Automatic Composition Software for Three Genres of Dance Using 3D Motion Data

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Abstract

This paper reports on the development of three automatic composition systems for dance that use 3D motion data captured from the performances of professional dancers. The systems can generate short choreographic works in three genres of dance: hip-hop dance, contemporary dance, and classical ballet. The authors label the method of automatic composition as analytic-synthetic choreography, where the dance movements are segmentalized along a time axis into short elemental motions and synthesized them to generate new dance movements. Both the elemental motions and the automatic composed movements are instantly simulated as 3D animation. After investigating the characteristic features of each dance genre, motion data archives and automatic composition algorithms were devised. We experimentally evaluated the usability of our software and verified its acceptability for hip-hop dance and ballet.

1. Introduction

This paper describes a new method of dance choreography that uses 3D motion data that were captured from performances by professional dancers. We name our method analytic-synthetic choreography, as explained in Section 2, and applied it to develop automatic composition systems for three genres of dance: hip-hop dance, contemporary dance, and classical ballet.

We have been working on computational dance study using 3D motion data for more than ten years [1-5]. This study forms part of our broader project whose goals include developing useful software in dance education, creation, and appreciation for the learners, instructors, choreographers, and audiences of dance performances. It introduces three types of software that allow users to create and simulate short choreographies of three dance genres.

There are some related works on computational dance study. Some research used dance notation and developed software applications [6, 7]. With these software, users can simulate already captured or precisely described dance animation. However, it is difficult to use these applications to compose original dances. Some research developed human animation systems using motion clips with GUI and a tangible interface [8]. With this software, composing choreographic works is difficult because it previews animations after editing the sequences. Our method allows users to compose new dance sequences easily and preview them immediately.

A dance simulation system using 3D motion data with handwritten sketch inputs was recently developed [9]. However, it is also difficult to compose creative and effective choreographies using this system because the number of dance motions is limited. Our proposed software allows users to create an unlimited number of different varieties of dance movements.

2. Analytic-synthetic Choreography

The basic concept of our method is to segmentalize dance movements performed by professional dancers into

short elemental motions and synthesize them as building blocks to generate new movements. Both the elemental motions and the synthesized movements can be simulated easily and instantly as 3DCG animation with a CG avatar. We call this method analytic-synthetic choreography.

In general, the history of dance in the 20th century as a performing art has two main choreographic trends: expressive methods and structural methods. Expressive methods use feelings, emotions, or narratives to establish the choreography. Structural methods use movements or concepts of movement structure. These two methods are not necessarily in conflict, but legendary 20th century choreographers Isadora Duncan (1877–1927), Martha Graham (1894–1991), and Pina Bausch (1940–2009) created their works basically with the former methods, while Merce Cunningham (1919–2009), Lucinda Childs (1940–), and the early William Forsythe (1949–) created with the latter [10, 11]. We were inspired by the latter group of choreographers and analytic-synthetic choreography is an extension of their ideas.

In analytic-synthetic choreography, the segmentalization of dance movements can be done in two ways. First, in whole-body segmentalization the dance movements are separated into basic whole-body movements along a time axis. Second, in body-part segmentalization the whole-body movements are articulated to extract the body-part motions.

Similarly, the synthesis of dance movements can also be done in two ways. First, several whole-body movements can be selected and combined in a row on a time axis to generate a short dance sequence. For example, when three movements denoted by A, B, and C are selected, the system can generate ABC, BAC, ACBA, CBCAAB, and so on. Second, part of a whole-body movement can be replaced by a body-part motion. For example, when a stamping forward movement with waving arms is selected, the system can replace the arms by folding them in front of the body. The movements overlap on the time axis unlike in the first way. We call these whole-body synthesis and body-part synthesis.

This paper introduces three types of automatic composition systems using whole-body segmentalization and whole-body synthesis. Although these systems do not use body-part segmentalization and body-part synthesis, these methods are still very powerful and promising for automatic composition, which will be discussed in Section 6.

3. Motion Data and Body Structure

The 3D motion data of dance movements were captured from performances by professional dancers using optical motion capture systems and a magnetic motion capture system. Three different types of dance were selected. Hip-hop movements were captured through cooperation with an award-winning hip-hop dancer. Contemporary movements were captured from a leading contemporary dancer and dance choreographer in Japan. Ballet movements were captured from performances by two professional ballet dancers.

