INTEGRATING AGE ATTRIBUTES TO VIRTUAL HUMAN LOCOMOTION

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ABSTRACT:

Computer animation of human locomotion has become popular in recent years because of the desire to use human beings as synthetic actors in three-dimensional simulation environments. However, it has always been a challenging problem in computer animation since techniques based on kinematics, dynamics, biomechanics, robotics, … may be required to produce a realistic human motion. Various control mechanisms to implement such human locomotion systems have been proposed, but most of them are only suitable for animation of adult locomotion, not for that of the elderly. In this paper, we present a model for simulating locomotion depending on age. Observations from biomechanics, gerontology about age-related changes in gait pattern, kinematics and kinetic values are integrated into the model in order to produce realistic ageing locomotion. The proposed model modulates a kinematic walking pattern as a function of the normalized velocity. The preliminary results have showed that they are realistic and able to be used in simulations of crowds or virtual human behaviours in virtual environment applications.

1. INTRODUCTION

Computer animation of human locomotion has become popular in recent years because of the desire to use human beings as synthetic actors in three-dimensional simulation environments. However, it has always been a challenging problem in computer animation since techniques based on kinematics, dynamics, biomechanics, robotics, … may be required to produce a realistic human motion.

A useful human locomotion animation system should be able to model various motions that range from straight line, curved path walking to different terrain adapting. It should also be able to be flexible enough to allow integrated personalities such as adult and elderly people.

Researchers have proposed various control mechanism to implement such systems. However, most current systems are only suitable for animation of adult locomotion, not for that of the elderly. In this paper, we present a model for simulating locomotion depending on age. Observations from biomechanics, gerontology about age-related changes in gait pattern, kinematics and kinetic values are integrated into the model in order to produce realistic ageing locomotion. The proposed model modulates a kinematic walking pattern as a function of the normalized velocity. The preliminary results have showed that they are realistic and able to be used in simulations of crowds or virtual human behaviours in virtual environment applications. Its results may be very useful for simulation of crowds and virtual human behaviors that is being used widely in virtual reality applications.

This document is organized as follows: the next section introduces related research work, then an overview of human gait with major parameters of human locomotion and requirements as well as the suitable approach for implementation of a human locomotion system. Observations of elderly gait are described in section 3 with studies about age-related changes in gait pattern, kinematics and kinetic values. Section 4 introduces the proposed model that is used for a simulating elderly walking. Finally, a discussion on the potential of the walking pattern modulation technique concludes the article.

2. RELATED WORK

In order to animate human motions, an articulated figure structure that consists of a series of rigid links connected by rotary joints with one, two or three degrees of freedom (DOF) is used. In physically based animations, physical attributes such as shape, mass, center of mass, moment of inertia is collected from the experimental data and computed based on graphical models [Hodgins J.K. et al, 1995].

Animation techniques could be separated into 3 categories: kinematic animation, physically based animation and motion data based animation [Multon F. et al, 1999]. Kinematic animation only deals with the geometry of motion while physically based animation uses the Newton's laws of motion to simulate. Motion data based animation uses motion data from existing motions to blend or edit so that new motions are produced.

The best-known kinematic animation technique is keyframing. To generating a motion, animators have to specify explicit definition of the key values of the character's DOF at specific time instants, namely "key frames". Then a piecewise cubic spline such as Hermite or Catmull-Rom spline is used to interpolate the values of DOFs so that in-between frames are generated. Keyframing provides a surprisingly realistic walking pattern when coupled with appropriate normalization and expressed as a function of the normalized linear speed [Boulic R. et al, 1990]. Such a procedural walking model can be associated to simple step length correction techniques to minimize the sliding effect appearing for virtual characters with a wider range of limb proportions than human beings [Boulic R., 2003]. More sophisticated approaches aim at enforcing strict foot constraints with Inverse Kinematics at the risk of losing the natural dynamics of the walking pattern (the well-known “magnetic shoes syndrome”). Within that frame of mind a recent successful method was proposed by Sun but it is unclear whether it can solve the case of continuously varying velocity in real-time [Sun01].

