Measuring the Steps: Generating Action Transitions Between Locomotion Behaviours

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***Abstract*—Motion synthesis is a complex process, especially in cases involving a variety of actions. In locomotion composition processes, in which virtual characters are called upon to perform a sequence of different actions, such as a sequence from walking to running, the transition is mainly generated linearly. However, to accurately model the way in which humans actually perform the transition between two different actions, computer animations must also capture the nature of between-action processes. This paper presents a simple approach for animating the transition process between different locomotion actions. The approach determines the relationship between the number of steps and the velocity of the root. Results of the measurements are then plotted on action transition graphs. Finally, the graphs are used in an experimental application that generates the correct transition between the origin and target actions of the character, given both the velocity of the root at the origin and at the target.**

***Keywords*—motion analysis, motion synthesis, motion editing, action transition, locomotion composition, character animation**

I. Introduction

Realistic representations of a virtual character's motion can be easily achieved using technologies that capture high-quality data on the motions of actual humans performing different actions [1]. Based on the recorded motion data, it is possible to accurately synthesise motions involving various combinations of recorded sequences. In addition, commercial applications give the ability to assign these motion sequences to virtual characters, thus generating realistic animation sequences.

However, even when the provided motions are quite natural, a variety of factors related to action transitions, which are the focus of this study, have yet to be thoroughly examined. Hence, considering the different actions of a character, the system should be able to generate not only a smooth transition between two different motion sequences, but also a human-like action transition that mimics the way actual humans perform intermediary actions. Our assumption is that realistic representations of human motions require complex mathematical models augmented by measurements that describe how actual humans perform different actions.

The measurements required for generating transition sequences are not always easy to obtain, as human bodies are complex articulated figures with many degrees of freedom (DOF); also, humans can perform different variations on the same motion. Moreover, gender, age, and a variety of physical properties (e.g., height, weight) play an important role in determining how each individual performs a given action. Thus, considering that generalisation of such transitions is difficult, our study is restricted to transition processes involving only two different actions, such as the transitions between walking, jogging, running, jumping, and stair stepping actions.

For this study, we obtained measurements on ten individuals, aged 18-27. The measurements included the number of steps and the velocity of the root during the transition from one action to another. In using this approach to analyse motion capture data, our goal was to enhance the naturalness of the generated motions of virtual characters who are called upon to perform different actions.

The remainder of this paper is organised as follows. Section 2 examines methods for measuring and understanding how humans perform different actions. Section 3 outlines the methods used in the proposed solution, and Section 4 presents an experimental application that generates transitions between different motions. Finally, Section 5 presents the conclusions and discusses the possibilities for future work.

II. Related Work

The use of motion capture data to produce new motion sequences has been thoroughly examined in recent years, and various methods have been proposed to generate the desired motions of virtual characters. Each of the techniques employed to generate human-like locomotion sequences has its own advantages and disadvantages. Multon et al. [2] analysed different types of motion composition techniques for walking motions, and their survey provides the basic categories of composition processes presented below.

The first category includes procedural techniques for generating motions using algorithms based on biomechanics principles [3] [4] [5] [6]. While these motion models can provide a high level of control over the movements of a virtual character, the generated animations tend to be unnatural looking and only particular behaviours may generated.

Another approach to synthesising and generating valid human motions uses example-based techniques. In this approach, the synthesised motions are based either on motion concatenation, which combines motions for generating a new and long motion sequence [7] [8] [9] [10], or motion parameterisation techniques [11] [12] [13], in which reference motions are interpolated so as to provide a new motion sequence fulfilling

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user-defined parameters, such as the position of an end effector. Examples that combine these two techniques have also been proposed [11].