Figure 1 shows capturing scenes using motion capture systems. The dancers had more than 30 markers on their bodies, and the 3D coordinates of each marker were picked up for 120 frames per second.

Figure 1. Capturing scenes using motion capture systems

The various formats for motion capture data are not always standardized. We created an original 3D human model to describe the dance movements [1]. Figure 2 shows a diagram of the structure of the human body that was used to create 3DCG dance animation in our research project. It is based on the "H-anim" standard, which is an international standard for Humanoid Animation proposed by the Web3D Consortium in the 1990's and standardized by the International Organization for Standardization (ISO) [12].

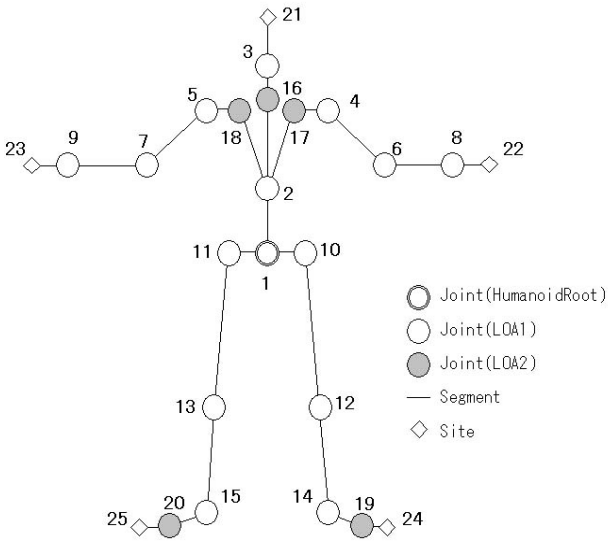

Figure 2. Human body structure for dance movements

Human joint positions are defined as 89 joints in H-anim. Since the data from motion capture systems usually have 15 to 20 joints, 14 joints were selected as our model based on Level of Architecture 1 (LOA 1) of H-anim. We added the neck, shoulder, and toe joints, which are based on Level of Architecture 2 (LOA 2), to rectify the model for dance movements. The model has hierarchical structure with 20 joint objects, 20 segment objects, and five site objects. The center joint is called the "HumanoidRoot". Figure 3 shows the human body hierarchy of the standard model for a dancer.

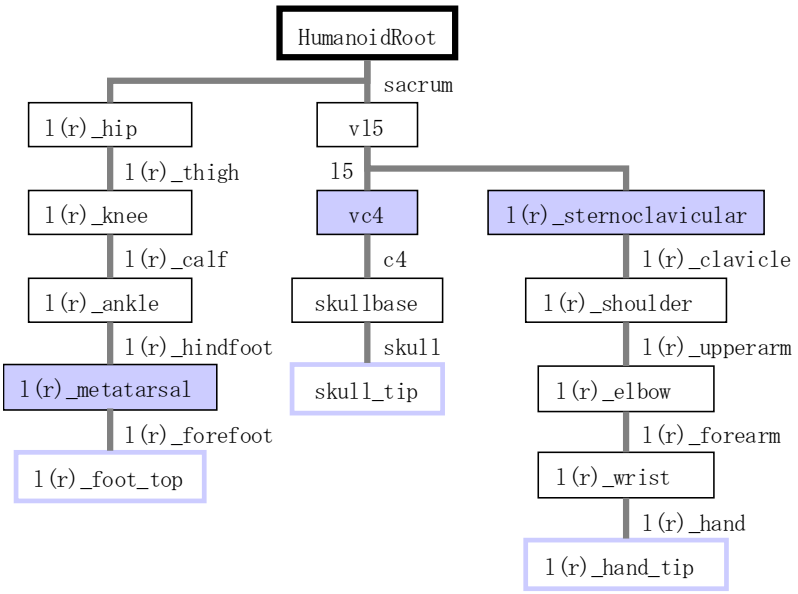

Figure 3. Human body hierarchy for dance movements

The motion data of dance movements we uses have 30 frames per second. They consist of two types of information: rotation and traveling. For each joint in each frame, there are 20 bits of rotation information, which is represented as quaternions. In addition, for each frame, there is one piece of traveling information of the HumanoidRoot joint. The traveling information is represented as a three-dimension vector.

