

# Realtime Control for Motion Creation of 3D Avatars

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**Abstract.** In this paper, we are proposing a new mechanism for controlling 3D (three dimensional) avatars to create user-designed peculiar motions of avatars in real-time using general interfaces, such as a mouse, a keyboard, or a joystick. The main idea is based on the new way of interactive control that is the combined usage of keyboard and mouse simultaneously. In order to generate natural human motions of avatars, we adopted the center line concept of art drawing and some influencing physics algorithms which developed intensively in the field of biped humanoid robot research. We demonstrate that user-designed motions of avatar can be created in real-time using proposed interaction method with keyboard and mouse. Also, we show that a rich set of peculiar behaviors can be generated from a ready-made motion with motion capture data or created and stored in our system. Note that the generated peculiar motions can be more natural if we appropriately apply our center line concept and physics algorithms.

**Keywords:** Human motion creation, 3D avatars, Real-time interactive control, Interface.

## 1 Introduction

As the virtual life closer resembles the real life, we tend to spend more time on the networked virtual world we call the Internet. In consequence, the desire to express ourselves using virtual avatars increases and development in this area is inevitable. In addition, the popularity of 3D (three dimensional) computer games with human characters has demonstrated that the real-time control of avatars is an important objective.

Real-time control of 3D avatars is important in the context of computer games and virtual environments. Two difficulties arise in animating and controlling avatars: designing a rich set of behaviors for the avatar, and giving the user control over those behaviors. Designing a set of behaviors for an avatar is difficult primarily due to real-time constraints. Providing the user with an intuitive interface to control the avatar's motion is difficult because the character's motion is highly dimensional and most of the available input devices are not.

Motions of avatars created by 3D authoring tools or motion capture devices allow only for playing the motions as they designed, and do not allow to be controlled in the middle of motions. We study the real-time motion controls of 3D avatars to overcome

this limitation. Like human bodies, an avatar can be made of the articulations of bones. Therefore, an avatar can move its body as human beings by controlling its articulations of bones.

We can model the structure of bones of an avatar and calculate the corresponding matrix values by modeling the hierarchy of articulations of human body. Diverse kinematics algorithms (such as forward kinematics and inverse kinematics) can be used to calculate the position of bones at given degrees of articulations. On the other hand, many of the ongoing studies on biped humanoid robots have been interested in the pattern generation and the walking control with the precise knowledge of robot dynamics including mass, center of gravity, and inertia of each link to prepare walking patterns. This research adopts the ZMP based approach [1], [2].

Recently, the methodologies for representing human being in 3D have developed a lot along with the popularity of computer games such as FPS (First Person Shooter) games. Many of the applications envisioned for avatars have involved interpersonal communication. As a result, much of the research has focused on the subtle aspects of the avatar's appearance and motion that are essential for communication: facial expressions, speech, eye gaze direction, and emotional expression. Also, many techniques concerning the motion capture and physics engines have been introduced for creating more natural human body movement. Because our focus is on applications in which whole body actions are required and subtle communication is not, we need to create an environment that allows the characters to move freely, and where the users can define the motions of these characters. Therefore, we are proposing an interactive control method for allowing users to create user-designed motion of 3D avatars, along with some appropriate interaction methods and interfaces. We will use common interfaces such as keyboards and joysticks to interact with an avatar. Eventually, we will study the development of a more comfortable control interface for interacting with an avatar.

The purpose of this study is to develop a system for creating natural human motions of avatars in allowing users to control the motion of 3D avatars in real-time using simple interactions. In this paper, we show that a rich set of peculiar behaviors can be created from extended real-time avatar control using a variety of input combinations from the keyboard and mouse. A unique aspect of our approach is that the original motion data and the interactively created motion data can be blended in real-time with respect to the physics algorithms concerning the human body movements.

The related work presented in the next section describes some of the animation techniques that have influenced our work. In the third section, some existing control systems are examined. Our ideas about human avatar control are then described in section four. These ideas lead to the new interactive control for peculiar motion editing described in section five, concluding our work.

