PARAMETRIC REPRESENTATION OF BASIC HUMAN LOCOMOTION

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1. Introduction

In this chapter, we propose a method for parametric synthesis of human walking. While human locomotion is generally extremely complex and hard to model abstractly, the use of kinesiology studies and machine vision techniques can assist in inferring a set of parameters, with the aid of which a wide variety of walk patterns can be reproduced. This set of parameters consists of the posture of the body at characteristic instances and the angle between specific body parts. By altering one or more of these parameters we succeed in animating several different walk cycles a 3D model, that differ from the original generic sequence ; thus, we can induce the notion of behavior or mood and reproduce them in a virtual world.

2. The Skeleton Model

At first, we model a skeleton mesh which consists of a hierarchical structure of rotational joints. The number of joints in the model and the degrees of freedom depend largely on the desired quality and complexity. In our approach, we employ a relatively simple model which consists of 21 objects, which are hierarchically defined in figure 1. Each object represents a part of the human anatomy. Similar models have been used in previous work on human body animation [1,2] and have been proved effective in describing human body locomotion, since they are based on biomechanical data [3].

As shown in figure 1, the pelvis object is the base of our hierarchical model. We use this kind of structure, because movements that occur in the pelvis, are transferred to all other parts of the human body [4]. Each joint, except the knee and elbow joints, which have only one degree of freedom, has three degrees of freedom for rotation around the *x*, *y* and *z* axes of the local coordinate system. The *z* axis of the local coordinate system is assumed to be oriented along the "bone" of the joint, that is, the segment which is lower in the hierarchical chain and is actually the rotating part of the joint. For each joint, we set several rotational limits [3], so that the model resembles an actual human skeleton.

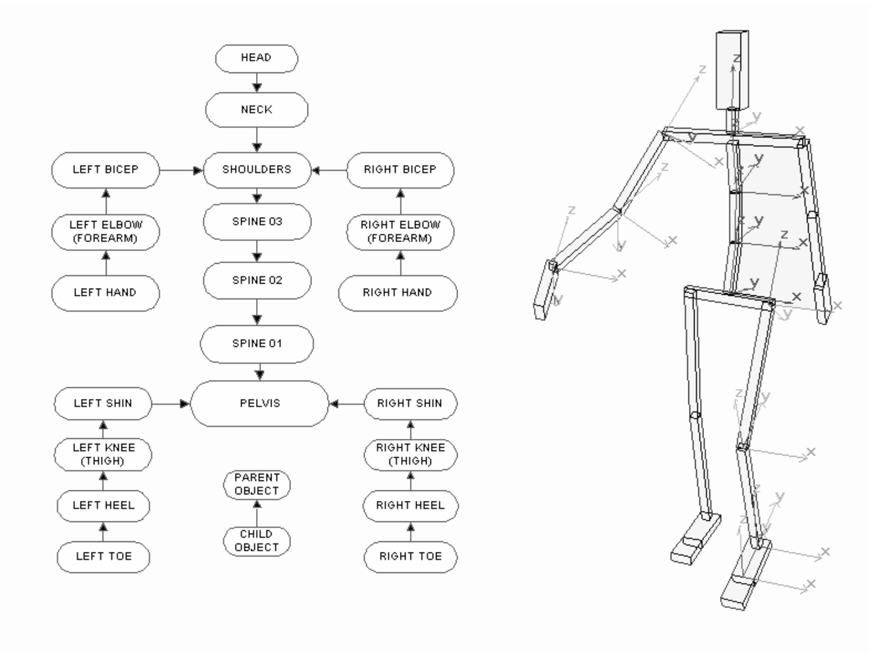


Figure 1 : the hierarchical jointed model

3. Analysis of walking

Kinesiology studies [4] show that during the human walk, the movement of the human body basically occurs at the pelvis and the legs. The rest of the body either follows (e.g. the torso) or compensates (e.g. the arms) for the movements of the pelvis and the legs, in order to preserve balance. Therefore a walking motion is defined by the rotation pattern at the pelvis (pelvis object in our model) and that of the hips, knee, angle and toes (shin, thigh, heel and toe objects in our model). When the pelvis rotates, the legs (thigh objects) rotate in the opposite direction, in order to maintain their straightforward orientation.

