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A RAPID ALGORITHM FOR REALISTIC HUMAN REACHING AND ITS USE IN A VIRTUAL REALITY SYSTEM

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ABSTRACT

The Graphics Analysis Facility (GRAF) at NASA/JSC has developed a rapid algorithm for computing realistic human reaching. The algorithm was applied to GRAF's anthropometrically correct human model and used in a 3D computer graphics system and a Virtual Reality system. The nature of the algorithm and its uses are discussed.

INTRODUCTION

The Graphics Analysis Facility (GRAF) at NASA/JSC provides tools and methods for visualization of space vehicles, structures, designs and procedures. A detailed 3-dimensional geometric database of the Space Shuttle, its payloads, and various Space Station designs in different stages of construction is maintained and continuously updated by GRAF. This information can be visualized by GRAF's customers with color printouts, transparencies, video tape animations, or within a Virtual Reality system. GRAF also maintains an accurate anthropometrically correct human computer model.

The aim at GRAF is to incorporate this accurate human computer model into a Virtual Reality (VR) system. A VR system allows the person who wears the helmet to visualize the simulated environment. The motion of the helmet is monitored to determine head motion of the person and to update the images displayed in his helmet. When this person is doing more than viewing his environment, and begins to perform tasks such as reaching and lifting objects, then it is necessary to track the motion of his arms. Usually, a magnetic tracking device is attached to the hand to record position and orientation of the palm. Some systems use this information to draw a non-jointed hand/arm model with the position and orientation as measured by the tracking system. This is fast and simple, but has limited use. When VR systems are being used with multiple people in the same environment, one user looking at another needs to see correctly positioned arms, not hands dangling in space. In order to display the person's jointed arm in his computer environment, it is necessary to calculate the actual joint angles necessary to position each limb of the arm to obtain the position and orientation (posture) of the end effector (palm).

Inverse kinematics was an early and popular method of determining the joint angles in the arm. The arm is, at a minimum, a 7 degree of freedom (DOF) device with 6 constraints. Inverse kinematics solutions for such a system need not be unique, with solutions often looking very unrealistic. Also, often the solutions get trapped in local minima, and the calculations can be slow.

The method of determining joint angles from posture of the hand used in GRAF is a simple look-up table approach. This approach always gives a solution (if a solution exists) and is extremely fast. The sections below describe this look-up table approach, its advantages and disadvantages, along with possible extensions and refinements to this approach.

REACHING

Reaching is a complicated task. Usually the entire body and not just the arm is involved in this task. The challenge is to monitor and reproduce an accurate reaching motion with a minimum of magnetic trackers on the person. Attaching magnetic trackers to each limb segment of a person would allow capture of the actual reach motions, but this method requires many trackers. We have developed a method of simulating realistic reaching motions using a limited number of trackers to determine basic body posture. Look-up tables give solutions for the joint angles needed to obtain this posture.

Consider a virtual environment with an EVA person attached to a portable foot restraint (PFR). The person wearing a VR helmet and magnetic trackers must move in this environment as if his feet were attached to the PRF. In our system the motion of the subject would be monitored using 3 magnetic trackers; one tracker on the back to determine motions of the torso, one tracker on the palm to determine posture of the hand, and a third tracker on the head to monitor head motion for viewing purposes (Figure 1). (Note: This configuration of 3 trackers monitors only one arm. Four trackers would be needed to monitor both arms.)

The tracker on the back is processed first. Translation motions of the tracker are used to move the figure's waist position forward/backwards. A look-up table determines the joint angles necessary to keep the feet attached to the PFR (Figure 2). Orientation of the tracker is used rotate the waist until the computer figure has the correct back orientation. With this new body orientation, the tracker on the head is processed to determine neck motion necessary to give the correct viewing direction. The tracker on the hand is used to get a position and orientation in space relative to the shoulder of the computer figure. A look-up table then determines the joint angles needed to position the arm. This requires 7 joint angles for our EVA figure. An unsuited figure would need 9 joint angles to allowing positioning of the clavicle to give a correct arm posture.

