An Overview on Dynamic 3D Character Motion Techniques in Virtual Environments

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Abstract: This paper presents a survey of dynamic motion manipulation for 3D character movement in the virtual environment. The survey is regarding the latest methods that have been used by researchers to transform dull motions into more dynamic and interactive movements. Comparisons of various motion algorithms used by other researchers are also presented. The survey focuses on dynamic 3D motion editor to get real 3D character movement which is a long standing problem in 3D animation industry. By utilizing motion capture technology, input data for character movement can be manipulated. Interested researchers on this area can obtain better understanding on the main issues and relevant techniques that have been used by recent researchers. This paper also reports on the highlighted evolutions of 3D motion techniques for dynamic motion in the virtual environments, focusing on three main parts; 3D character hierarchy, motion editing techniques and motion dynamic control.

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1. Introduction

Motion animation has become one of the most important aspects of games, simulations and advertisements not only virtual environment (Kolivand, 2012) but also Augmented Reality systems (Kolivand, 2013a). Dynamic 3D character motions are the main effect to make animation scenes realistic due to generate a smooth motion.

Generally, motions created by the animators are static. These motions are created to achieve certain situation of movement. As a result, the character will be repeating the same motion in real time animation. Therefore, it looks impractical and the character cannot respond any physical interaction. Character in real time animation requires a combination of motions from different sources such as motion capture, manual keyframes, dynamic and kinematics simulation (Hu, 2010).

The development involves character skeleton joints and bones that will simulate movement through virtual environment. Using 3D Software, animators design the character and make models more optimize. After that, skeleton will be set up for character rigging. The main process is to edit input data for mapping into the character before producing the movement animation. The movement of a character in computer games is not smooth and realistic when compared with the movement of people resulting to the non-real-time animation as cartoons and movies. To achieve a realistic virtual character, the character should be adjusted to similar human movements in the real world. Analysis of actual human movement data can be applied to the characters in real time using motion capture technology. One of the biggest challenges in interactive computer games industry is to produce a dynamic character movement and reactions to the physical interaction.

Dynamic motion refers to the physical properties of 3D object, such as mass or inertia, and specifies how the external and internal forces interact with the object (Oshita, 2006). With the dynamic input of character data, the control of the character's specific motion: walking, running or jumping looks more realistic and natural. Real-time characters consist of solid sections connected by joints. These sections and joints together are known as a skeleton. Motion of the skeleton can be specified in terms of rotation and translation. The kinematic approach refers to virtual character properties such as position, orientation, and velocity. Forward kinematics approach directly controls the relative geometric transformation of each bone of the skeleton. Meanwhile, Inverse Kinematics solve the problem to a given point in the geometric locations.

This paper focuses on dynamic motion algorithms. The basics of the hierarchy in producing dynamic motion control for real time animation character are also analyzed. This review will concentrate on skeleton hierarchy and kinematics, motion editing techniques, and active dynamic motion control.

2. Previous Surveys

Dynamic 3D character motions are one of the most important aspects in 3D character development (Kolivand, 2013b). The early research about dynamic character motion started in 1980 and many researchers then continue to improve this motion state technique. The previous record has revealed that several researchers have conducted studies on 3D motion character. One of the earliest surveys was done by Cavazza (1998), which had focused on techniques which control the virtual human body. They covered higher level interfaces for direct speech input and issues of real-time control. They also classified virtual human by controlling synthetic actors' motion and proposed four new classes of synthetic actors: participatory, guided, autonomous, and interactive-perceptive. The paper also includes a study of language interpretation and behavioral models

Another good survey on 3D character motion can be found in (Moeslund, 2006). They identified a number of general assumptions used in the motion research for the early stage of development. They evaluated the state of the art of major applications and analyzed the methods used. The fundamental explanation from this paper does not cover dynamic motion topic, but is more focused on automatic initialization, tracking, pose estimation, and movement recognition.

Li et al. (2009) presented dynamic motion generation and control for virtual characters. They concentrated on two main parts in dynamic motion control: how to build the dynamic simulator and how to establish the controller to realize various tasks.