In the dynamic approach, the human body is regarded as a linked structure of rigid bodies having shape, mass, moment of inertia … Newton-Euler or Lagrangian mechanics is usually used to formulate the dynamics of the model.

It is different from simulation of passive objects responding merely to gravity, friction, and collision forces, simulation of such active objects as human body is much more difficult because human motion is controlled by internal torques applied at the joints. The main problem here is how to specify forces and torques, which actually move the human figure in a way, which the animator might desire.

There are two approaches proposed: using dynamics as constraints to guarantee certain realism to a predefined motion and directly synthesizing the motion. In the former approach, motion is first computed by a standard kinematic model. A post-processing stage then checks the physical relevance of the motion [Lee P. et al, 1990] [Ko H., Badler N., 1996]. The latter approach can be divided into two classes. The first poses the problem in terms of a trajectory through state-space and time, which is subject to the constraints of physics and the constraints of the desired motion [Witkin A., Kass M., 1988]. The second approach involves creating a controller, which produces motion by directly supplying actuating forces, and torques to a mechanical simulation [Hodgins J.K. et al, 1995] [Van de Panne M. et al, 1994] [Laszlo J.F. et al, 1997].

Another animation technique is motion capture, in which magnetic or vision-based sensors record the actions of a performer in three dimensions. A computer then uses these data to animate a character. Motion capture is growing in popularity because of the relative ease with which many human actions can be recorded; however, a number of problems prevent it from being an ideal solution for all applications. Firstly, accurately measuring the motion of the human body is tricky because markers placed on skin and clothing shift as the performer moves, creating errors in the data. Secondly, discrepancies between the shapes or dimensions of the subject and the graphical character can lead to problems. Finally, the current technology makes it difficult to record certain movements with large displacements. Magnetic systems also produce noisy data when metal objects or equipment such as treadmills are used to capture the motion of the subject. Optical systems have problems with occlusion caused by one body part blocking another from view. In spite of these drawbacks, much of the motion in commercial animation is generated by modifying captured data to match the size and desired behavior of a virtual character.

Recent work attempts to address the reusability of captured motions by modifying them in order to create a variety of specific animations that may take the synthetic environment into account. They are motion blending [Sun H., Metaxas M., 2001] and motion adapting [Gleicher M., 1998] [Monzani J.-S. et al, 2000]. Motion blending uses a database of captured motions and interpolation techniques in order to generate new motions. For example, to make a virtual human walk in a more or less tired fashion, it is possible to interpolate between a normal and a tired gait. The latter method is to edit existing motions. Recently a number of such methods have been proposed. These methods introduce constraints that the transformed motion needs to enforce and then transform the motion parameters so that all constraints are satisfied while trying to be as close to the original motion as possible.

3. ELDERLY GAIT

3.1 An overview of human gait

Basically, all normal people walk in the same way. According to observations from human gait , the differences in gait between one person to another occur mainly in movements in coronal and transverse planes. Throughout the whole body, joint movements taking place in the sagittal plane are similar between individuals, and if the upper limbs are neglected, they actually demonstrate a stereotyped pattern of mutual movement in phase with the lower limbs. The above observations lead most design of human walking system to focus more on lower limb joint movements, especially in the sagittal plane, and leave the rest of the body joints to the animator for desired movements.

For the purpose of computer simulation, the analysis of human gait is broken down to temporal and spatial components. The former relates to the period of time during which events take place, and the latter refers to the positions or distances covered by the limbs. Gait cycle is defined as the time interval between two successive occurrences of one of the repetitive events of walking. A gait cycle usually begins at the instant which the heel of one foot strikes the floor and ends at the moment when the same heel strikes the floor again. Based on the events during the gait cycle, it can be subdivided into support, swing, and double support phases, which describe the periods of time when the foot is either in contact with the floor, or swing forward in preparation for the next step. Besides, in order to describe the time a foot stays on the ground, a leg duty factor is used as a fraction of the gait cycle. For bipedal gait, this can be used to distinguish between walking and running. If the leg duty factor exceeds 0.5, the figure is in walking mode, and if it is less than 0.5, the figure is in a running state. Human gait observations have shown that during average speed of normal walking, the support phase takes about 60% of the time of gait cycle, and the swing phase about 40%. This means that average normal walk has a leg duty factor about 0.6.