4. Automatic Composition Systems

Automatic composition systems have been developed for three dance genres to actualize a method of analytic-synthetic choreography. In the initial stage of this research, we targeted elementary-level dance learners as users of the systems, which are intended for dance beginners and their instructors.

For each dance genre, a motion data archive and automatic composition algorithms were devised according to the characteristic features of the genre. Each archive stores a set of short motion clips which were created by whole-body segmentalization from the motion data of the dance movements. Then each algorithm, which defines the particular sequencing laws, is designed to generate dance sequences by whole-body synthesis. According to the algorithm, some motion clips are selected from the archive and synthesized into a new dance sequence that can be performed by elementary-level dance learners. The synthetic result is immediately displayed as 3DCG animation with a CG avatar on a tablet or a notebook PC. Figure 4 shows an image of the automatic composition systems.

Figure 4. Image of automatic composition system for hip-hop dance

4.1 Hip-hop Dance

Hip-hop dance emerged in the late 1960's as part of Hispanic and African-American street culture in the United States and is typically performed to hip-hop music. The genre includes a very wide range of dance styles, such as breaking, locking, and popping. Its physical techniques continue to develop [13].

After an investigation of hip-hop dance with experienced hip-hop dance instructors, we identified a number of its characteristic features. Beginners of hip-hop dance need to learn many elemental steps and practice them to the rhythm of the music at the same tempo. The timing of steps is constrained relative to the music such that a step is not allowed to carry over from one musical bar to the next. In elementary-level lessons, most elemental steps have two or four counts. The order of the elemental steps is not strictly constrained so that any step can be succeeded by another step. A motion data archive and an automatic composition algorithm for hip-hop dance were created based on these features [5].

The motion data archive has 44 types of elemental hip-hop steps that are frequently taught in elemental-level lessons, such as box step, cross step, crab step, side kick, and the body wave. The durations of all the steps are unified in four counts (four beats). A mirroring motion clip of each type was created so that the archive stores 88 four-count motion clips.

We devised an automatic composition algorithm that generates 32-count dance sequences. Eight slots are arranged, and the system randomly fills them with four-count clips. Repetition of the same motion is allowed, but the algorithm has a constraint on the maximum number of repetitions, so a 32-count dance sequence has at least three different types of elemental steps. Figure 5 shows a transition diagram for creating hip-hop dance sequences. Figure 6 shows an example of a generated sequence.

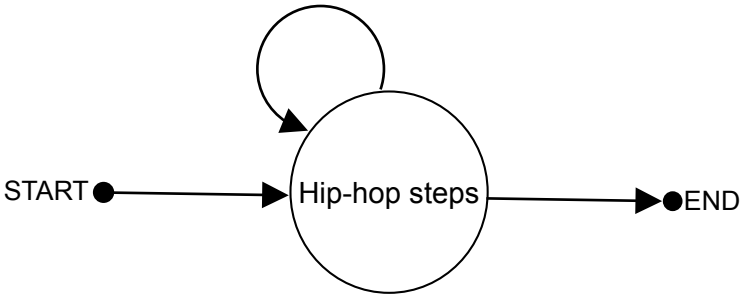

Figure 5. Transition diagram for hip-hop dance sequences

Figure 6. Example of a hip-hop dance sequence (from upper left to lower right)

4.2 Contemporary Dance

It is difficult to define contemporary dance because its territory is continuously spreading, but the term became popular in the 1960's in western countries. This genre is a successor of modern dance, which emerged at the beginning of the 20th century. Contemporary dance has been one of the most dominating performance genres of dance art in the 21st century. It has no common or standard manner of choreography, and it assimilates any dance style to exploit its artistic territory, such as classical ballet, jazz dance, Butoh dance, and worldwide ethnic dances [10, 11, 13].

