A Model for Animation and Control of Articulated Figures Using a Simplified Dynamics Approach

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Abstract. This paper describes a model to represent the movement of articulated systems involving different methods for transmission of external force. A simplified approach of dynamics is used to movement control, description and specification. Constraints and physics based analysis are used to animation control.

1 Introduction

The animation techniques based on dynamics aims at the presentation of more and more realistic results [WAT 92]. Many projects in this area have been developed: rigid bodies [WIL 89] [LEM 93], deformable bodies [TER 88] [NED 93] and articulated bodies [KOL 92] [PAN 92].

This project presents a model based on physics for animation and movement control of articulated systems. It was developed as an MSc dissertation at "Curso de Pós-Graduação em Ciência da Computação - UFRGS" [MUS 94]. The main goal of the work was to provide a model of the dynamics that should be simple and efficient in results and processing time. Furthermore, constraints were placed in the model to complement the movement control.

We present the dynamic model used in the generation of the movement through the considered force components. Besides, we compare the methods developed for the transmission of external force by the parts (limbs) of the articulated figure.

2 The Dynamics Model

There are two kinds of mechanical analysis of the movement: kinematics and dynamics analysis. The former describes the movement based on the variation of the position of the body in a function of time, whereas dynamics refers to the description of the movement concerning the action of the forces and torques acting in the mass of the bodies [RES 80].

It is well known from dynamics that the movement is produced by accelerations and velocities which result from the application of forces and torques. Finally, accelerations and velocities cause the variation of the kinematics information (angular and linear offsets) originating the movement. The forces acting in the systems were considered in order to determine the resulting force in each limb of the articulated structure. This is the way we defined the movement model based on dynamics.

2.1 The Acting Forces Model

The goal of the movement model is to describe the way the movement in the articulated structure occurs. To determine the resultant force in each limb, the forces acting in the system were defined [MUS 93], namely:

$$\vec{F}_{result} = f(\vec{F}_{grv}, \vec{F}_{int}, \vec{F}_{ext}, \vec{F}_{ent}, \vec{F}_{fric_{air}}, \vec{F}_{fric_{link}})$$

where:

- $\vec{F}_{result}$ is the resultant force calculated for each limb of the articulated system;
- $\vec{F}_{grv}$ is the gravitational force of the environment where the simulation of the movement occurs;
- $\vec{F}_{int}$ is the internal force transmitted by other limbs of the articulated system;
- $\vec{F}_{ext}$ is the external force that takes action over the system. This component will be named internal force when transmitted to other limbs;

- $\vec{F}_{ent}$ is the entailed force responsible for keeping the connection that defines the articulations and the one that relates the system to the external world;
- $\vec{F}_{fric_{air}}$ is the component of resistance of the movement defined in terms of the air friction coefficient;
- $\vec{F}_{fric_{link}}$ is the energy loss that occurs in the links (joints) of the articulated figure.

The external force is transmitted into all limbs of the articulated figure generating internal forces. The methods developed for the transmission of forces through the limbs is presented in the sequel.

3 Methods for External Force Distribution

We have developed three methods for distribution of the external force. The processing time spent in each method represents the total time spent for generating the frame, which involves all the demanding computing (resulting forces and integrating methods) and the output time.

The articulated system have eight limbs and was simulated using three methods for distribution of external force.

3.1 Homogeneous Method

This method distributes the external force in an homogeneous way along all limbs of the system. The force is propagated on an equal basis for all limbs in the articulated figure, regardless of either the mass of each limb or the distance of the limbs to the external force application point. Figure 1 shows the movement generated by this method. Notice that the application point of the force is not clearly distinguished because the resultant forces in all limbs are equal. The spent processing time for each frame was 0.34 seconds.

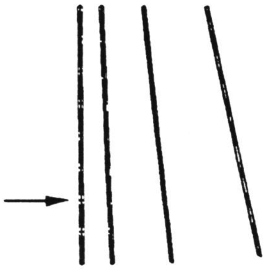

Figure 1: Homogeneous Method for External Force Distribution.