These studies also indicate that walking is a repetitive, periodic movement. In other words, both legs go through the same motions periodically during a walk. Scientists divide each walk cycle in two basic periods for each leg: the support period, in which the respective leg is on the ground, and the airborne period, in which the leg is airborne. The support period covers normally about 60% of the walk cycle, while the airborne phase covers the remaining 40%.

The same studies indicate that, during a walk, each leg joint moves independently, as a result of distinct fundamental rotations along three joints; which are hip, knee and ankle flexion and extension. These motions correspond to rotation around the local *x* axis of the shin, thigh and heel objects of our jointed model; the toes are transformed likewise, due to the fact that the walk consists of steps against a rigid surface and thus the relevant objects rotate against it, in order to preserve their horizontal positioning. In addition to that, the human pelvis rotates in a way that corresponds to rotation of the pelvis object around the local *z* and *y* axis of the skeleton model.

The rotation at the hips, knees and heels during a normal walk cycle, beginning and ending with the right leg touching the ground (beginning of the support period) is shown in figures 1, 2 and 3, while the *z* and *y* rotation of the hips object during the same period is shown in figure 4. The actual values that describe these curves depend highly on the analogies of the skeleton or body that is animated. In our approach, we concentrate on the positions of the extrema during the walk cycle and not their actual values.

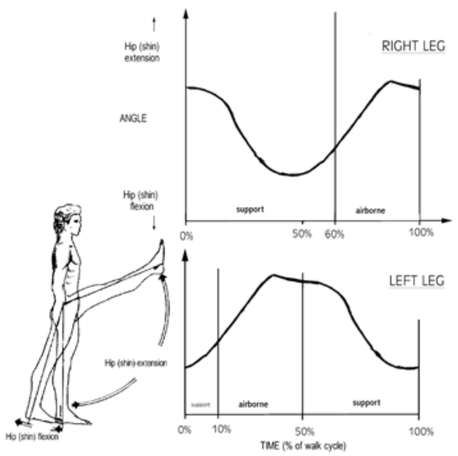


Figure 2 : hip rotation

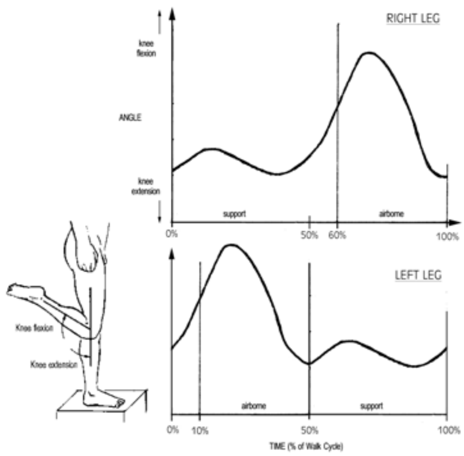
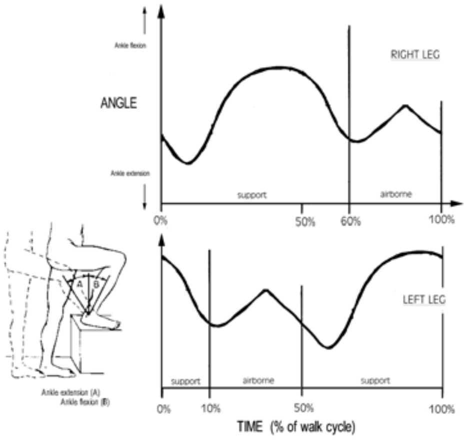


Figure 3 : knee rotation



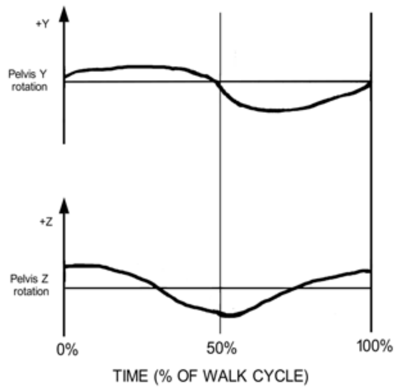


Figure 4 : ankle rotation **Figure 5 : pelvis rotation**

Further analysis of these curves indicates that the second half of a cycle can be described as a time delayed copy of the first half for the shin, thigh and heel objects and a mirror of the first half for the pelvis object. This means that in the second half, the rotation of the left leg follows the same curve with the one that the right leg followed in the first half, and vice versa. Therefore, a normal walking motion can be defined by observing and analyzing only the first half of a walk cycle. Furthermore, we have observed that the maximum and minimum values of all three curves for both legs can be detected, within a certain minimal threshold, in four distinct characteristic instances. These instances occur at certain percentages of the total walk cycle and the stance of the body at these instances can be defined by a set of global or local extrema.