## 2 Related Works

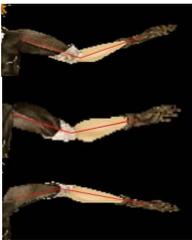
The behaviors required for animating virtual humans range from very subtle motions such as a slight smile to highly dynamic motions such as diving or running. Our focus is on applications in which whole body actions are required. Thus, we review only the

research related to whole body human motion. Animated human figures have been driven by key framed motion techniques, rule-based systems [3], control systems, dynamics [4], and of course, motion capture data. Motion capture data is the most common technique in commercial systems because many of the subtle details of human motion are naturally present in the data rather than having to be introduced via domain knowledge. Most research on handling motion capture data has focused on techniques for modifying and varying existing motions [5]. This need may be partially obviated by the growing availability of significant quantities of data.

However, adaptation techniques will still be required for interactive applications in which the required motions cannot be precisely or completely predicted in advance. A number of researchers have shared our goal of creating new motions for a controllable avatar from a set of examples. For simple behaviors like reaching and pointing the current set of motions may be adequate. This section presents some existing concepts already developed in the area of computer animation and influenced a lot our work: they are Kinematics, ZMP, and Skin Mesh.

## 2.1 Forward and Inverse Kinematics

Kinematics is the study of motion without regard to the forces that cause those motions. Forward kinematics is a method for finding the end-effector given the joint positions and angles. Inverse kinematics is a method for finding the original joint positions and angles of the robot arm given a goal position. Advantage of forward kinematics comes from its easiness for implementation. However, it is difficult to calculate the desired position of end-effector if it involves many joints. On the contrary, inverse kinematics is advantageous in the cases of many joints, because the calculation starts from the end-effector. The disadvantage of inverse kinematics is that the solution is often non-deterministic, even infinite or not existing. For example, as shown in Fig.1 we could obtain three different solutions and it is difficult to select an appropriate solution [6]. However, this problem can be resolved by restricting the degrees of joint rotations, as human joints cannot rotate 360 degrees. Note also that applying the Jacobian matrix is helpful to reduce the amount of calculations of inverse kinematics.



The elbow joint is rotated to the direction of X-axis

The elbow joint is rotated to the direction of Z-axis

The elbow joint is rotated to the direction of Y-axis

**Fig. 1.** Three different solutions of joint movements calculated using inverse kinematics

Kinematic control, either forward or inverse, has proven to be a powerful technique for the interactive positioning and the animation of complex articulated figures [7]. Until now, cooperation of both techniques has been widely studied in motion design.

## 2.2 ZMP

Extensive research has been done on the control of biped humanoid robots. Among these, the most influencing method is the ZMP proposed by Miomir Vukobratovich. The ZMP is the point on the ground where the tipping moment acting on the biped, due to gravity and inertia forces, equals zero. The tipping moment being defined as the term of the moment that is tangential to the supporting surface. ZMP is not a perfectly exact expression because the normal term of the moment generated by the inertia forces acting on the biped is not necessarily zero. If we bear in mind, however, that ZMP abridges the exact expression “zero tipping moment point,” then the term becomes perfectly acceptable. ZMP corresponds to the point of balance in a support polygon. For example, if a robot stands on one foot, the support polygon corresponds exactly to the shape of robot’s foot. ZMP is the dynamically changing center of gravity. The basis of robot walking is to control robot’s movement while keeping ZMP inside the support polygon.

## 2.3 Skin Mesh

Skinning is a popular method for doing deformations of characters and objects in many 3D games. Skinning is the process of binding a skeleton hierarchy to a single mesh object. This is done by assigning one or more influencing joints (ie: bones) to each vertex of the mesh, each with an associated weighting value. The weight value defines how much a specific bone influences the vertex in the deformation process. Skeletons in a 3D character animation have a direct correlation to a human skeleton: they consist of articulated joints and bones, and they can be used as a controlling mechanism to deform attached mesh data via "skinning". Skinning deformation is the process of deforming the mesh as the skeleton is animated or moved. As the skeleton of bones is moved or animated, a matrix association with the vertices of the mesh causes them to deform in a weighted manner.