After investigating contemporary dance with a Japanese contemporary dance choreographer who is also a university teacher, we identified a number of its characteristic features. In contrast to hip-hop dance, contemporary dance has inherently no elemental steps that beginners need to learn, although there are some movement methods such as the Graham technique, the Limón technique, the Forsythe technique, and GAGA. Contemporary dance instructors and teachers have individually their own teaching method for elementary-level lessons. The timing of dance motions is not constrained by the music, and motions are frequently allowed to carry over from one musical bar to the next. The duration of step units also varies widely. Similar to hip-hop dance, since the order of steps is not constrained, any step can be succeeded by another step. A motion data archive and an automatic composition algorithm for contemporary dance were created based on these features [4].

To capture dance motion data, a Japanese contemporary dance choreographer performed her own elemental movements that she usually teaches in her elementary-level university lessons. The movements included both steps and motions without steps. The motion data archive has 53 elemental contemporary dance movements, such as contraction, neck roll, arm swing, side dive, and jump forward. The duration of the movements varies widely. The 53 movements are categorized into five families: 22 body-part motions, 14 balance motions, five jump motions, four pivot motions, and eight floor motions.

We next devised an automatic composition algorithm that generates about 15-second dance sequences for beginners. To create a well-organized sequence that provides intriguing practice for beginners, we used a well-known structure of Chinese and Japanese narratives that originated in ancient Chinese poetry that consists of four parts: introduction, development, turn, and conclusion [14]. The turn part is the climax of the narratives in the structure.

The algorithm consists of the order of the arrangement of four parts and a number of selection constraints using the categorization of movements. The system arranges the elemental movements in the order of turn, conclusion, introduction, and development. First, a movement is selected from other motions than the body-part motions for the turn part. The movement in the turn part can appear only once in a sequence. Second, for the conclusion part, a movement is selected from other motions than the off-balance motions and the motion that was already selected in the turn part. Third, for the introduction part, a movement is selected from other motions than the jump motions and the movements already selected. Finally, for the development part, movements are selected repeatedly from other motions than the movements already selected until the sequence has sufficient duration. The algorithm allows the conclusion part to be omitted. Figure 7 shows a transition diagram for creating contemporary dance sequences. Figure 8 shows an example of a generated sequence.