3.2 Pondered Method

This method distributes the external force along the limbs by means of an equation that ponders the information concerning the mass of the limb and its distance from the application point of the force.

Let $\vec{F}$ be the external force applied to the articulated system, d the distance from the limb under consideration to the application point of the force, m the limb mass, $totdim$ the system total dimension, and $totmass$ the system total mass. Then, the limb internal force ($\vec{F_{IntL}}$), which was transferred to it by the application of the external force, will be

$$\vec{F_{IntL}} = \vec{F} - \frac{(\vec{F}\frac{d}{totdim})+(\vec{F}\frac{m}{totmass})}{2}.$$

The above equation ponders the force in relation to the considered attributes: the limb mass and the distance from the limb under consideration to the application point of the force. Figure 2 shows the application of the Pondered Method in the movement specification presented in the previous method. The processing time spent in the generation of each frame of this movement was 0.5 seconds.

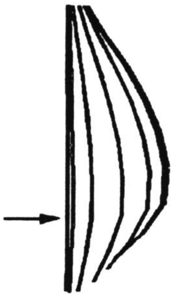

Figure 2: Pondered Method of External Force Distribution.

3.3 Accelerations Equivalence Method

The Accelerations Equivalence Method considers that neighbour limbs have the same acceleration, that is, the external force affects each limbs in such a way that the accelerations caused by the force would be equal across the limbs. The resultant force can promote different accelerations of the limbs depending on additional information of the model such as friction and connection.

In this method the external force distribution on each limb (Li) is calculated using the following algorithm:

```
External Force Distribution
Begin
    $\vec{a}_{L_i} = \frac{\vec{F}_{ext_{L_i}}}{m_{L_i}}$
    For lower level neighbour limbs
        $\vec{a}_{L_{i+1}} = \vec{a}_{L_i}$
        $\vec{F}_{int_{L_{i+1}}} = \vec{a}_{L_{i+1}} m_{L_{i+1}}$
    For higher level neighbour limbs
        $\vec{a}_{L_{i-1}} = \vec{a}_{L_i}$
        $\vec{F}_{int_{L_{i-1}}} = \vec{a}_{L_{i-1}} m_{L_{i-1}}$
End
```

We have accordingly established that the internal forces of each limb (except for the limb in which the external force has acted) are the external force distributed along the limbs. Figure 3 depicts the movement of the same example where the previous methods were applied. The processing time spent in the generation of each frame for this movement was 0.5 seconds.

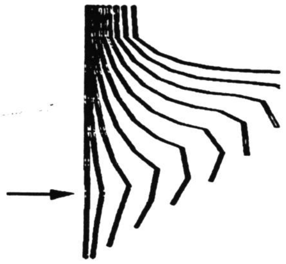

Figure 3: Accelerations Equivalence Method.

3.4 Methods Final Analysis

As can be observed, the Homogeneous Method does not present a result consistent with reality, however it presents the lowest computational cost. The Pondered Method does not present the same degrees of realism as the Accelerations Equivalence Method, although it shows an interesting result regarding visual aspects. Concerning computational cost, the last two methods are equivalent. Thus, it can be concluded that the Accelerations Equivalence Method is the most suitable method for force distribution.

4 Movement Control

Dynamics is frequently used in computer animation and simulation because it promotes the production of realistic movements. Furthermore, it requires a reduced amount of input data. However, it has a serious problem: the data entry is not intuitive for the animator [GRE 89], that is, the specification of forces and torques in a movement generation is not trivial. Many works have been approaching the problem of dynamic control of systems [COH 92] [KOL 92] and the search for solutions seems to be the use of hybrid systems, which comprehends the characteristics of different models [BAR 88].

Since this work uses direct dynamics in the generation and description of the movement, we conceived a hybrid model for the movement control based on constraints and key-frame specification. This was done to ease the task of movement control by the user.