In contrast, approaches based on measurements of human performance during different actions have not been thoroughly examined. Such measurements can give the ability to generate human-like motion sequences while analysing how humans perform different actions. Only a few such methods have been proposed, such as the solution by Glardon et al. [14], in which an analysis of motion capture data generates the correct velocity required of the character, as in the transition to jumping over an obstacle. However, Glardon et al.'s method has only been applied to actions involving walking, running, and jumping. Nevertheless, the results generated by this solution are more human-like than those generated by approaches using techniques in which the analysis of locomotion is not taken into account.

Other solutions that examine the ability to measure human performance and then pass the executed results to motion models have come to the attention of crowd simulation researchers. For example, the solutions presented by Lee et al. [15] and Li et al. [16] use measurements of how humans perform path-planning processes to generate crowd flow models that mimic human behaviour. The solution proposed by Lerner et al. [17] is based on evaluations of algorithmic representations of crowd flow. The solution proposed by van Basten et al. [18] uses motion capture data to understand collision-avoidance strategies involving human-human interactions. The rules obtained from these measurements are then applied to agent-based simulations to give more realistic simulations.

Although a general understanding of human motions has been achieved, there is one basic limitation. The solution proposed by Glardon et al. [14], which is similar to the solution proposed in the present study, only examines the ability to adjust the motions of characters before a jumping tasks, rather than generating a general model that computes the optimal velocity of the character at every step during the transition processes. Thus, our solution employs the ability to measure transitions based on the number of required steps. Hence, given a desired target motion for the character, the system is able to execute the number of required steps, and to procedurally increase or decrease the velocity of the character depending on the character's origin and target velocity based on the transition graphs that are generated.

III. METHODOLOGY

This section presents the methodology used to achieve the desired results. In the first step, each participant was called upon to perform two different actions for each combination of motions, as measuring only one action of the user would not provide sufficient motion capture data. In addition, every human performs the same action with different variations. Hence, each participant performed each action five times, which yielded data for 500 motion sequences. Figure 1 illustrates the architecture of the approach.

A. Action Transition Components

Having retrieved the motion capture data, the next step in our method was to build the mapping between motions having similar behaviours, such as between walking and running or between running and jumping. Then, for each motion, the velocity of the root, which characterises the transition process, was assigned as the main parameter for understanding the differences between the individual actions employed in the motion sequence. More specifically, the velocity of the root between two different actions should have a minimum or a maximum value that characterises one of the target actions. This approach was used to generate the desired velocity components assigned to each transition (see Table I for examples). For example, in the transition from a walking to running motion, the inverse transition, from running to walking, is executing by inversing the registered results, rather than using measurements from the motion capture data. The inverse process is used because it is assumed that this procedure can provide the desired result, as well as reduce the number of generated transition graphs.

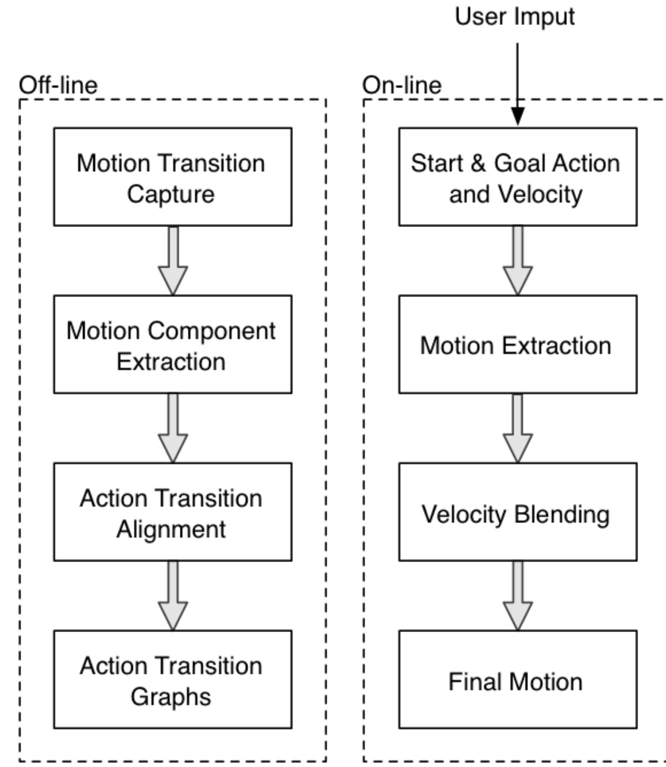

Fig. 1. Architecture of the proposed solution, which consists of off-line and on-line computations.