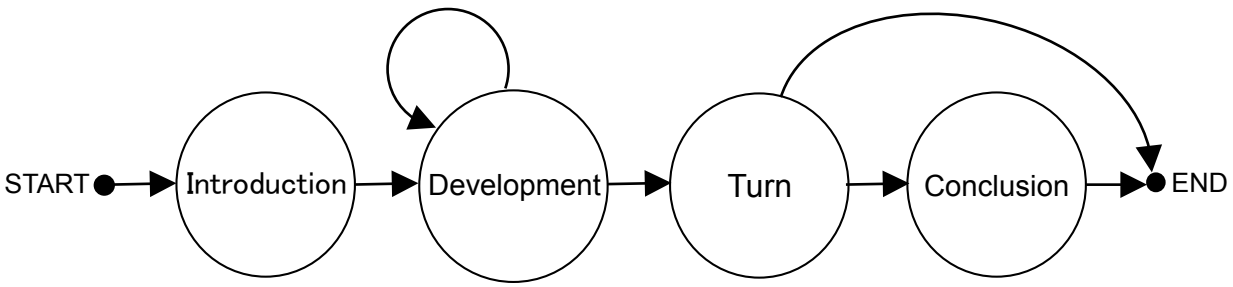

Figure 7. Transition diagram for contemporary dance sequences

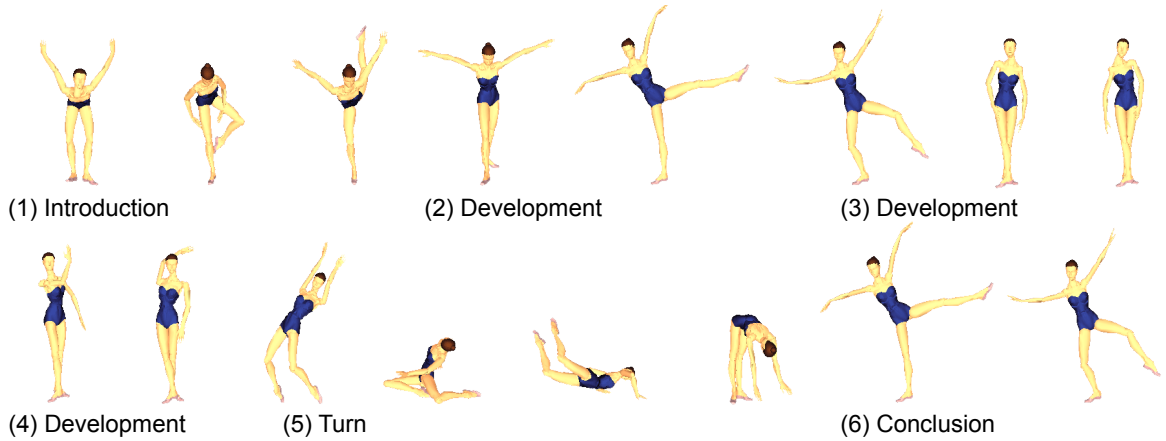

Figure 8. Example of a contemporary dance sequence (from upper left to lower right)

4.3 Ballet

Ballet originated in the Italian Renaissance courts of the 15th century and its basic technique was established in the French courts of the 17th century. It became widespread in most modernized countries in the 20th century and has been globally influential as the fundamental dance technique of many other genres of dance. It has different teaching methods, such as the French method, the Cecchetti method, the Vaganova method, and the RAD method, but the genre has a widely common standard of movements and a strict canonical manner of choreography in contradiction to the unrestricted manner of contemporary dance [13].

After an investigation of ballet with experienced ballet teachers, we identified a number of its characteristic features. Beginners of ballet need to learn many elemental steps and practice them to the rhythm of the music at the same tempo. The timing of steps is constrained relative to the music such that a step is never allowed to carry over from one musical bar to the next. These features are similar to hip-hop dance, but ballet has a much stronger standard and stricter rules than hip-hop. In elementary-level lessons, most elemental steps have one count whose duration is shorter than hip-hop. Ballet has its own vocabulary based on French terminology that is used around the world. The order of elemental steps is closely constrained based on its conventions. A motion data archive and a set of automatic composition algorithms for ballet were created according to these features [1, 2, 3].

To capture the dance motion data, experienced ballet teachers exhaustively enumerated the ballet steps that are required for elementary-level female *petit allegro* in ballet schools. All the steps were captured from performances by professional ballet dancers. The motion data archive has 215 elemental ballet steps. The most steps have one count, but some have two to four counts or a half count. The 215 steps are categorized into the following four families:

Allegro steps: quick movements without rotation, ex., *sauté, changement, assemblé, glissade, jeté, sissonne fermée.*
Rotation steps: turns around the dancer's vertical axis, ex., *pirouette en dehors, pirouette en dedans, chaînés, piqué en dedans*.
Transition steps: movements that usually link other step families or part of a necessary preparation, ex., *chassé, pas de buorrée, pas de basque.*
Fragmentary steps: short motions used to generate a seamless series among the other families, ex., *demi-plié*, changing the supporting leg.

The authors also enumerated 84 basic foot poses that can be either the beginning or the ending pose of elemental ballet steps. The beginning and ending poses of each of the 215 steps are identified as one of the 84 poses.

We devised a set of automatic composition algorithms that generates 16-count female *petit allegro* ballet sequences or "*enchaînement"*. To create a well-organized sequence that adheres to ballet conventions, we used the constraints of musical phrasing, transitions between steps, and transitions between step families. First, the constraint of

musical phrasing requires that a step is never allowed to carry over from one musical bar to the next. The system selects steps one by one to comply with this constraint. Second, the constraint of transitions between steps requires that the ending pose of the previous step becomes the beginning pose of the next step. The system uses the 84 poses to comply with this constraint. Third, the constraint of transitions between step families requires a natural and organic structure that obeys the artistic conventions of ballet. The system uses the four families to comply with this constraint. Figure 9 shows a transition diagram for creating a *petit allegro enchaînement*.