Those four instances [5] are named as follows : extended position (0% of the walk cycle that begins with the support phase), recoil position (12%), passing position (25%) and the anticipation phase (37% of the walk cycle). Figure 5 shows which angles of either the support or the airborne leg obtain their maximum or minimum values during each phase.

The characteristics of the four phases described above can be detected in a video sequence, using several machine vision techniques. The next step consists of inferring a set of parameters from the results of these techniques, with the use of which we can parametrically reproduce a human walk on a 3D jointed model.

Similar characteristic phases can be detected in a variety of human motions, such as running. We can use this abstraction in order to discriminate between two different kinds of motions, because the set of instances and postures detected during a walk cycle is exclusive to it. For example, we can observe that during a running motion, there is a characteristic instance where both feet are off the ground; such an instance does not exist within a walk cycle and can therefore be used to set these cycles apart.

				SUPPORT LEG				AIRBORNE LEG			
	HIPS ROTATION			X ROTATION							
	X	Y	Z	SHIN	KNEE	HEEL	TOE	SHIN	KNEE	HEEL	TOE
EXTENDED POSITION (0% of walk cycle)	0	0	MAX		MIN		0	MAX			MIN
RECOIL POSITION (12% of walk cycle)	0				Local MAX	Local MAX	0			MAX	0
PASSING POSITION (25% of walk cycle)	0	MAX	0		Local MIN		0		MAX		0
ANTICIPATION PHASE (37% of walk cycle)	0					MIN		MIN		Local MIN	0

Figure 5 : definition of the four characteristic instances during a walk cycle

3. Simulation - Motion Synthesis

Based on the preceding analysis, we can deduce that a complex motion such as walking, can be parametrically described using the rotation of the joints and the values of the local and global extrema, which define the four characteristic phases. In order to reproduce a normal walk, we use those phases as keyframes, while employing a simple linear interpolation scheme to calculate the inbetween frames.

Control of the model is achieved by using forward kinematics (FK) for the legs and spine objects, while inverse kinematics (IK) is used for the arms. Since we are interested in animating a walk cycle with the use of postures defined by rotation extrema, we employ FK which permits direct angle designation at the relevant leg joints. Unlike that of the legs, the behavior of the arm joints cannot be similarly modeled during a walk. For that reason we use IK as an "attachable engine" [6] for the part of the hierarchy that begins at the hands and ends at the shoulders. This means that we can explicitly specify the position of the hand (end effector), while the appropriate values for all arm joints are computed automatically.

The walk cycle of our model is completed in 32 frames and takes place on a determined ground level, considered to be a rigid surface. As a result of the duration of the cycle, the extended position appears in frame 0, the recoil position in frame 4, the passing position in frame 8 and the anticipation phase in frame 12. Mirrors or copies of the parameters that define these keyframes are also used to define the remaining ones during the second half of the walk cycle, completing the periodic sequence.

The model posture in each keyframe is defined according to the following sequence :

- We first adjust the pelvis object rotations, while rotating the thighs in the opposite direction, in order to maintain their straightforward orientation.
- The keyframes are created by adjusting the thigh, knee, ankle and toe rotation, while maintaining the positions of the extrema for each rotation. The toe object is rotated during the anticipation phase and the extended position (rear leg), in order to maintain its horizontal orientation against the rigid ground level.
- In the next step, the vertical position of the pelvis in each phase is adjusted in a way that guarantees that the feet objects are not under the ground level. That is easily achieved because of the hierarchical structure of the model : if we calculate the vertical position of the heel, or the toe in the anticipation phase, and raise the pelvis in the opposite direction, the rest of the body (and the feet) follows and is finally positioned above the ground level.
- Finally, the horizontal position of the pelvis is adjusted so that the feet do not slip. We first measure the translation of the back of the heel object between the extended and passing position keyframes, and that of the toe object until the beginning of the second half. Then, we move the pelvis object accordingly, so that these objects do not move while the respective leg is in its support phase.