Based on Table I, it is possible to generate the velocity that characterises each target action. However, as the velocity is not the sole parameter, the number of steps taken to move from the origin to the target is also measured. This measurement is made using a simple foot detector [19], which recognises foot contact with the ground based on the velocity and height of the foot. Using this approach, the velocity component that characterises the target action is determined, as is the time period for which the velocity of the action is maximised or minimised. It is then possible to determine the number of steps required to generate the velocity representing the maximum or minimum value.

TABLE I. THE DISCRETE VELOCITY CHARACTERISTIC USED BETWEEN TWO DIFFERENT ACTIONS FOR THE TRANSITION PROCESS. VELOCITY COMPONENT WITH ASTERISK (*) DID NOT MEASURED. ALTHOUGH, THE INVERSE MEASUREMENTS ARE USED FOR DESCRIBING EACH OF THOSE TRANSITIONS.

From \ To	Walking	Jogging	Running	Stair Stepping	Jumping
Walking	-	max	max	min	max
Jogging	min (*)	-	max	min	max
Running	min (*)	min (*)	-	min	min
Stair Stepping	min (*)	max (*)	max (*)	-	max
Jumping	min (*)	min (*)	max (*)	min (*)	-

B. Action Transition Alignment

Having calculated the root velocity in accordance with the foot contact approach, the next step of the method is to align the motions. The alignment process is based on the ability to align the number of steps with the root velocity. More specifically, two features are extracted for each motion: the number of steps s_i and the velocity of the root v_i at each step, such that each recorded motion m_i is represented by $m_i = \{(s_1, v_1), ..., (s_n, v_n)\}$, where n denotes the $n - th$ registered step of the human derived from the motion capture data. Having extracted each action transition from those components, the next step is to align the motions (see Figure 2) based on the $i - thstep$, where the $i - th$ root velocity is equal to the maximum velocity v_{max} or the minimum velocity v_{min}, depending on the discrete behaviour of the action transition mentioned above. This alignment ensures that all of the registered motions have the same transition behaviour and are aligned with the correct phase.

C. Transition Graphs

The proposed transition graphs represent the velocity of the root of each motion, as based on the corresponding steps. Considering that the number of steps for each registered motion varies, depending on the transition process, it is necessary to identify which steps should actually be included in the graphs. For the motion analysis process, it is necessary to remove the undesired steps (i.e., those that are not taking part of the transition process). Thus, for computing the actual steps that are required, the mean average of the number of steps before and after the velocity component is used to validate the number of required steps for the transition process.

Having aligned the steps based on the velocity property and having removed the undesired steps, to generate correct transition graphs, the actual numbers of steps and the root velocity are plotted, as illustrated in Figure 3. Based on the graph, it is possible to develop a general approach to the transition between two different actions by measuring the mean root velocity at each step. Based on the mean average of each action transition at each step, an action transition graph is constructed which presents the mean velocity of the root at each step of the character, presented as $m_{action} = \{(s_1, v_1^{mean}), ..., (s_n, v_n^{mean})\}$. With this general representation of the transition process, it is possible to understand how each transition action should evolve. In addition, this mean average is used as the parameter for executing the transition process during the runtime of the application, as is presented in the following section.