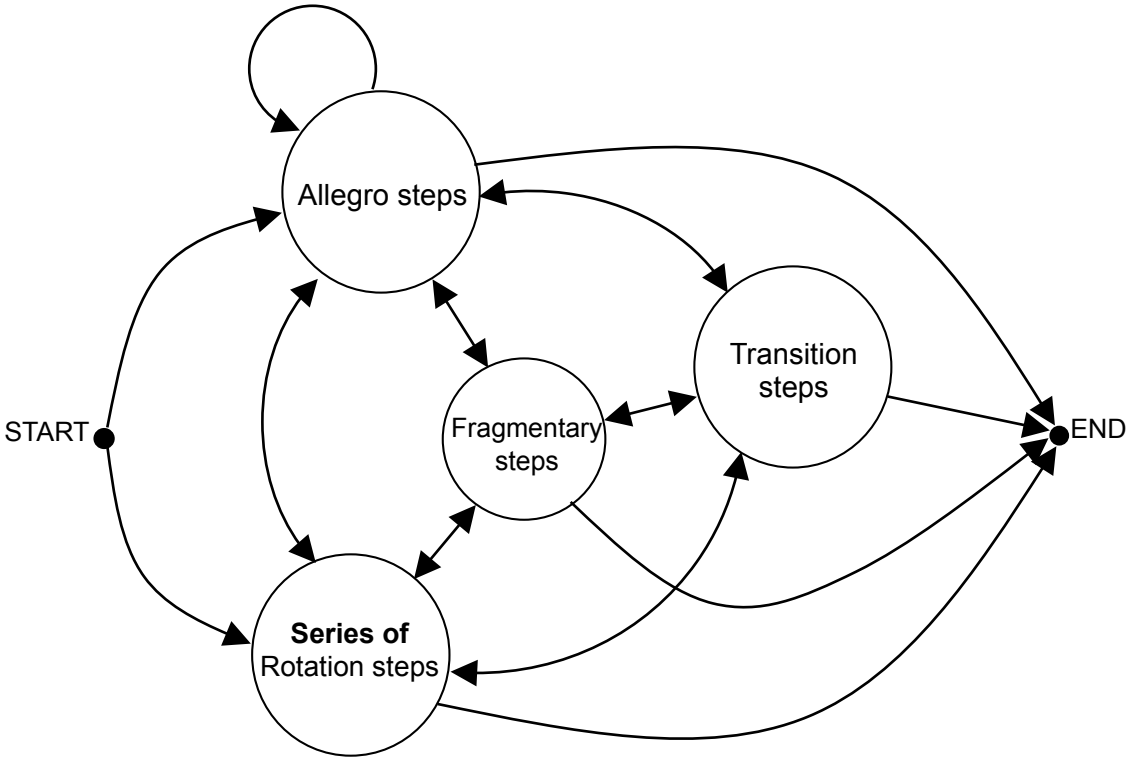

Figure 9. Transition diagram for ballet sequences

Regarding the steps in the rotation family, the algorithm allows only one rotation step in the immediate succession at the elementary-level (i.e., no double turns).This rotation step is always preceded by a preparation action. There is an option to follow the rotation step with a short recovery action; otherwise the next step must be from a different family. An additional overall rule in the algorithm for rotation steps also places another constraint: only one set of rotation steps can occur in a single *enchaînement*.

Furthermore, the algorithm has a constraint on the starting and final poses of the sequence. Any *enchaînement* starts with the 5th position of the feet and ends with one of three possible poses that were identified by the ballet teachers as appropriate final positions. The *enchaînement* duration was restricted to just 16 counts (four bars in four-four). The system selects steps repeatedly based on the algorithm until the sequence has 16 counts. Figure 10 shows an example of a generated sequence.