Two major parameters to define a specific instance of a gait are step length and step frequency. Their product is the speed of the locomotion. Walking is possible at a wide variety of combinations of step length and step frequency. However, a person, when asked to walk at a particular velocity, is most likely to naturally choose the parameters which minimize energy expenditure. This observation is expressed in the experimentally established formula from Inman [Inman et al., 1981]:

$$f = 0.743.\sqrt{V} \qquad (1)$$

where V is the linear velocity normalized by the leg length
f is the cycle frequency (two steps)

An interesting issue regarding the walking speed and gait characteristics is the adjustment of leg duty factor in the gait cycle. That is, the support phase of the gait should slightly extend as the speed of walking decreases, and reduce as the walking speed increases.

For the purpose of various gait motions, the system should allow the user to override these attributes arbitrarily. For example, in certain steps during the locomotion, we may extend (or shorten) the step length, to overcome obstacles along the travelling path. A hierarchical control mechanism is generally used to implement human walking systems. The idea is to incorporate empirical knowledge on different levels about a particular motion into the animation system and guide automatic motion generation. The motions produced are typically parameterized in a way that is directly meaningful to animation and allows interactive fine-tuning.

By using a hierarchical motion control mechanism, the desired motions can be flexibly directed and controlled. At the high level, only minimal locomotion parameters, such as speed, are required to generate the corresponding basic motions. While at the middle level, additional locomotion parameters, such as state-phase and gait determinants, are used to achieve different gait characteristics. Finally, at the low level, animation attributes affecting the upper body are fine-tuned to simulate different locomotion styles and personalities.

3.2 Gait of the elderly

In the research on elderly gait, it was widely documented that elderly people tend to walk more slowly [Spirduso W.W., 1995], [Prince F. et al, 1997]. Studies [S-Cook A., Woollacott M., 1995] outlined three stages of age related changes in walking. Stage 1 changes were found in adults between 60 and 72 years of age, and included decreases in walking speed, shorter step length, lower cadence (the number of steps per minute), and less vertical movement of the center of mass. Subjects between 72 and 86 years old showed stage 2 gait changes, including a disappearance of normal arm-leg synergies, along with an overproduction of unnecessary movements. In stage 3, in subjects ages 86 to 104 years, there was a disintegration of the gait pattern, arrhythmia in the stepping rate and an absence of arm swing movement.
The relationship between age and velocity was showed by the following formula from [Imms F. J, Edholm O. G, 1981],

$$V = 1.669 - 0.0119 * age \qquad (2)$$

Where V is expressed in m/s
age varies from 60 to 99 years

In [Prince F. et al, 1997], it was pointed out a reduction of walking speed ranges from 0.1-0.7% per year. Moreover, many elderly people are unable to walk faster than 1.4m/s (this is the minimal speed recommended to safely pass an intersection) [S-Cook A., Woollacott M., 1995].

The slowness of speed in older subjects causes the elderly gait pattern to have shorter, broader step dimensions, and a lower swing-to-stance time ratio so that the period of double support is increased. Old adults, therefore, take more steps to cover the same distance, and the time when both feet are on the ground is longer. When older people are asked to accelerate their walking, they do so by increasing the cadence of their gait. Young adults, in contrast, increase their stride length. Older people may not use the strategy of increasing their stride length either because somewhat compromised. Increasing stride length also decreases the amount of double support time, a pattern which requires greater balance. At an enforced very slow walking speed, old subjects tend to prolong the double support phase of the gait cycle in order to enhance their balance.

