Figure Motion for Visual Simulation. *Modeling and Computer Simulation*, *5.(3)*, 222–241.

Griesbeck, C. (1996). LimeLight. `http://www.rz.uni-frankfurt.de/~griesbec/LIME.HTML#Introduction`. Last accessed Novemeber 2006.

Griesbek, C. (1996). LabanPad. `http://www.rz.uni-frankfurt.de/~griesbec/LABPADE.HTML`. Last accessed December 2002.

Grochow, K., Martin, S., Hertzmann, A. & Popović, Z. (2004). Style-Based Inverse Kinematics. *ACM Trans. Graph.*, *23(3)*, 522–531.

Grosso, M., Quach, R., Otani, E., Zhao, J., Wei, S., Ho, P., Lu, J. & Badler, N. (1987). Anthropometry for Computer Graphics Human Figures. Technical Report MS-CIS-87-71, University of Pennsylvania.

Guye-Vuilléme, A. & Thalmann, D. (2000). Requirements for an Architecture for Believable Social Agents. In *AGENTS '00: Proceedings of the Fourth International Conference on Autonomous Agents* (pp. 48–49). ACM Press.

Hall, N. & Herbison-Evans, D. (1990). BALLONES: A Ballet Animation Language. In *Proceedings of Australian Computer Graphics Association (AUSGRAPH90)*.

Heidelberger, B. (2005). B/E/O/S/I/L: Cal3D, A Free 3D Animation Library. `http://cal3d.sourceforge.net/`. Last accessed February 2005.

Herbison-Evans, D. (2001). Dance and the Computer: A Potential for Graphic Synergy. `http://www-staff.mcs.uts.edu.au/~don/pubs/synergy.html`. White paper (Updated). Last accessed November 2002.

Herbison-Evans, D., Edward, F., Hunt, S. & Politis, G. (2004). LED and LINTER: An X-WINDOWS Mini-Editor and Interpreter for LABANOTATION. `http://linus.socs.uts.edu.au/~don/pubs/led.html`. Last accessed January 2004.

Herbison-Evans, D., Green, R. & Butt, A. (1982). Computer Animation with NUDES in Dance and Physical Education. *Australian Computer Science Communications*, *4(1)*, 324–331.

Herbison-Evans, D. & Hall, N. (1989). The Computer Interpretation of Classical Ballet Terminology. Technical Report TR364, University of Technology, Sydney.

Herda, L., Fua, P., Plänkers, R., D., Boulic, R. & Thalmann, D. (2000). Skeleton-Based Motion Capture for Robust Reconstruction of Human Motion. In *Computer Animation*. Philadelphia, PA: IEEE Computer Society Press.

Humaine (2005). Humaine: emotion-research.net. `http://emotion-research.net/`. Last accessed June 2005.

Institute, B. (2004). About The Benesh Notation Editor. `http://www.benesh.org`. Last accessed December 2004.

Kahol, K., Tripathi, P. & Panchanathan, S. (2004). Automated Gesture Segmentation From dance Sequences. In *Proceedings of the Sixth IEEE International Conference on Automatic Face and Gesture Recognition (FGR2004)* (pp. 883–889). IEEE Computer Society Press.

Kendon, A. (1980). *Gestication and Speech: Two Aspects of the Process of Utterance* (pp. 207–227). The Hague: Mouton and Co.

Kshirsagar, S., Magnenat-Thalmann, N., Guye-Vuilléme, A., Thalmann, D., Kamyab, K. & Mamdani, E. (2002). Avatar Markup Language. In *EGVE '02: Proceedings of the Workshop on Virtual Environments 2002* (pp. 169–177). Eurographics Association.

Laban, R. (1966). *Choreutics* (Second Ed.). MacDonald and Evans Ltd.

Lansdown, J. (1995). Computer-Generated Choreography Revisited. In Robertson, A. (Ed.), *Proceedings of 4D Dynamics Conference* (pp. 89–99). De Montfort University: School of Design and Manufacture.

Li, Y., Wang, T. & Shum, H. (2002). Motion Texture: A Two-Level Statistical Model. In *Siggraph 2000, Computer Graphics Proceedings* (pp. 465–472). Addison-Wesley Publishers Ltd.

LIMS (2004). Laban/Bartenieff Institute of Movement Studies. `http://www.limsonline.org`. Last accessed January 2005.

Linux DV (2004). Digital Video for Linux. `http://kino.schirmacher.de/`. Last accessed November 2004.

Liu, K. & Popović, Z. (2002). Synthesis of Complex Dynamic Character Motion from Simple Animations. In *SIGGRAPH '02: Proceedings of the 29th Annual Conference on Computer Graphics and Interactive Techniques* (pp. 408–416). ACM Press.

Lootsma, F. (1972). *Numerical Methods for Non-linear Optimization.* Academic Press Inc.

Magnenat-Thalmann, N. & Thalmann, D. (1989). Synthetic actors. *Comput. Bull., 1(1)*, 12–14.

MathWorks, Inc. (2004a). MATLAB 7. `http://www.mathworks.com/products/matlab/`. Last accessed January 2005.

MathWorks, Inc. (2004b). Spline Toolbox 3.2.1. `http://www.mathworks.com/products/splines/`. Last accessed January 2005.

M.Cavazza, R.Earnshaw, N.Magnenat-Thalmann & D.Thalmann (1998). Motion Control of Virtual Humans. *Computer Graphics and Applications*, *18(5)*, 24–31.

Moeslund, T. B. & Granum, E. (2001). A Survey of Computer Vision-Based Human Motion Capture. *Computer Vision and Image Understanding: CVIU*, *81(3)*, 231–268.