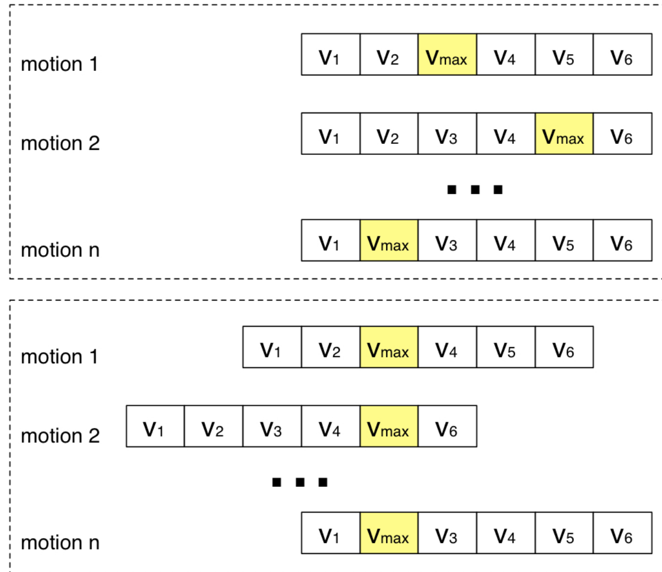

Fig. 2. Alignment process of the step for which the velocity of the root is assigned to the velocity component that characterises the target action. An example is given for before the alignment (upper plate) and after the alignment (lower plate). Each rectangle denotes a step; the yellow rectangles denote the step at which the velocity component is executed.

IV. EXPERIMENTAL APPLICATION

Having presented the methodology for handling the motion capture data and generating the action transition process, this section presents an experimental application designed to generate the correct transition between two different motions.

A. Implementation

For the implementation of the proposed solution, all registered motions are first downsampled to 60 fps. In addition, to enhance the collection of motion sequences, mirror versions are designed for all motions. Finally, the action transition graphs are stored in a lookup table.

During the runtime of the application, the user is called upon to choose the start and target actions of the character, as well as the velocity of the root. To avoid a deadlock in the system caused by choosing a velocity which is not contained in the registered motion sequence, each different action is assigned a velocity with bounding limits, such as $v_{action} \in [v_{min}, v_{max}]$. Figure 4 shows the interface for the application. The system executes the most suitable motions so as to generate a desirable result.

B. Motion Generation

The system proposed in the previous section is able to generate desirable transitions between two different actions.