There are several explanations for the preferred slow gait of older people. Endurance of weaker muscles in the lower limbs is maximized with the use of shorter strides, and the energy cost of walking is minimized. Less flexible ankle and knee joints constrain the stride length. Having a more precarious balance on one foot encourages individuals to spend less time in the single support phase of the gait. Except for unexpected perturbations of balance, a slower gait also allows an older person more time to monitor the progress and result of walking and to react to changes in the environment [Spirduso W.W., 1995].

Regarding kinetic, very limited information comparing the young and elderly are available. Riley et al, [Riley P.O. et al, 2001] investigated the relationship of hip, knee and ankle function to gait speed in healthy elderly subjects. Their conclusion confirmed the kinematics alterations at the hip are a cause of reduced gait speed in the elderly.
And finally hip, knee, and ankle flexion range of the elderly is smaller than in young adults, and the whole shoulder rotation pattern is shifted to a more extended position, with less elbow rotation as well.

4. THE ELDERLY LOCOMOTION MODEL

4.1 Introducing key personification profiles

The current human walking model at the VRlab LIBHWALK uses simple kinematics approach based on experimental data [Boulic R. et al, 1990]. The major attraction of this work is to allow the animator to design different gait styles of different body configurations by specifying personification factors. Walking constraints are overcome through a correction phase based on inverse kinematics in order to preserve the original characteristics of the walking data.

There are two levels in this model. At the low level, all key positions, spatial and temporal parameters of generic walking are calculated depending on the theoretical velocity. Joint trajectories of human body are interpolated from one of three sets of control points corresponding to three ranges of theoretical velocity from slow gait to fast gait. Once the theoretical velocity changes, these control points are recalculated to ensure the coherence between parameters while animating. At the high level, actual human body angle values calculated from the walking engine and personification factors are directly mapped to human body configuration to simulate human walking.

The actual walking trajectories are the trajectories of flexion/extension at the thigh, knee, ankle, and toe. Therefore, the other joint angles may be change arbitrarily to allow the animator to design personifications for each individual. The personified motion is derived from the original motion associated with a scalar parameter (cx) and an offset parameter (co) using the following equation:

$$Personified\ motion = cx*original\ motion + co \qquad (3)$$

The most personification factor of this model is hip flexion/extension since hip range of motion is used to compute the step length. When this factor changes, making actual velocity change, a trial-error process of adjusting theoretical velocity is performed to search in possible theoretical velocities so that the best approximate one is returned for computing joint trajectories [Boulic R., 2003].

As stated in previous sections, the simulation system of elderly gait must be able to allow the user to alter gait parameters while producing motions so that we can highlight the following characteristics of elderly gait:

- Slowed velocity
- Decreased cadence
- Shorter step length
- Longer duration of each gait cycle
- Greater stance/swing ration so that greater double support time
- Decreased pelvis rotation, pelvis tilt, knee flexion at initial swing, plantar flexion, arm-swing, back tilt, …

The main idea is to modulate the walking pattern as a function of the linear velocity. The trajectories of all these degrees of freedom can be scaled for some key velocities (they can also have different offset for these key velocities). As a result the walking pattern display a changing behavior with speed which is what we need for elderly persons. At slow speed they have a similar walking pattern as other adults but as the speed increase their cycle frequency increases faster than younger adults. Enforcing this effect is immediate with the scaling factor associated with the hip flexion. Our internal velocity control loop ensures that a decrease in the hip flexion amplitude is compensated by the necessary increase in cycle frequency to maintain the user defined velocity.

We have developed an interface allowing the definition of personification profiles for key linear velocity values (the whole set of scaling and offset coefficients is a bit less than 80 values). Only a few of these values need to be changed to reflect the walking style of elderly persons. The hip flexion is the essential trajectory to adjust. Figure 1 shows the upper part of the interface where each human silhouette appearing above the speed scale represents a key personification profile. In-between the key velocities the personification parameters are interpolated thus covering the whole velocity range (we even cover some negative velocity values for animation purposes). Figure 2 shows one sub-panel for adjusting the personification parameters for one key velocity (here the leg parameters appear). The whole set of personification profiles together with their associated key speeds can be saved in a gait file and assigned to any human model compliant with the H-Anim standard [Boulic R., 2003].