The latest survey has been done by Guerra-Filho (2012), focusing on human motion databases describing data sources related to motion synthesis and analysis problems. Meanwhile, Geijtenbeek et al. (2012) provided a survey on interactive 3D character animation using simulated physics. They covered three core parts: controllability, style and usability.

The ideas of this particular research compared to the previous surveys include five points. First is to explain techniques in manipulating the motion state of 3D character. The method calculates and changes the joints' speed and trajectory by adding external forces following Newton's law. The method is simple but quite effective. Second is to compare the latest algorithms used in dynamic motion for 3D character. Third is to explore the fundamentals of dynamic motion through a study on skeleton hierarchy and kinematics. Fourth is to discuss about algorithm in active dynamic control for character animation and finally, to give a suggestion for research improvement and future of this research area.

3. Character Hierarchy and Kinematics

Human movement development in computer games involves joints of 3D models controlled by the skeleton hierarchy. These joints have been combined with three-dimensional geometric models, such as polygonal mesh. There are three main techniques commonly used to produce animation; keyframing technique, procedural techniques and motion capture technique.

Key-framing technique involves main frames for main character poses and in-between frames used to transform the position, placing, or timing of an object. The animator will make character movement editing and interpolation at in-between frames and has direct control over the positions, shapes, and motions of character at any moment in the animation. The effect of changing a parameter value is often predictable in keyframing techniques. Meanwhile, procedural technique provides initial conditions and adjusts rather abstract physical parameters, such as forces and torques. The animators have to run the simulation in virtual environment to see the result of parameter value changing. The animators specify physical rules and initial conditions to the character. The simulation calculation uses either kinematic or dynamic methods.

Currently, motion capture techniques have been used widely from video game animation to computer graphic effects in movies. An actor is placed in a special suit containing sensors that record the motion to get the real human movement data. Although it seems simple for human to understand motion situations, it is quite complex for computers due to complicated functions of sensing, learning, and interfaces (Liu, 2013) which are still longstanding problems in this area. The motion data output is often far from perfect because it needs a cleanup from the keyframe animator to make it look more natural. Output data from motion capture technology shows more realistic, convincing and better character movement than other techniques.

In general, human character in real animation is represented by a skeleton. A skeleton is described by the arrangement of bones that have been linked by specific joints (Wrotek, 2006). A real time animation character has 16 rigid links and 23 main ball joints that can be manipulated and controlled as shown in Figure 1. The total number of degrees of freedom (DOF) of virtual character is 41(Xiao, 2005).

3D character movements are controlled using skeleton structure or hierarchy. An example of a 3D character motion data hierarchy is shown in Figure 2. A hierarchy uses grouping or parenting concept. For example, of human leg, the hip is the parent of the upper leg. Meanwhile, the lower leg is the child of the upper leg, and the foot is the child of the lower leg. In real time animation environment, each bone depends on the orientation and the joint with its parent (Wrotek, 2006). Generated motion has to be enforced with physical law of motion to create a realistic human character motion.