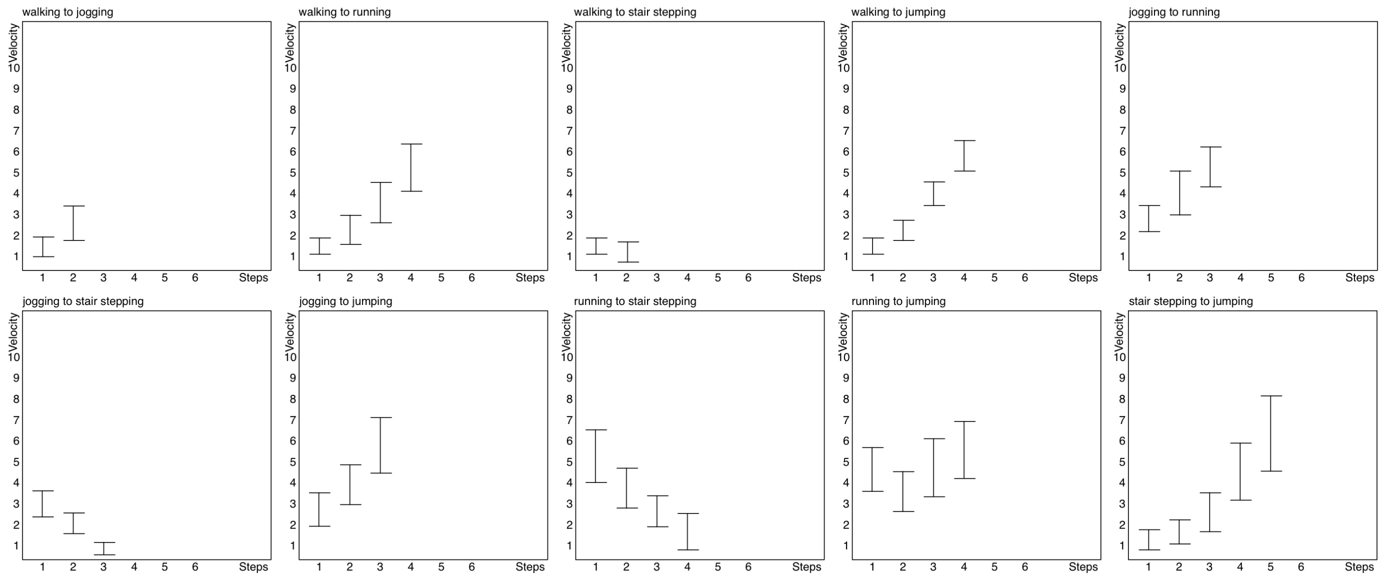

Fig. 3. Velocity of the root versus the number of steps taken after the alignment process. At each step it is represented the minimum and maximum value of the velocity of the root.

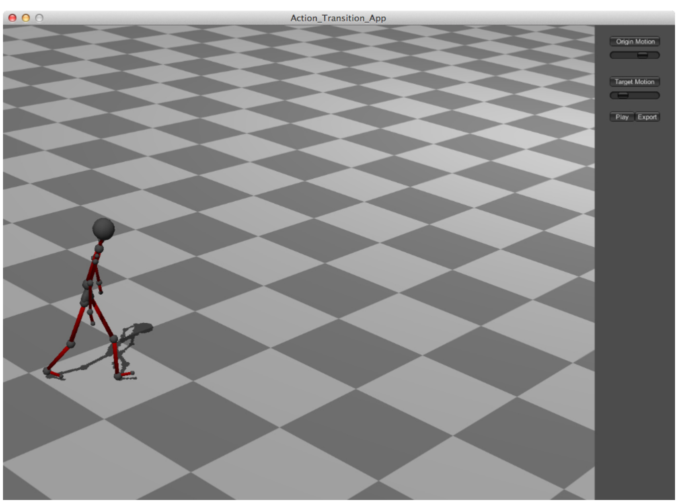

Fig. 4. Interface of our application for generating a well transitioned motion sequence.

More specifically, the user is able to select the origin and the target motion, as well as the desired velocity of the roots for both motions. The desired velocity of the origin motion is the velocity of the character at step s_1, and the velocity assigned to the target action is the minimum or maximum velocity of the root when the character reaches step s_n. Based on user inputs, as well as on the corresponding transition graph, the system first executes the required number of steps based on the target velocity. If the exact target velocity is not contained in the database, the nearest neighbour velocity is used for executing the number of steps.

In the second stage of the generation process, the system should be able to generate the desired motion by exactly reaching the desired goal velocity of the character. However, a linear approximation of the velocity of the root at each step, achieved by connecting the velocity v_1 of the first step with the velocity v_n of the last step, is not desirable. Hence, the mean average graph that represents the general behaviour of the action transition process, scaled on the basis of user inputs fulfilling both the origin and the target velocity, is used as a parameter. Hence, a scalar parameter λ is computed from:

$$\lambda = \frac{\|v_1 - v_n\|}{\|v_1^{mean} - v_n^{mean}\|} \tag{1}$$

Then, the action transition process of the motion sequence is computed by multiplying the velocity of the root at each step with the parameter λ, resulting in a particular behaviour of the form $m_{transition} = \{(s_1, \lambda * v_1^{mean}), ..., (s_n, \lambda * v_n^{mean})\}$.