4.1 Key-frame Control of External Force

The control of animations via Key-frame Interpolation considers that the parameters to be animated are specified in terms of initial and final times and the animation system generates the parameter in the intermediary times. This kind of control was proposed aiming at providing further resources and possibilities of movement control.

The parameter to be controlled via key-frame is the external force, since we consider this as the only component at the model which is potentially subject to modification in function of time in a single simulation. Furthermore, this control is justified because the simulation starts from the static equilibrium, which is a characteristic of the model. This implies a difficulty of generating a movement at the end of another. However, using the key-frame control it is possible to modify the external force during the simulation.

The variation of external force during the movement acts on the new velocities and accelerations. For instance, it is possible to simulate the instantaneous forces (the ones that act in a determined instant and then stop) and constant forces (the ones that act for a period of time in the animation) using key-frame control. There is, still, the possibility of changing the movement direction, disaccelerating it until it stops and accelerating it in the desired direction.

The following example shows the syntax of the language for specifying external force in the key-frame control:

```
FRAME=0      EXT_FORCE=50 0 0
FRAME=100    EXT_FORCE=-50 0 0
```

In that case, the external force equals (50,0,0) from frame 0 to frame 99 and equals (-50,0,0) in frame 100, according to illustration shown bellow:

```
EXT_FORCE [FRAME   0] =  50 0 0
EXT_FORCE [FRAME  99] =  50 0 0
```

```
EXT_FORCE [FRAME 100] = -50 0 0
EXT_FORCE [FRAME 150] = -50 0 0
```

With that specification, this object which was accelerating due to the constant presence of external force, will disaccelerates from frame 100 until it stops. Afterwards, it will start accelerating in the inverse direction.

4.2 Constraints Control

The use of constraints is considered as a complement of the movement, that is, it does not act on the laws of Dynamics, but acts on the generated movement, according to the input data specification.

The kind of constraints to be considered in this work were based in [BAR 88] and adapted to articulated figures. They are presented in the sequel:

- **Articulation of the Figure Constraint to a linear Path:** Constraints the specified articulation in a path also specified by the user. The path is specified through initial and final positions and its interpolation is linear, as figure 4 shows.

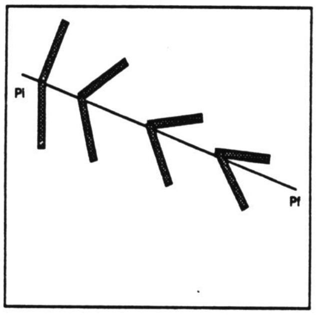

Figure 4: Constraint that Bounds the Movement of an Articulated Figure to a Path.

- **Positional Bounds for the Articulation of the Figure:** In this case, the specified articulation must not surpass the planes that describe the limits of the movement. The planes are defined by a point and three orientations, that is, the localization of the plane in space and its three orientations in relation to the axis X, Y and Z. Such constraint is depicted in figure 5.
- **Rotational Bounds for the Articulation of the Figure:** Here, the maximum and minimum angular offsets that a limb may have during its movement, in relation to an articulation, are defined.

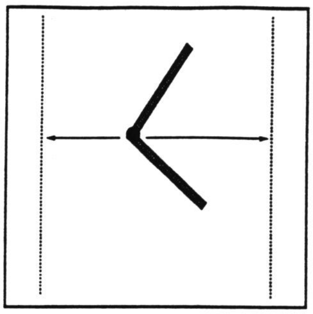

Figure 5: Constraint Specifying Positional Bounds for an Articulation.

In figure 6, we present an example that shows two articulated figures that are being controlled by constraints. In such case, the constraint used was the positional bound, which was intended to simulate a "break". This animation sequence was used in the overture film of the SIBGRAPI'93 Video Show, in Recife – Pernambuco – Brazil.