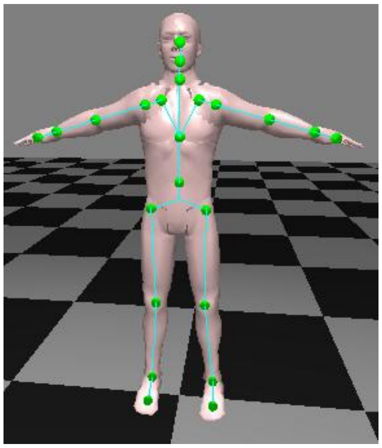

Figure 1. 3D character figure model with skeleton joints

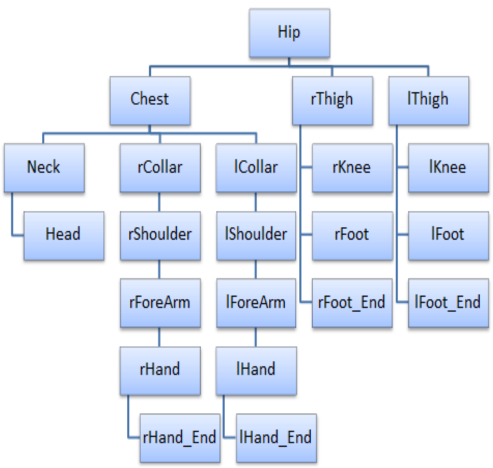

Figure 2. Animation character motion data hierarchy

Figure 3 shows a parent body and required translation to the child body for 3D character. After transforming the child body into a global space, the new position of the body is calculated. The parent body rotation matrix is defined as R_0 and parent body position as $\vec{p}_0$. When the parent body moves, automatically the child body transforms from local body space to the global space.

Meanwhile, the child body is defined as R_1 and $\vec{p}_1$. When the parent body moves, the joint position, J_0 and J_1 change to the same coordinate place. To transform a child body from a local space into global space:

$$\vec{j}'_n = R_n\vec{j}_n + \vec{p}_n, \ n=0,1 \qquad (1)$$

To get the vector $\vec{d}$, $\vec{j}_o$ and $\vec{j}_1$ are subtracted. The new body position $\vec{p}'_1$ is:

$$\vec{p}'_1 = \vec{p}_o + R_o\vec{j}_o - \vec{R}_1 j_1 \qquad (2)$$

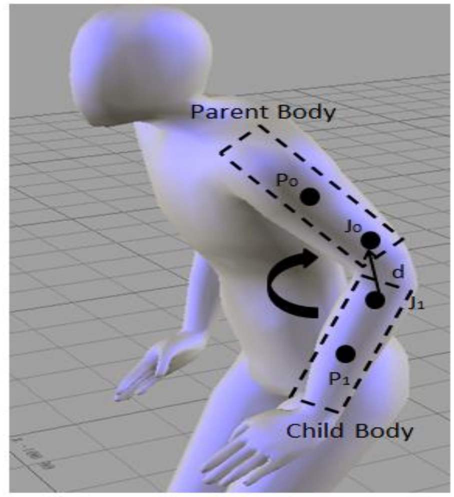

Figure 3. Animation character parent-child body relationship

The function of inverse kinematics and forward kinematics is to calculate the bone's position, including the joints' position and angles (Kim, 2005). Normally, inverse kinematics calculate the motions at the lower part of a character's body such as joints from the foot to the pelvis (Wrotek, 2006; Xiao, 2005; Kim, 2005; Basori, 2012). It is difficult to use forward kinematics because the body position will be moving below the surface or ground. This transaction makes the character's motion very unreal and unconvincing.

In the case of shoulder rotation, or to get the position of the upper arm, forward kinematics calculation is used by Kim (2005). Forward kinematics is a top-down technique rotation used to position the character's upper body part in real time animation. Each skeleton joint has its local transformation, and the parent transformation will determine the global transformation of each skeleton joint.

In summary, forward kinematics can control the rotation of a skeleton. Single joints and the children joints will follow automatically when the top level joints are rotated. On the other hand, inverse kinematics is useful when movement of a single object is needed to pose in the above direction of the skeleton hierarchy from the moving joint.

4. Motion Editing Techniques

Motion capture technology has been used in many areas, including computer game, character motion researches and movie making. By using motion capture devices, a researcher can manipulate and track full body motion of the character in the virtual world. The purpose of motion tracking is to get a sample of frames that can replace the motions of real human in the virtual environment. Motion tracking records the position of each joint of the human skeleton (Huang, 2009). With the motion capture data, natural character motions can be created in real time animation. Motion capture technologies are generally classified into active and passive sensor-based capture according to the nature of the sensor used (Choi, 1999). This sensor can mimic a real human movement, and the raw measurement data will be applied to the virtual character motion.