Neagle, R., Ng, K. & Ruddle, R. (2004). Developing a Virtual Ballet Dancer to Visualise Choreography. In *Proceedings of the AISB 2004 on Language, Speech and Gesture for Expressive Characters* (pp. 86–97). Society for the Study of Artificial Intelligence and the Simulation of Behaviour.

Neagle, R. J. & Ng, K. (2003). Machine-representation and Visualisation of a Dance Notation. In *Proceedings of the Electronics Imaging and the Visual Arts (EVA2003)* (pp. 22.1–22.8).

Neagle, R. J., Ng, K. & Ruddle, R. A. (2002). Notation and 3D Animation of Dance Movement. In *Proceedings of the International Computer Music Conference (ICMC2002)* (pp. 459–462). The International Computer Music Association.

Neagle, R. J., Ng, K. & Ruddle, R. A. (2003). Studying the Fidelity Requirements for a Virtual Ballet Dancer. In *Proceeding of Vision, Video and Graphics Conference (VVG2003)* (pp. 181–188). Eurographics Association.

Neff, M. & Fiume, E. (2004). Artistically Based Computer Generation of Expressive Motion. In *Proceedings of the AISB 2004 on Language, Speech and Gesture for Expressive Characters* (pp. 29–39). Society for the Study of Artificial Intelligence and the Simulation of Behaviour.

Noma, T. & Badler, N. (1997). A Virtual Human Presenter. In *IJCAI Workshop on Animated Interface Agents: Making Them Intelligent* (pp. 45–51).

Noverre, J. (1760). *Lettres sur la danse et sur les ballets*. Editions Ramsay. Jean-Georges Noverre, Letters of Dancing and Ballet, Translated from revised and enlarged edition (St Petersburg 1803) by Cyril W. Beaumont, London 1930.

Oasis (2005). Cover Pages: XML and Music. `http://xml.coverpages.org/xmlMusix.html`. Last accessed November 2005.

Ortony, A., Clore, G. & Collins, A. (1988). *The Cognitive Structure fo Emotions.* Cambridge university Press.

Parsons, T. (2004). Ballet-Modern FAQ. `http://www.dancer.com/tom-parsons/faq_1.html`. Last accessed in April 2005.

Perlin, K. (1994). Danse Interactif. SIGGRAPH'94 Electronic Theatre.

Perlin, K. (1995). Real Time Responsive Animation with Personality. *IEEE Transaction on Visualisation and Computer Graphics*, *1(1)*, 5–15.

Perlin, K. & Goldberg, A. (1996). Improv: A System for Scripting Interactive Actors in Virtual Worlds. *SIGGRAPH '96: Proceedings of the 23rd annual conference on Computer graphics and interactive techniques* (pp. 205–216).

Price, R., Douther, C. & Jack, M. A. (2000). An investigation of the effectiveness of choreography for the portrayal of mood in virtual environments. In *Proceedings of the fourth international conference on Autonomous agents* (pp. 54–55). ACM Press.

Pullen, K. & Bregler, C. (2002). Motion Capture Assisted Animation: Texturing and Synthesis. In *Siggraph 2002, Computer Graphics Proceedings*. ACM Press / ACM SIGGRAPH / Addison Wesley Longman.

Ramsay, J. & Riddoch, M. (2001). Position-Matching in the Upper Limb: Professional Ballet Dancers Perform with Outstanding Accuracy. *Clinical Rehabilitation*, *15(3)*, 324–331.

Ryman, R. (2001). Labanotation and Life Forms: Computer Animation as a Complement to Dance Notation. In *Processings of the International Council of Kinetography Laban/Labanotation (ICKL2001)*. ICKL Publication.

Simpson, J. & Weiner, E. (Eds.). (1989). *Oxford English Dictionary* (2 Ed.). Oxford University Press.

Ohio State University (2000). LabanWriter. `http://www.dance.ohio-state.edu/labanwriter/`. Last accessed September 2002.

Stevens, C., Mallock, S., Haszard-Morris, R. & McKechnie, S. (2002). Shaped Time: A Dynamical Systems Analysis of Contemporary Dance. In *Proceedings of the 7th International Conference on Music Perception and Cognition, Sydney* (pp. 161–164). AMPS and Causal Productions.

SYSTAT (2004). SigmaPlot. `http://www.systat.com/products/SigmaPlot/`. Last accessed October 2004.

Thalmann, D. (2000). The Virtual Human as a Multimodal Interface. In *AVI '00: Proceedings of the Working Conference on Advanced Visual Interfaces* (pp. 14–20). ACM Press.

Thirumalai, M. (2001). An Introduction to Natya Shastra-Gesture in Aesthetic Arts. *Language in India*, *1(6)*, 27–33.

Thomas, F. & Johnson, O. (1981). *Disney Animation: The Illusion of Life*. Abbeville Press, New York.

Troje, N. (2002). Decomposing Biological Motion: A Framework for Analysis and Synthesis of Human Gait Patterns. *Journal of Vision*, *2(5)*, 371–387.

Unuma, M., Anjyo, K. & Takeuchi, R. (1995). Fourier Principles for Emotion-Based Human Figure Animation. In *SIGGRAPH '95: Proceedings of the 22nd annual conference on Computer graphics and interactive techniques* (pp. 91–96). ACM Press.

Wilks, J. (1980). *Benesh Movement Notation Beginners' Manual: 1. Still Life* (Second Ed.). The Benesh Institute of Choreology, Ltd.

Zhao, L. (2001). Synthesis and Acquisition of Laban Movement Analysis Qualitative Parameters for Communicative Gestures. PhD thesis, University of Pennsylvania.

Zhao, L., Badler, N. & Costa, M. (2000). Interpreting Movement Manner. In *CA '00: Proceedings of the Computer Animation* (pp. 112–120). IEEE Computer Society Press.