The following formulas allows for calculating the world coordinate of a vertex that is influenced by two bones.

$$V_w = V_m \times M_1 \times w + V_m \times M_2 \times (1 - w)$$

$V_w$  = coordinate of a vertex in world coordinate

$V_m$  = coordinate of a vertex in local coordinate

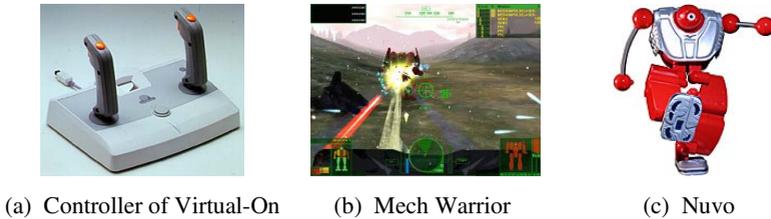
$M_i$  = transform matrix of  $i^{th}$  bones

$w$  = weight (the sum of weights is less than 1)

## 3 Control Interfaces

The objective of this study is to develop a system for creating natural human motions of avatars in allowing users to control the motion of 3D avatars in real-time using simple interactions. We would like to present some existing control systems relevant to our study and some general control interfaces in this section.

Control interfaces for user interactions are usually developed for unique uses in their own systems. Some control systems for interaction for games and Scientific Fiction simulation games are interesting to examine: they are the control system of a mechanic action game Virtual-On, that of Mech Warrior, and the controller of home-use walking robot Nuvo.



**Fig. 2.** Existing control systems relevant to our study

- Virtual-On

Sega developed CYBER TROOPERS: VIRTUAL-ON which is an action shooting game and is high-speed mobile battles in virtual 3-D world with gigantic robots (Virtuaroids). Its direct operations, its high quality and the stylish VR design are combined to give it a high reputation. Sega also developed a double stick controller for Virtual-On. This model allows users to command diverse operations using its 2 sticks rotating 8 directions and 4 buttons. This controller is a simple and intuitive interface with various operations. However, it does not provide the capability for detailed control of movement and equipping the interfacing device (controller) can be expensive.

- Mech Warrior

This is a robot simulation game developed by Microsoft which uses almost all keys of a keyboard to control mechanical robots. Every key is mapped to a specific action, such as key “c” which corresponds to the action “sit down” or “stand up”. The user interface of this system provides a variety of operations without any extra expense for equipping it. However, it is difficult to memorize the functions of all keys described in the manual of Mech Warrior.

- Nuvo

Creating a humanoid robot has been a recurring dream for mankind for quite some time and humanoid technologies are rapidly developing now. Robots are generally controlled remotely from PCs. Recently robots which can be controlled from PDAs and cellular phones. Nuvo developed by TOKYO – ZMP Inc., which stands 39cm tall and weighs 2.5kg, can stand up, walk, dance and perform other movements, responding to voice commands or signals from a remote control. The robot can also be operated remotely from a cellular phone. With this function, users can check their homes while they are out – viewing images captured by the robot’s built-in camera on their cell phones. Nuvo’s core technology was developed by ZMP (refer to Section 2.2).

## 4 Some Ideas About Human Avatar Control

Providing the user with an intuitive interface to control the avatar's motion is difficult because the character's motion is highly dimensional and most of the available input devices are not. The nature of human motions is characterized by intentional movements of body parts and the tendency for balancing the whole body. In this section, we would like to examine the nature of human motions in order to define how to control avatar's body for creating natural human motions.

### 4.1 Control Structure

Among the movements of the human body, the movement of the arms, the legs, the head, the rotation of the torso, and walking are the most important. If we could control these parts of a 3D avatar freely, then the avatar would be able to move freely in a virtual space. But how can the body parts of an avatar be controlled in this fashion? That's the question.

The arms and the legs each use 2 joints excluding the movements of the wrists and ankles. Thus, there are 4 pivots in the movements of arms and legs, and there is a limitation in the rotation angle around each pivot. In the control scheme of marionette dolls, the movement of the fingertips and the tiptoes can create the motion of a marionette without any consideration about the pivots of arms and legs. If we control just the fingertips and the tiptoes, we have 4 positions for control. These 4 positions are moving in 3D coordinates and are limited by the length of the arms and the legs, and the limited angles of the related joints.