Editing and reuse of motion capture data have become a challenging task. An early framework introduced optimal trajectory method (Witkin, 1995) that had solved dynamic constraint problem. A famous methodology in producing a natural character motion in real time animation is the space time optimization framework (Popović, 1995; Safonova, 2004; Gleicher, 1998). This method is capable to edit or use motion capture data and keep physical properties at the same time. Although optimization in the framework keep the physical properties, constraints such as processing of the bones during the transformations and kinematics computing still appear. Recently, there have been many studies on motion capture data editing and retrieval. One of them utilized fuzzy inference to create a personalized animation of virtual character (Szczuko, 2009; Pedrycz, 2007). This method uses fuzzy rules to calculate motion capture data parameters. Algorithm for fuzzy rules is created from the results of subjective animated movement. New proportionality coefficients α and β was defined that are strongly correlated with subjective features of animation (Szczuko, 2009). A comparison of this approach is illustrated in Table 1.

Table 1. Comparison of 3d character motion data editing techniques

Techniques	Description
Physic-based motion editing	These techniques have involved combination between motion capture data and dynamic simulation (Popović, 1999; Abe, 2006; Liang, 2011) to develop character motion while interacting with virtual environment. The editing process uses correction of the momentum and balance constraints.
Interpolation-based motion editing	Straightforward interpolation of joint angles (Abe, 2006) and blend motion sequences with various inverse kinematic (Rose, 2002).
Momentum-based motion editing	This technique optimizes the algorithm from motion capture data to meet high-level user limitation (Abe, 2006) while protecting physical properties.
Interaction mesh	A new approach in editing motions that involve close interactions such as dancing, fighting and other motions (Ho, 2010).

To modify the same motion capture data, dimension of the data needed to be reduced using Principal Component Analysis (PCA), making a trained dictionary to get indexed motion data, and test the data using Support Vector Machine (SVM). This method can reduce the retrieval time of motion capture data (Choi, 2009). PCA can reduce the dimensions of motion capture data, which is compressing and matching the input parameter (Alexa, 2000). The outline of this method has two core parts: process of making dictionary and process of posing discrimination. From the input training data, the output training dictionary is processed with SVM to get the retrieval data. Motion tracking is the core part in character motion dynamic and control. Using motion data, a user can directly control and modify the character motion in real time animation.

5. Dynamic Motion Control

3D games character has a rigid body that has its own forces, velocity, mass and physical properties. Using dynamic engine application such as havoc physic, massive and open dynamic engine (ODE), the physical realistic of real time animation has been upgraded to another level. This application can solve dynamic calculation (Badler, 1999; Yamane, 2000), dynamic contact and friction for the rigid body dynamic.

Although physic properties can be applied to character motions in real time animation, it is still limited when it comes to rigid objects. Active dynamic control can be achieved from any athlete motion (Wrotek, 2006) for example, cycling, fighting, running and swimming. A feedback control system (Wrotek, 2006; Wang, 2010) is used to process motion capture data. Human motions can be generated using physical simulation such as a robotic-derived controller based approach and performance optimization based approach (Li, 2009). The structure of the dynamic motion control is shown in Figure 4.

Several researchers have focused on the study of dynamic character motion. The timelines of related researches about dynamic motion control is shown in Figure 5. Zordan et al. (2005) introduced a new method that allows characters to respond to unexpected changes in the environment based on the specific dynamic effects. The system generates a physics-based response and takes advantage of the realistic movement that is achieved by an actuated dynamic model of motion capture process.

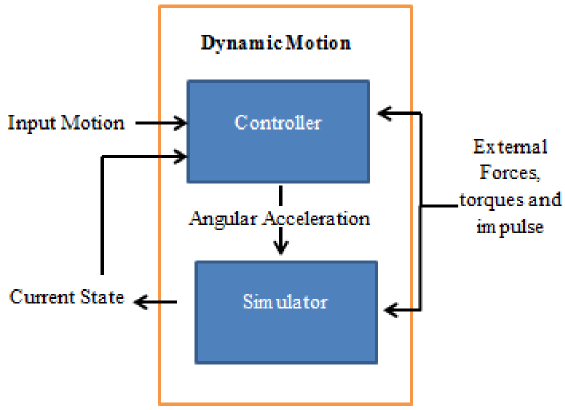

Figure 4. Dynamic motion controller and simulator structure

The dynamic character simulation responds to contact forces and determines the best plausible re-entry into motion library playback following the impact. To produce the results, a physically valid response will be created and the blending process will be generated into the desired transition-to motion. The dynamic motion controller will act in accordance with the upcoming motion. These techniques' main focus is to improve the character impact, but problems with responsive and interactive dynamic reaction for virtual human are still faced.