The resulting motion sequence indicates that realistic motion can be produced using only four keyframes and employing the simplest method of interpolation. The rotation of the model's joints during the animated walk cycle is shown in figures 6 through 10.

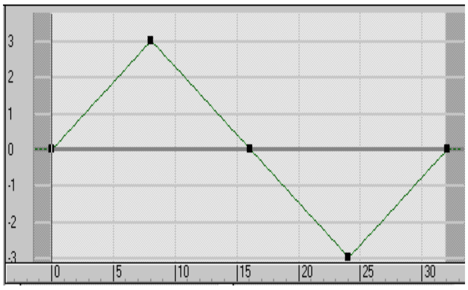


Figure 6 : pelvis *y* rotation

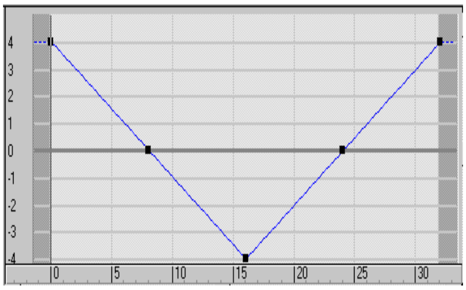


Figure 7 : pelvis *z* rotation

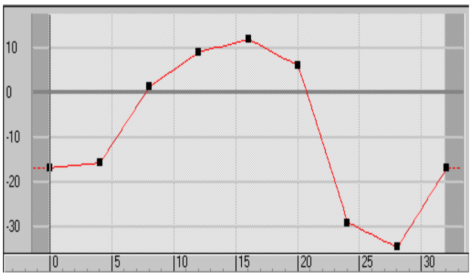


Figure 8 : shin *x* rotation

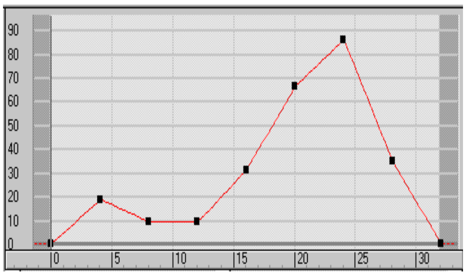


Figure 9 : thigh *x* rotation

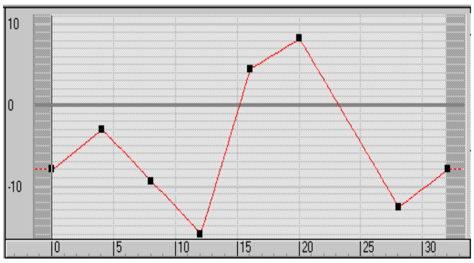


Figure 9 : heel *x* rotation

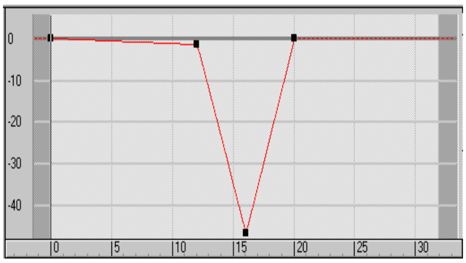


Figure 10 : toes *x* rotation

Figure 11 shows the four keyframed positions that make up the first half of the walk cycle.

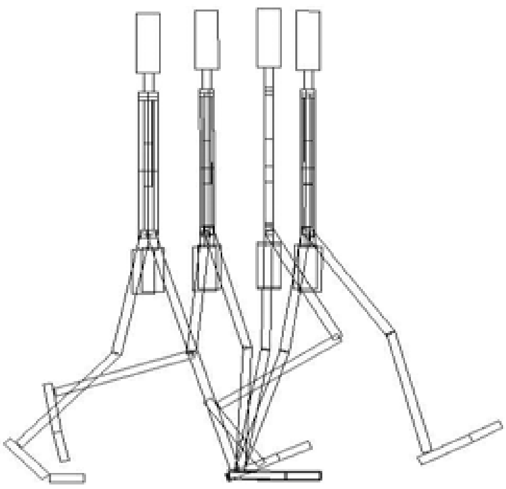


Figure 11 : the four keyframes (frames 0, 4, 8 and 12)

4. Motion Generation

By altering the values of the joints of the model in the four phases we can produce a variety of walk cycles, which differentiate from what can be described as a "normal" walk. This sequence was created by posing the model in the four keyframes described in section 3; the actual values that define the keyframes of the normal walk depend on the proportions of the model's joints. By altering the values of the extrema, while maintaining the shape of the rotation curves shown in figures 6-10, we have animated a cycle that can be identified as a "tired" walk.