The final step of the action transition process is based on the ability to execute and blend the desired motion sequences at each single step of the character. Considering two motions that enclose the required velocity of the character such that $v_{char} \leq v_i$ and $v_{char} \geq v_j$ for each step of the character, as derived from the mapping process mentioned above, the system linearly blends the velocity distances so as to provide the desired motion, by assigning a weighted interpolation function. Hence, the desired velocity of the character is computed at each $k-th$ step, such that $v_{s(k)} = w_i v_i + (1 - w_i) v_j$, where $w_i = v_{graph} / (\|v_i - v_j\|)$. Then, for each transition step, the nearest neighbour motions are extracted, following the previously mentioned blending process, to generate the final action transition. Finally, after having synthesised the corresponding motions, a motion graph [7] synthesis process is employed to generate a smooth transition between the individual steps of the character. Some examples of generated motions are illustrated in Figure 5.

V. Conclusion

This paper presents an approach for measuring action-transition processes between different locomotion behaviours. The proposed solution is based on the ability to analyse the recorded behaviours of the participants for each action transition independently. Then, by analysing the motion capture data

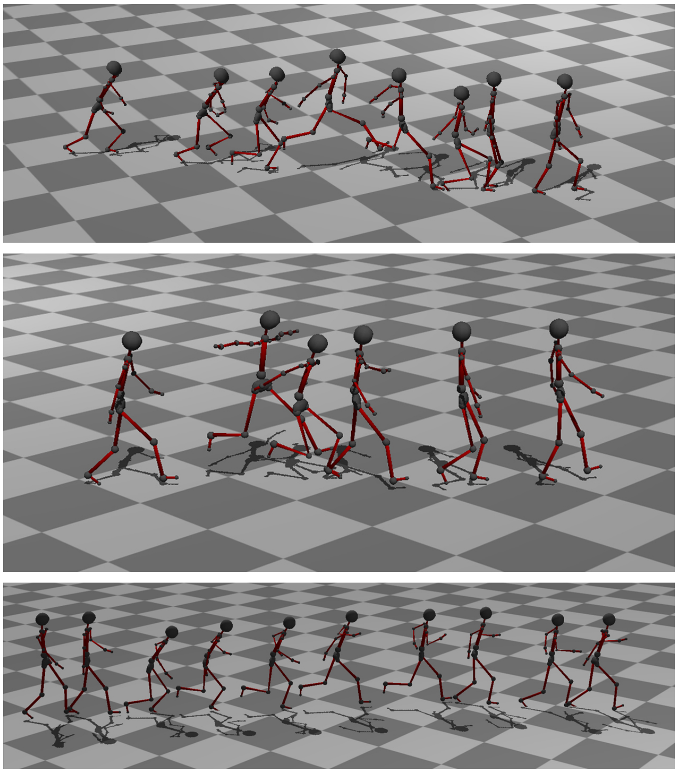

Fig. 5. Example action transition motion generated using the proposed solution. From jumping to stair stepping (upper row), from jumping to walking (middle row), and from running to walking (lower row).

based on the number of steps versus the velocity of the root, the desired action-transition graphs are generated. These graphs provide a more valid or natural-looking transition process during the motion of the virtual character, thereby enhancing the naturalness of the generated motion. Thus, in accordance with our measurements, a simple experimental application that is responsible for generating a locomotion sequence between two different actions with given desired velocities at the start and target of the action is implemented.

One of the limitations of our current solution is related to the ability to synthesise action transitions based on various other criteria, such as age, gender, and weight of the character; these limitations are imposed by the vast amount of experimentally captured data required to generate a desirable result using multiple variables. In the future, we would like to thoroughly research transition processes involving multiple parameters, by measuring how actual humans with various characteristics perform transition actions. In addition, we would like to research more deeply how this method can be implemented in various automatically generated scenarios, where autonomous characters can perform various actions related to locomotion during path planning. Finally, as the transition process had not previously been examined thoroughly, our future plans include the ability to measure the perceptions of humans while action transitions are being implemented, either in interactive applications such as in video games, or in static scenarios such as in 3D videos. The results of such analyses should give us the ability to understand how both users and participants/observers feel about the ability to generate such transitions.

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