Shapiro et al. (2005) focused on the "DANCE" platform for the development of physically based controllers for articulated figures. The main aim of this platform is to train an inexperienced user to develop dynamic controllers. In 2007, the system has been improved by creating a toolkit for dynamic articulated characters controllers [33] under the physical simulation. The dynamic character controllers developed by using key-framed based control, reduced dimensionality physics, scripting controllers via a controller language, and interactive control of dynamic characters. However, this technique cannot perform a complete motion stage while interacting with the environment.

"Dynamo" is a technique that allows a character to set and maintain poses robust to dynamic interactions introduced by Wrotek et al. (2006). The system produces physically plausible transitions between motions without directly using a blending process. The main idea is to apply torques to match the desired world-space pose and maintain root orientation. After that, the motion blending emerges from continual simulation. The main weakness of this system is that it cannot collaborate with implausible situation such as displaying super-human abilities.

Abe (2006) worked on a control algorithm that generates realistic animations by incorporating motion data into task execution. The system's focus is on interactive animation of dynamic manipulation tasks such as lifting, catching, and throwing. This interactive system allows Cartesian space force limits. The method always provides new command vectors that produce manipulation. This control algorithm has problems with the loss of control over some degrees of freedom. The motion stage will not be completed without pre-planning of the torques of motion.

Allen ET AL. (2007) is another researcher who worked on virtual human dynamic motion controller. His approach focuses on timing constraints using a natural looking motion and allows a realistic response. However, the algorithm does not take into account subsequent effects for Parent-Childs concept using torques.

Muico et al. (2009) proposed a nonlinear control system using character contacts to emulate motion-capture data. The framework uses nonlinear controllers with a large set of different styles of possible motions. The drawback of this control system is it cannot recover from larger changes in the environment because that requires intentional deviation from pre computed reference trajectories.

Ye et al (2010) proposed a physics-based method that uses motion transitions in the character response stages. They explored automatic methods for clustering data into local models.

Sok et al. (2010) presented an integrated framework for interactive editing of the momentum and external forces in a motion capture sequence. They used trajectory optimization with constraint editor in their system. The technique is based on the concept called normalized dynamics and covered momentum profile for whole-body motion synthesis. However this research did not explore the correct balance between user controller and the maintenance of physical plausibility.

Recently, Kenwright et al. (2011) proposed a real-time modeling of 3D skeletal motion with balancing properties. They described an approach in modeling mid-to-lower body of 3D human movement in real-time. The dynamic motion in this research did not cover upper part of the body and human behavior interaction. Another latest research on 3D Character motion can be found in (Munirathinam, 2012). They concentrated on two strategies in dynamic motion control: nonlinear time scaling of joint trajectories and how to modify the joint angles directly.