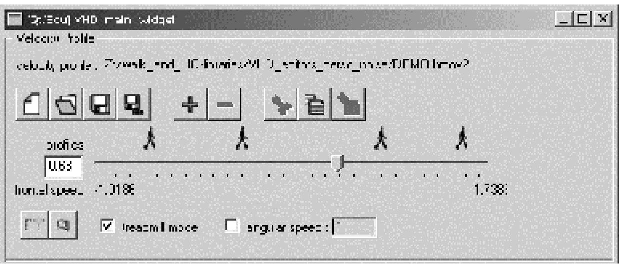

Figure 1: speed range highlighting the key personification profiles with silhouettes

At run time the current speed is converted in a normalized speed to drive all the walking pattern trajectory except the hip flexion. For his latter, the hip scaling personification is applied to the hip flexion trajectory and a search is made to ensure the realization of the current velocity. As a consequence a personified cycle frequency will be produced that drives the walking cycle phase update (by integration over time).

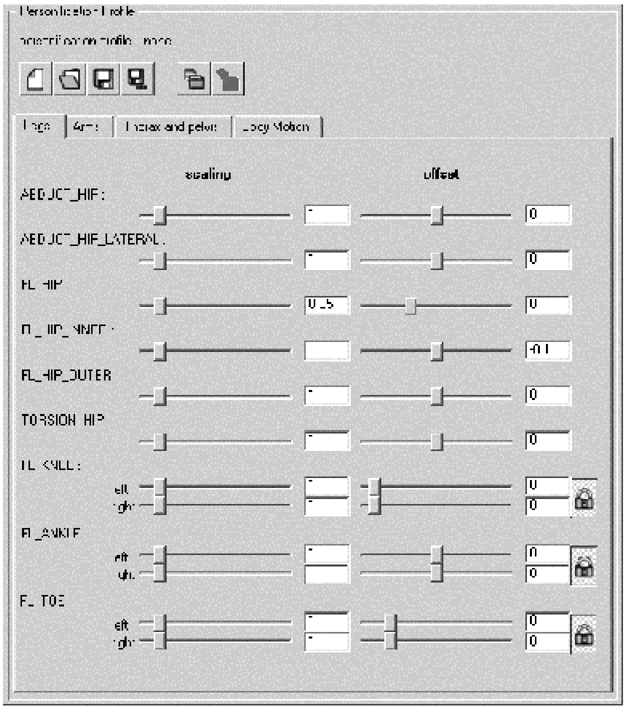

Figure 2: setting the parameters of one key personification (leg trajectories index)

4.2 Some preliminary results

The results are live recorded animations from test applications running on top of VHD++ a middleware developed and Vrlab and MIRAlab [Ponder02]. The animation files that can be found at the following web address:

`vrlab.epfl.ch/~boulic/WALK_Engine`

Different gait style have been adjusted to mimic the influence of age(on a generic human model with full mobility). Others examples highlights the potential of this tool for animating a wide range of characters.

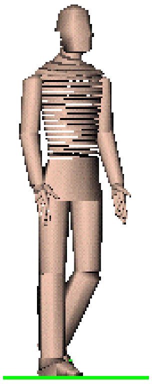

Figure 3: The generic human model used for the different gait styles

5. DISCUSSION

Modeling human motion depending on age is a complex task because ageing changes are very personal and dependent on many other factors such as diseases, healthy conditions, … In this paper, based on studies of age related changes, a age-dependent locomotion model is proposed through key personification profiles. The resulting modulation of the walking pattern is very powerful for characterizing gait as in the case of elderly persons but also as a production tool for general inhabited virtual world.

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