The torso rotation is fixed by the vertebra. The vertebra consists of the cervical vertebra (7 units), the thoracic vertebra (12 units), and the lumbar vertebra (5 units). The cervical vertebra influences the movement of the neck. The thoracic vertebra influences the bending and straightening of the chest and the back. The lumbar vertebra influences the movement of the rotation of the whole torso. As far as we are concerned, we need not consider the cervical vertebra because it is related to the movement of the head. Thus, we have 2 pivots related to the movement of the torso.

Walking is influenced by the stride and pace, and the angle of the land surface. Users need not control the influence of the land surface's angle as this can be resolved by some interpolation methods proposed in several other studies. Therefore, the only parameters we must consider for the users control are the stride and the pace of walking.

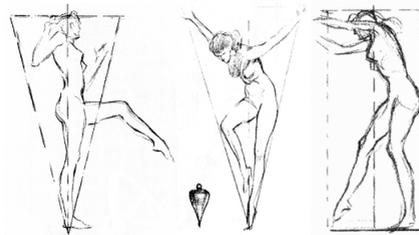
Consequently, we should consider the movements of head and shoulders. We exclude the control of the shoulders, because their rotation angle is quite small and their movements can be calculated from the movements of other related parts – such as the arms. Also, we must consider the diversity of walking patterns. This can be resolved by using the motion capture technique. However, motion capturing is not in the scope of this study and we do not discuss the walking patterns in this paper.

### 4.2 Balancing Structure

As we examined the control aspect in the previous section, let's turn to the balancing aspect. If the movement of human body is not balanced, motions are not natural.

Natural human motions can be obtained if human motions are balanced. The balanced state of human body is the state where the body weight is distributed equally. If a human body is inclined to one side, the hand or the foot stretches to the opposite side to balance its weight. If a human stands on one foot, the body weight is balanced as a top spins. In this case, the body status can be compared to an inverted triangle. If a human stands on two feet, the status can be compared to that of a rectangle.

It is certain that human motion looks more natural if the human body is distributed equally on the left part and the right part of the center line in the body polygon. Fig. 3 illustrates some examples of center lines which pass through the center of the body polygon (a triangle or a rectangle) of human motion [8]. The balancing mechanism of any human body follows the principles of mechanical movements of rigid objects [9].



**Fig. 3.** Center lines in human body movement

The weights of human body segments have been calculated through many studies and experiments [8]. Table 1 summarizes the mean weight of each body segment relative to the weight of whole body.

**Table 1.** Ratio of the weight of each Segment to the weight of whole body

Head and Trunk	Upper arm	Forearm and hand	Thigh	Calves and foot
55.9%	5.80%	4.60%	21.5%	12.2%
	(2.90% each)	(2.30% each)	(0.72% each)	(6.1% each)

The center of gravity in the human body, denoted by  $M$  can be calculated using the following equation, where each  $W_i$  denotes the ratio of the weight of each segment to the weight of the whole body and each of  $x_i$ ,  $y_i$ , and  $z_i$  denotes the coordinates of its position on the x-axis, y-axis, and z-axis respectively:

$$M(x, y, z) = \frac{W_1(x_1, y_1, z_1) + W_2(x_2, y_2, z_2) + \dots + W_9(x_9, y_9, z_9)}{W_1 + W_2 + \dots + W_9}$$

If there are some supporting points on the ground surface, we can draw a geometrical figure (a triangle, a rectangle, or a polyhedron) by connecting the supporting points on the ground surface and extending the supporting polygon until the top of the head. We can estimate that the avatar is balanced if its center of gravity exists within the geometrical figure.

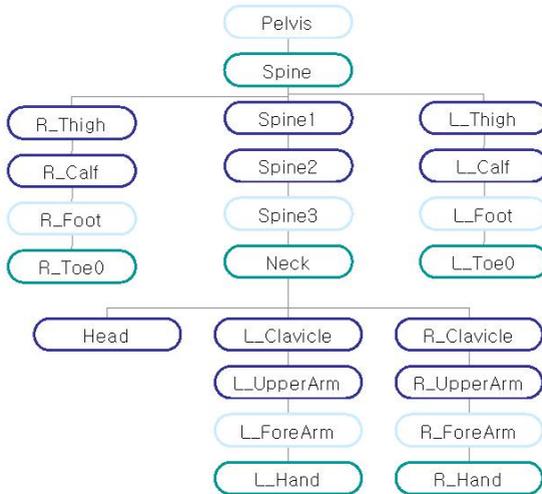
## 5 Suggestion of a New Interactive Control

The Avatar of our system is actively in pursuit of mimicking human motions as similarly as possible; therefore our avatar's bones and joints should resemble that of human. The relationship between the representation of the avatar's bones and the kinematics are discussed in this section.