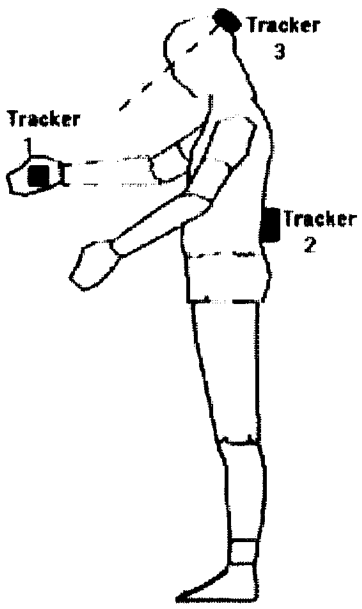

Figure 1. Location of magnetic trackers

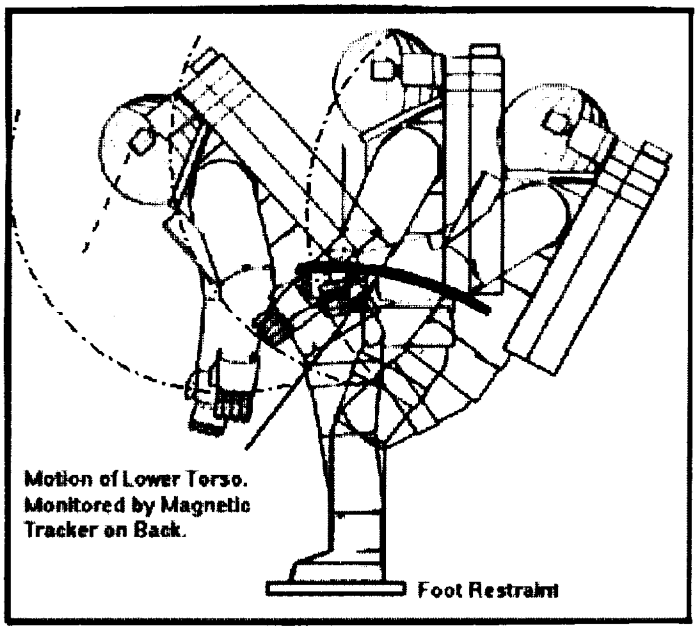

Figure 2. Motion of Torso and arms determined by trackers.

Look-up Table Generation

In order to generate our look-up table, all the arm joints of the computer figure were exercised through their range of motion. This generated vast amounts of data relating position and orientation of the palm to the joint angles necessary to achieve these postures. This data was organized into a grid of points, with a grid of orientations for each point. This table initially contains redundant data. Various methods to prune the data could be used. A strength criterion was used initially to prune the solution set. This criterion assumes that the human body uses maximum strength[1] as the preferred position for the joint chain. Isokinetic strength data was previously collected on 14 subjects for all degrees of freedom of rotation of the arm[2]. The redundant joint chain solution in the reach table at a particular position and orientation were compared in terms of their available strength at those joint angles. The table was then purged to maximize strength. This scheme is still under research. For EVA motion, we are also considering looking at joint postures closest to neutral body posture for pruning the table .

The advantages of the look-up table are that a solution is always obtained (if one exists), many criteria (such as strength, posture, or task dependencies) may be applied to select the correct set of solutions, and it is very fast (three orders of magnitude faster than the inverse kinematics routine[3] used in our lab). The disadvantage is that the resolution of the solution is dependent on the table size, and even with moderate resolution, the table size may be enormous (e.g., a 2 inch resolution requires 1.2 million data points).

USE OF THE REACH LOOK-UP TABLE

The reach look-up table was installed in the 3D interactive graphics system used in the GRAF Lab. The user can “fly” the end effector using keyboard commands, and the reach algorithm fills in the joint angles to produce a realistic reach. The end effector may be the hand or the waist; a separate look-up table is used for each. This application allows computer animations to be generated with greater realism and speed. Formerly, human motion for animations was guided by providing commands to control each joint individually. It was a tedious procedure and often produced unnatural motion.

The reach algorithm was also installed in a Virtual Reality system. The system's hardware consists of two Silicon Graphics Reality Engines, a Virtual Research head-mounted display (HMD), two Ascension Technology Bird magnetic trackers, and one Polhemus Isotrak magnetic tracker. The magnetic tracking information is used to update the computer human model motions. For a description of the Virtual Reality System implementation see [4]. Work is now in progress on recording animation scripts from the motion of VR users immersed in the environment of the animation.

The suitability of the VR system, equipped with the reach algorithm, as a planning and analysis tool for reaching tasks is also being studied.

CONCLUSIONS

A very rapid algorithm for producing approximate solutions to human reach problems was described. The method uses a look-up table, and the accuracy of the solution increases with the table size.

The algorithm has been integrated into a 3D interactive graphics system and a VR system. It has proved useful for generating animation and promises to be useful for planning and analysis of reaching tasks.

FUTURE WORK

Ways of using the look-up table data in methods that can represent the data in a more compact form will be explored. Work has begun on looking at using the look-up table data to train neural networks. We are also looking at ways of interpolating between data points to improve resolution.

In the hope of further increasing the realism of the solutions, a look-up table will be constructed using data collected by tracking the actual movements of human subjects instead of arbitrarily exercising joints in the computer figure.

We have noted that accurate judgment of distance is often difficult in VR systems. We intend to investigate the causes of this difficulty and to look for ways to improve distance judgments. The use of artificial depth cues will be considered.

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Session H3: PSYCHOPHYSIOLOGY, PERFORMANCE, AND TRAINING TOOLS

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