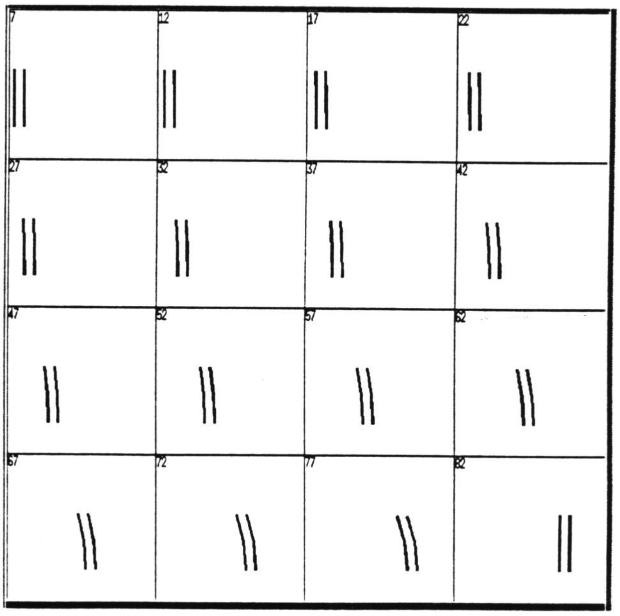

Figure 6: Constraints Controlled Articulated Systems.

5 Global Execution Flow

The Global Execution Flow shows the global algorithm of the movement generation.

```
Main Program
Begin
    For each frame of the simulation
        Apply the external force in limbs
        For each limb
            Compute internal force
            Compute entailed force
            Compute resultant force
            Compute resultant torque
            Compute angular and linear offsets
            if angular or linear offsets cause one
                rupture of the any constraints
                    Compute the possible offsets
                    with the kinematics
            Apply the offsets in the movement
                generated
End
```

6 Some Results Obtained

This section is intended to show some results from simulations on ARTIC that aimed at graphically characterizing the model here defined. All simulations presented in this section were generated by the Accelerations Equivalence Method. The Prototype developed runs on Sun Workstations under UNIX Operating Systems, and developed using C programming language.

6.1 CASE 1: Articulated Figure in a Free Fall

Next we present an Articulated Figure Free in 3D space that falls due to gravity. In figure 7 one can see the animation, and in table 6.1 the parameters related to the simulation process.

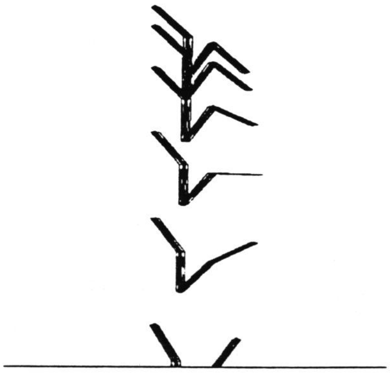

Figure 7: Articulated Figure in a Free Fall.

MODELING PARAMETERS	
Limbs Mass	10.0
Dimensions $< x, y, z >$	1,10,1
Friction in Articulations	0.3
Translational Connection	FREE
Rotational Connection	FREE
ENVIRONMENT PARAMETERS	
Air Friction	0.3
External Force	0.0, 0.0, 0.0
Articulation - (Acting force)	–
Gravity	0.0, -9.8, 0.0
PERFORMANCE DATA	
Delta Time	0.01
Generated Frames	80
Number of Iterations	8000
Time (80 Frames)	67 sec.
Time (1 Frame)	0.84 sec.

Table 1: CASE 1 – Simulation Parameters.

6.2 CASE 2: Linked Articulated Figure

Now we present an Articulated Figure that do not have the possibility of translation from a fixed support. The animation can be seen in figure 8 and in table 6.2 is the information concerning the simulation process.

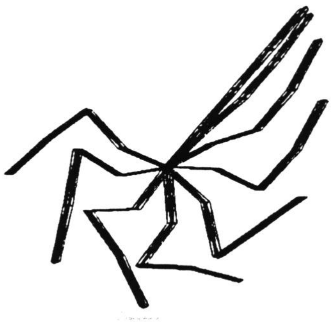

Figure 8: Articulated Figure with Fixed Support.

There is no external force acting besides the gravitational one and the figure falls trying to find static equilibrium state. During this time, it oscillates due to Dynamics effects of the movement.