### 5.1 Skeleton Hierarchy and Kinematics

As shown in Fig. 4, A good skeleton building technique is to place the pelvis at the root, make the abdomen (corresponds to the pelvis) and thighs children of the pelvis, then make the torso a child of the abdomen, then make the biceps and neck children of the torso, and so on.

When adding bones, you are defining the hierarchy (called a skeleton), indicating which connections should be kinematics chains, and specifying the local space of each bone. Before adding a bone, you first select its parent (if no bone is selected, the new bone is added at the root). The skeleton can be adjusted later by using drag drop in the Project Workspace tree. A parent bone passes its translation, rotation, and scale on to its children.



**Fig. 4.** Skeleton hierarchy of human body

For inverse kinematics, add nulls at the root of the hierarchy for use with hand and feet constraints. The nulls can have a hierarchy of their own to ease in moving them together. For example, you can have a null that is the parent of all nulls, one that is the parent of the lower body nulls, the left leg nulls, etc. Reordering the bones in the Project Workspace tree with drag and drop can easily modify the skeleton. Rearranging the skeleton also changes the inverse kinematics.

The orientation of a bone defines its local frame of reference. Along the length of the bone defines the local Z-axis; the roll handle is the bone's local Y-axis, and the local X-axis is perpendicular to both the bone and the roll handle. This is the coordinate system that scale, rotate, and translate uses when animating. Two models that are to share actions require the bones to have the same names and same basic hierarchical relationship. In addition, the bones and the roll handles should be placed into the model in the same way. If the roll handle points to the back on one model, then it should point the same way on the other model. However, if one character is modeled with its arms out and another with its arms down, then the actions can still be shared.

Kinematics, either forward or inverse, can be applied to calculate the position of bones given the joint positions and angles in this skeleton hierarchy. Now, we should decide which kinematics will be used to create motions. In the case of walking motion, as the foot is an end-effector, the inverse kinematics is desirable for calculating the joints from the foot to the pelvis. If forward kinematics is used, it could be complicated to create movement sequentially from the pelvis to the foot, and the foot may position below or above the earth surface. Therefore, time-wasting adjustment of foot positions may occur. However, if we calculate the positions of the upper arm or the fore arm according to the rotation of the pelvis or the shoulder, then forward kinematics is more advantageous than inverse kinematics. The selection of the more efficient kinematics control depends on the situation and it requires the appropriate and well-timed decision. In summary, it is recommended that inverse kinematics be used for calculating joint positions in the upward direction of the pelvis of the skeleton hierarchy from the moving joint, while the forward kinematics is useful for calculating joint positions in the downward direction to the joint from the pelvis [10].

## 5.2 Control Interface

Nowadays, the user interfaces are wide-ranging from keyboards, mouse, and joysticks, to human iris, human eye movements, human brain waves, etc. However, we would like to focus on only the very common general interfacing devices, such as keyboards, mouse, joysticks, etc. We adopt the keyboard and mouse as the user interface for commanding our 3D avatar into action. The combined usage of keyboard and mouse can provide a rich set of control commands. However, it is also necessary for user to provide an easy way of simultaneous usage of keys and mouse.

In addition, human body acts and reacts in order to put his or her center of gravity at the position where the body can balance itself [11]. The position corresponds to the ZMP; Zero Moment Position. Therefore, we can consider a 3D avatar as a sort of rigid body with mass which always tries to balance itself with respect to gravity [10]. Supposing a 3D avatar is a rigid body, we propose two control mechanisms: there is one method using only the keyboard, and another method using both the keyboard and mouse.