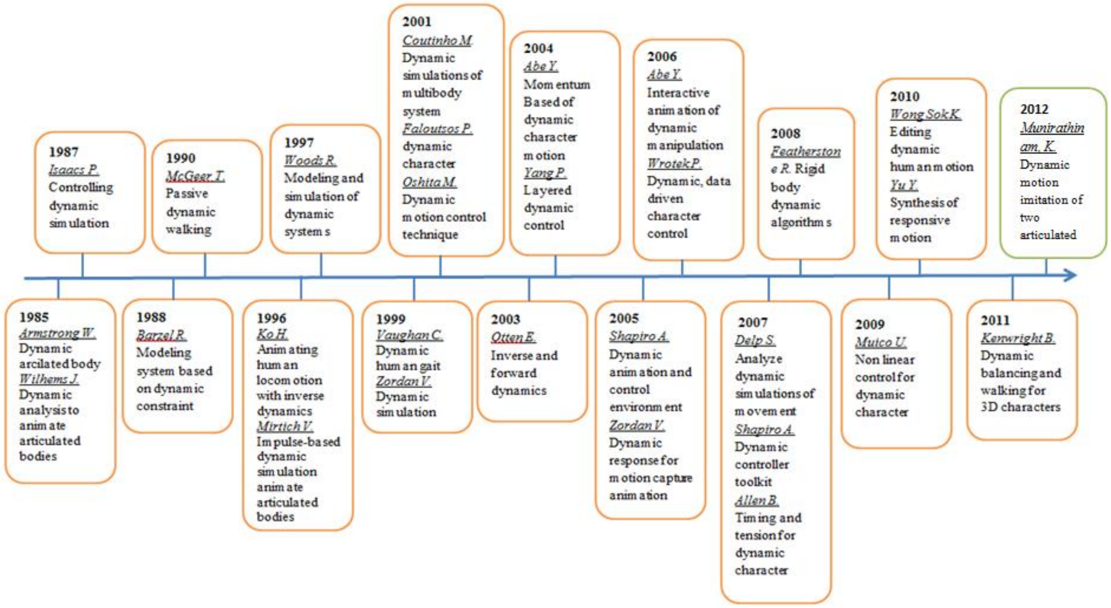

Figure 5. Research focus on dynamic 3D character motion area

6. Discussion

In general, dynamic motion control structure must have two core parts: controller and simulator. Using controller function, we can calculate the angular joint acceleration directly by referring to the latest state of the motion capture data input. After that, the simulators will update the process through dynamic character motion stage. The results input are based on combination of a human body model and external physical input for the controller and the simulator.

Several approaches have been developed for the purpose of character motion control based on dynamic interaction. One example is by using a muscle strength model for the inverse kinematics method. This method can calculate and change the motion speed and trajectory using the joints of skeleton. Another technique is by creating a motion using inverse kinematics method and then produces a human walking motion using inverse dynamic (Liu, 2002).

A recent survey for the dynamic motion generation and control revealed a new process of virtual character motion control based simulation. This structure combines the active control torque (Kenwright, 2011) and other external physical interaction. The output motions have been generated by the physical simulator. User needs to know how to control the basic dynamic simulation of character movement. The acceleration dynamic of body movements and the external forces actions can be categorized into two classes: maximal coordinate position and optimize parent-child joints trajectory. Several researches composed short sequence motion, so it is possible that it may not recognize correctly a more complicated motion pattern (Oshita, 2002) for games development and humanoid robot systems.

7. Conclusion and Future Work

This paper presents an overview on the main parts in dynamic 3D character motion in games. Evolution of dynamic motion algorithms for 3D character motion with timeline figures is discussed in detail. The main advantages and shortcomings of each technique are presented for future development in this area.

This review can help researchers to select the most suited algorithm to achieve the aim and objectives of 3D dynamic motion research. There are a variety of different techniques used to control 3D characters motion including the use of motion capture, dynamics and optimization. As described, there is no algorithm that can meet all dynamic motion requirements in every situation, and they cannot solve all the problems at once.

Nowadays, researchers are trying to find a perfect balance between motion control and sophisticated long sequence interaction. Researchers need to control large data sets and automatic methods for mapping the correct input data into local models. Multiple learned models and different control methods need to be explored for the purpose of getting a natural, balanced dynamic character motion while maintaining the character's physical properties

The future challenge for character motion in real time animation is to make the characters move automatically and be controlled like a real human. Meanwhile, the virtual human behavior interaction focusing on ages and gender can be extended to the next level in the future. The final purpose of the human animation is to simulate a virtual human behaving like a real human. Since character animation is essentially a very complex topic, the human behavior takes up the leading role. It would be better if the researcher could point out the relation between the behavior generation, and the dynamics simulation to get the initial research directions. The real human behavior and dynamic human interaction must be combined to get the believable and natural virtual human motion. Editing and modifying techniques for motion capture animation data need to be brought to the highest level to achieve realistic and convincing motions for virtual characters.

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