In order to animate a different sequence, we follow the four steps presented in section 3. During this process, steps three and four are repeated every time a parameter changes; this process can be automated, ensuring the animator that the heels and toes of the skeleton model will never be below the ground level.

The changes made to the parameters in each phase must obey the following rules:

- If a parameter concerning the support leg is altered, then the angles in all other joints of this leg must also be altered, so that both the heel or the toe remain horizontal. Since the vertical position of the relevant objects is always calculated at the end of the process, we do not need to pay special attention to this. This alteration means that the sum of the angles in the shin and thigh objects must be equal to the angle in the heel joints, with respect to their magnitudes. In the anticipation phase, the angle between the shin, thigh and heel objects must be equal to that of the toe, in order to maintain their horizontal orientation; the same rule is applied to the rear leg during the extended position.
- The positions of the local and global extrema in time must be maintained, so that the resulting motion is consistent with the general qualitative shape of the rotation curves.
- If the angle of the airborne leg is adjusted, the changes are limited - with respect to the magnitude of the angle - by the rotational limits of the joints, set for the hierarchical model or the horizontal level of the support leg.
- Changes in the keyframe that defines the extended position are usually limited to the length of the stride. This is because in this position both legs are in their support phase and they also have to be on the same horizontal level. Altering the value of any other parameter would result to a posture with the heel of one leg being below the ground level and therefore being inconsistent with the keyframe. Changes of the

stride length are also reflected to the speed of the walk, because the positions of the keyframes within the cycle are constant.

The keyframes that define the "bored" walk cycle are shown in figure 12.

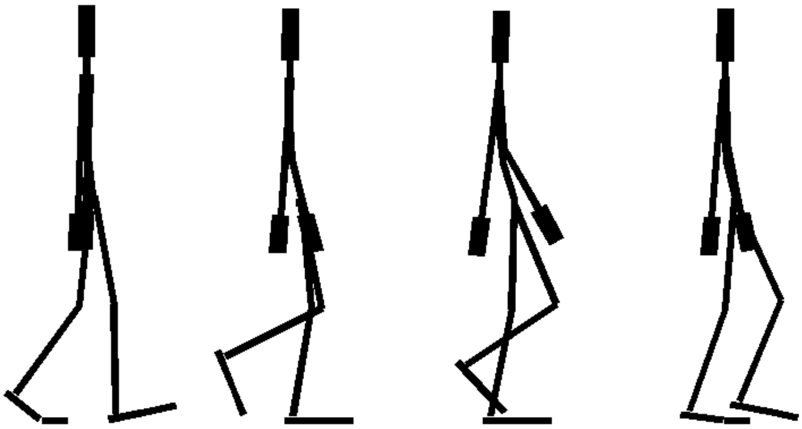


Figure 12 : the four keyframes of the "bored" walk cycle

5. Conclusions

In this chapter we proposed an systematic approach to human locomotion parameterization and reproduction. Even though walking is a complex motion, as it is a result of superimposing translations and rotations of jointed objects, these transformations can be abstractly described with a small set of keyframed stances. Changing the values that define these stances, within certain thresholds, results in walking patterns that induce the notions of emotion or mood for the model. Thus, we can use this system to recreate the mood of the user in a virtual environment by appropriately adapting the relevant actor's walk cycle. Inversely, we can map different walk cycles to relevant moods or emotions and use them to detect the frame of mind of a person with real time feedback. Because the values that define each keyframe and, as a result, each walk cycle, heavily depend on the proportions of the model or human in question, we can also use the concept of fuzzy operations while attempting to recreate or parameterize the object's walk pattern.

6. References

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