- Method 1: Using keyboard only (like marionette)

This control method originates from the way of controlling marionette dolls. Each of 5 direction keys corresponds to the left hand, the right hand, the left leg, the right leg, and the head, respectively. The left-shift key gives effect to lower the string, and the release of left-shift key gives effect to lift up the string upward. Each of W, A, S, D

keys gives effect to move to the 4 directions: left, right, up, down. Once, one of the W, A, S, D keys is activated, the string movement is deactivated. Table 1 illustrates the key allocations and the operations of combined usage of keys. Those keys in the table 1 can be used in multiple and simultaneously. This control method is intuitive and advantageous because avatar motions can be created using simple key controls and multiple parts of avatar body can be manipulated at the same time. However, very subtle delicate motions may not be controlled with this marionette method.

**Table 2.** Key allocation table for method 1: Using keyboard only (like marionette)

	Num 1	Num 3	Num 4	Num 6
None	Raise the left foot	Raise the right foot	Raise the left hand	Raise the right hand
+ Left-Shift	Put down the left foot	Put down the right foot	Put down the left hand	Put down the right hand

	Num 1	Num 3	Num 4	Num 6	Num 5
W	Put up the left foot	Put up the right foot	Put up left hand	Put up the right foot	Put up the head
S	Put down the left foot	Put down the right foot	Put down the left hand	Put down the right foot	Put down the left foot
A	Put left the left foot	Put left the right foot	Put left the left hand	Put left the right hand	Put left the head
D	Put right the left foot	Put right the right foot	Put right the left hand	Put right the right hand	Put right the head

- Method 2: Using keyboard and mouse simultaneously

The Second method needs both of keyboard and mouse. Main control is performed by the mouse and the keyboard is used in assistance. Mouse resembles the joysticks is a device which has 2 sticks and 1~6 buttons. The reason why we choose mouse as interface is that the speed of movement is more controllable than joysticks. Mouse takes charge of the rotations of screens, the rotation of characters, and the rotations of joints. The Microsoft mouse has 2 buttons and a wheel and it is sufficient to be used in our second control method. This control method is advantageous as it allows user to control the speed of movement with mouse. However, it still remains the problem of making natural movements because it still uses the 2-dimensional control for movement of 3D avatars. Fig.5 illustrates some examples of new motions created by using method 2.

**Table 3.** Key allocation table for method 2: Using keyboard and mouse

	Mouse left button	Mouse right button	A	S	Z	X
+ Mouse	Camera translation	Character rotation	Left hand translation	Right hand translation	Left foot translation	Right foot translation

D	G	R	F
Walking to the left	Walking to the right	Walking Forward	Walking Backward



**Fig. 5.** Examples of new motion creation: kicking and saluting

## 6 Conclusion

For allowing users to express freely their intention and emotion through an avatar in diverse immersive virtual environments, we proposed a new interaction mechanism for controlling 3D avatars.

Many current studies on the motion creation are biased to the retreating of motion capture data for generating more natural human motions. Working on motion capture data should confront the limitation of the diversity of motions, because we could not capture all kind of human motions with the limited equipments and manpower. In order to overcome this limitation, we developed a prototype system that allows users to create new motions not existing before, using a general and intuitive control mechanism. Our prototype system corresponds to an interactive real-time editor of 3D avatar's motion and it demonstrates an extensible real-time motion creation of 3D avatars. Some experiments using our system lead us to conclude that our method can provide the capability of repeatedly creating some new human actions by editing concurrently the playing animation. The playing animation can be a ready-made motion generated from motion captures databases or created and stored in our system.

Our study will contribute a method of creating diverse services using avatars, which can act like human beings without any limitation of motion. Some simulation tools for motion of human bodies can also be developed based on our study. Some new genres of games can be explored from our study. The results of our study can be integrated into any existing 3D avatar services such as online games and avatar chatting for expressing their action and emotion freely. Existing game engines or rendering engines can include the result of our study for allowing their avatars to move as users interactions controls.

Note that the generated peculiar motions can be more natural if we appropriately apply the center line concept and physics algorithms. In the future, we will investigate the optimized algorithms for applying the center line concept physics algorithms for making generated motions more natural.

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