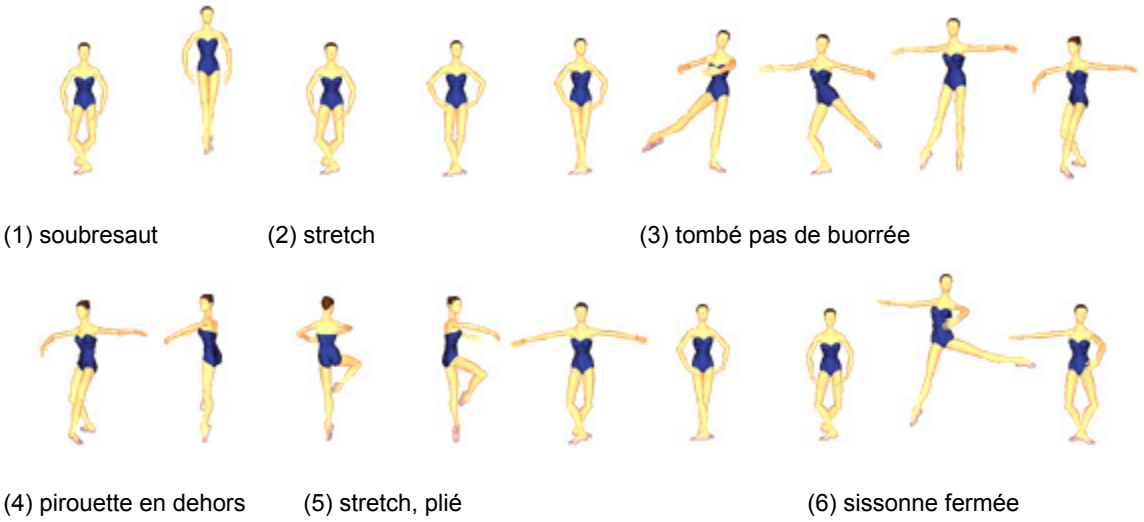

Figure 10. Example of a ballet sequence (from upper left to lower right)

5. Experiments

Experiments were conducted to verify the usability of the two systems for hip-hop dance and ballet. Experienced instructors and expert teachers of the two dance genres evaluated a group of the dance sequences for elementary-level dance learners that were generated by the automatic composition systems. An evaluation experiment of the contemporary dance software has not been conducted yet.

5.1 Hip-hop Dance

A group of 25 hip-hop dance sequences was composed automatically by the software. An expert hip-hop teacher who has been teaching for eight years evaluated the usability of each one. The level of usability was rated on a scale from 1 to 5. The result of the ratings is shown below.

1. Inappropriate for a hip-hop lesson	0
2. Upper limit for an advanced lesson	0
3. Appropriate for a normal advanced lesson	7
4. Upper limit for an elementary-level lesson	13
5. Appropriate for a normal elementary-level lesson	5

72% of the ratings considered the sequences appropriate for an elementary-level lesson either at the limit of upper level or at normal level. No sequence was considered to be inappropriate for a hip-hop lesson.

5.2 Ballet

A group of 20 female *petit allegro enchaînements* was composed automatically by the software. Five expert ballet teachers evaluated the usability of each one. The level of usability was rated on a scale from 1 to 5. The number of total ratings of the 20 *enchaînements* by the five teachers was 100. The result of the ratings is shown below.

1. Inappropriate for a ballet lesson	8
2. Upper limit for an advanced lesson	5
3. Appropriate for a normal advanced lesson	22
4. Upper limit for an elementary-level lesson	30
5. Appropriate for a normal elementary-level lesson	35

65% of the ratings considered the *enchaînements* appropriate for an elementary-level lesson either at the limit of upper level or at normal level. Only 8% of the ratings considered the *enchaînements* generated by the algorithm to be inappropriate for a ballet lesson. Five *enchaînements* were evaluated as inappropriate by a single teacher, and another one was evaluated as such by three teachers.

6. Conclusions

Three automatic composition systems for three dance genres were developed using 3D motion data. The software is designed to generate short dance sequences for elementary-level dance learners using a method of analytic-synthetic choreography. Two evaluation experiments were conducted for the systems of hip-hop dance and ballet. As a result of the experiments, we verified that the software is useful for elementary-level dance learners and their instructors and teachers.

With respect to contemporary dance, we uncovered a crucial fact for automatic composition during our research. In this study, we used the method described whole-body segmentalization and whole-body synthesis (Section 2). However, body-part segmentalization and body-part synthesis must be used for contemporary dance, because whole-body methods are likely insufficient to satisfy the requirements of contemporary instructors and teachers. Contemporary dance always requires the discovery and innovation of new dance movements, but whole-body methods cannot generate any movements other than those stored in the motion data archives. The body-part methods are more productive and adaptable for contemporary dance.

In future work, we will amend the software by augmenting the user interface, increasing the motion data archives, and upgrading the algorithm of automatic composition. We are focusing on the automatic composition software for contemporary dance that actualizes body-part segmentalization and body-part synthesis of analytic-synthetic choreography.

Acknowledgements

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