MODELING PARAMETERS	
Limbs Mass	10.0
Dimensions $< x, y, z >$	1,10,1
Friction in Articulations	0.3
Translational Connection	FIXED
Rotational Connection	FREE
ENVIRONMENT PARAMETERS	
Air Friction	0.3
External Force	0.0, 0.0, 0.0
Articulation (Acting Force)	-
Gravity	0.0, -9.8, 0.0
PERFORMANCE DATA	
Delta Time	0.01
Generated Frames	100
Number of Iteration	10000
Time (100 Frames)	77 sec.
Time (1 Frame)	0.77 sec.

Table 2: CASE 2 - Simulation Parameters.

6.3 CASE 3: Key-frame Controlled Articulated Figure

Finally, we present an Articulated Figure that is controlled via Key-frame, that is, the external force is modified during the simulation. In figure 9 is pictured the animation and table 6.3 is the information regarding the simulation process.

Figure 9: Key-frame Controlled Articulated Structure.

MODELING PARAMETERS	
Limbs Mass	10.0
Dimensions $< x, y, z >$	1,20,1
Friction in Articulations	0.3
Translational Connection	FREE
Rotational Connection	FREE
ENVIRONMENT PARAMETERS	
Air Friction	0.3
External Force 1	200.0, 200.0, 0.0
External Force 2	0.0, -200.0, 0.0
Articulation (Acting Force)	ARTIC=3
Gravity	0.0, -9.8, 0.0
PERFORMANCE DATA	
Delta Time	0.01
Generated Frames	40
Number of Iterations	4000
Time (40 Frames)	21 sec.
Time (1 Frame)	0.53 sec.

Table 3: CASE 3 - Simulation Parameters.

7 Conclusion

The development of such model for generation and control of articulated figures movement has originated the ARTIC System. This system has already been validated in the scope of the Computer Graphics Group at Curso de Pós-Graduação em Ciência da Computação (CPGCC) - Universidade Federal do Rio Grande do Sul (UFRGS). Some animations has already been accomplished using the ARTIC System, for example the overture of the video show of SIBGRAPI'93 (which sequence is shown in section 4). Figure 10 pictures an image of that film.

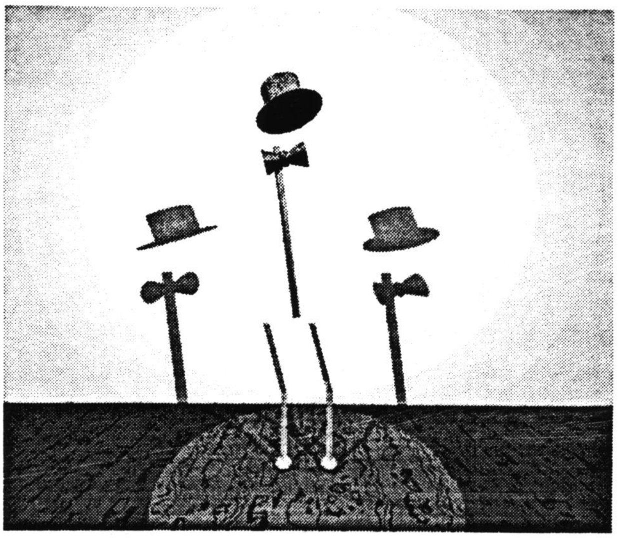

Figure 10: Actor Legs Movement.

Some improvements proposed on this model are:

- inclusion of the inverse dynamics in the movement generation; the advantage is that the user informs kinematic data instead of forces and torques; and
- inclusion of collision in the movement model.

We believe that the model is useful for the "simulation" of articulated figures movements that do not need a trustworthy realism. Besides, we intended to generate realistic movements alongside a good processing time performance, which is an important feature for animation users.

Acknowledgements

We would like to thank the Computer Graphics Group at UFRGS, Prof. Jean-Dominique Gascuel for his useful comments and specially Rafael Heitor Bordini for english revisions. CNPq and CAPES partially supported this work.

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