A Study of a Human Model Augmented with Stilts in a Work Environment

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Abstract

The objective of this paper is to study the interactions of the augmented human model in an environment, while performing a task. Stilts, commonly used for installing drywalls in the construction industry, were chosen to be the subjects of study. In this study, the stilts are modeled as rigid bodies that support the human weight and transmit the ground reaction forces to human model. A detailed knee model is implemented in the full human model, including stabilizing ligaments, patello-femoral and tibio-femoral contact joints as well as hamstrings and quadriceps muscle groups. The forces in the knee and other human joints are calculated using an inverse dynamics approach. This approach involves introduction of "motion agents", which are parts attached to the body segments with spring elements. As the motion data drive the agents, the motion of the body segments are thus "influenced" rather than "governed" and the motion of the joints and muscles can be recorded. The forces in the joints and muscles can then be estimated by reproducing the movements with proportional-derivative (PD) controllers.

Introduction

The emphasis on improving working environment has been increasing over the years. Safety and enhancement in work performance are the two major contributing factors. Researchers in biomechanics often use computer simulation to investigate not only the mechanics of the human body but also the interactions of human and the environment.

The purpose of this paper is to demonstrate an approach of studying the interactions of human and work environment. A human model augmented with stilts was built using FIGURE.

FIGURE, a plug-in of ADAMS, is designed to help people build human model efficiently for a wide variety of interests. A base model in FIGURE, which composed of 15 segments and 16 joints (head, neck, upper torso, central torso, lower torso, upper and lower arms, upper and lower legs, feet), can be easily set up in many applications of full body simulations, such as gait, fall, and crash. When the focus of study is on specific part of the human body or high level of biofidelity is required, detailed models of specific human parts can be created to replace the segments and joints in the base human model.

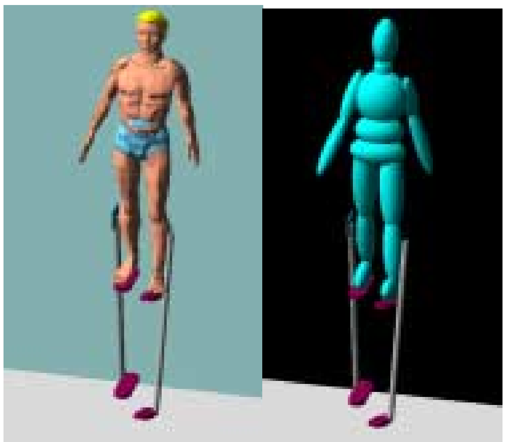

Figure 1 The human model with 15 segments and stilts

Human Model Augmented with Stilts

The human model

With the tools in FIGURE, a base human model with 15 segments was built based on the weight (162 lbs) and height (68 inches) of the subject. These 15 segments are connected by standard tri-axis hinge joints. To reduce the complexity of analysis, only the degree of freedom in the sagital plane is allowed at each joint location. When the joints are implemented, each joint angle should be adjusted so that the human model is posed as the initial position of the motion data.

In this study, we are particularly interested in how the loads of knee joints are adapted to the stilts. Therefore, a more detailed knee joint is more appropriate than hinge joints for this purpose. Figure 2 shows the knee joints and soft tissues in details. The knee joint is modeled as a force-based joint with an addition patella segment and two major contact forces; one between lower (tibia) and upper leg (femur) and the other between the knee cap (patella) and the upper leg.

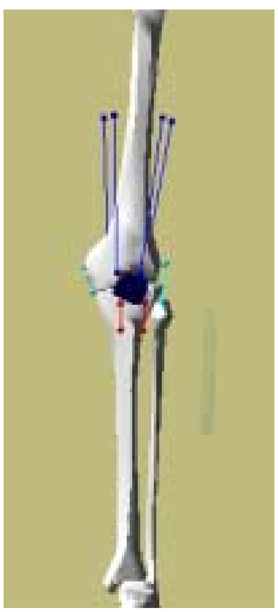

Figure 2 A force-based knee model with patella segment and soft tissues

Also, there are soft tissues (muscles, tendons and ligaments) in the knee model to stabilize/drive the knee joint. The soft tissues include the hamstrings muscle strand attaching to the upper and lower leg and the quadriceps muscle strand attaching to the upper leg to the kneecap.

The stilt model

A conceptual stilt model with 7.3 lbs each and height of 24 inches (from footplate to ground) are used to support the weight of the human. It is created as a single rigid part despite of the geometry, which is a composed of plates and rods. The stilts are attached to the human feet and lower legs with bushings. The reaction forces between the stilts and the ground are represented by two sphere-plane contact forces (front and rear) on each stilt. The friction coefficients of these contact forces are intentionally set high enough to allow little slip during the ground contact.

Simulation

Inverse Dynamics

The purpose of inverse dynamics is to drive the motion of the human model with the influence of motion agents. Twenty-five motion agents, located at human segments and stilts, are created after the human model and stilts are posed and attached properly.

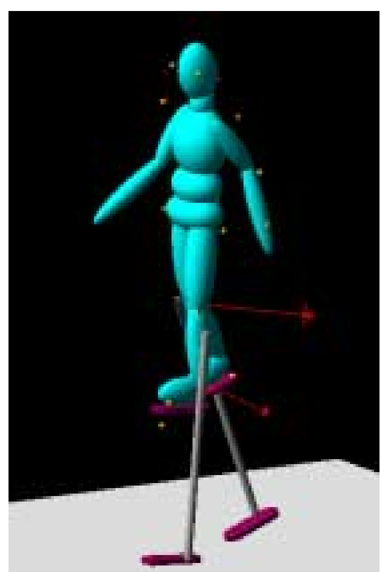

Figure 3 The human model augmented with stilts driven by the motion agents

The motion agents are attached to the human segments and stilts with springs and dampers, rather than rigidly connected to the parts. This set up will allow some separation between the motion agents and the attached parts. It can be witnessed during the animation of the inverse dynamics. Red balls are rigidly attached to the parts and yellow balls track the exact positions of the motion data. The discrepancies between the red and yellow balls are used to account for errors in the motion data measurement.

Forward Dynamics

After running the inverse dynamics simulation, the time histories of the joint motions and soft tissue elongation are recorded and can be used to drive the forward dynamics. Since the model contains both hinge joints and soft tissues, both of them are used to drive the simulation of the forward dynamics. In the forward dynamics approach, proportional-derivative (PD) controllers are automatically generated to produce torques that track the splines associated with the time history of joint angles.

One of the difficulties in simulating the gait of human is how to keep the balance of human body during the motion. To achieve this goal, a motion agent was created to hold the central torso in such a way that the human model follows the longitudinal and lateral trajectory recorded in the inverse dynamics simulation. At the same time, the vertical direction of the motion agent remains free in order to obtain realistic contact forces from the ground.

As a comparison, the same inverse/forward dynamics approach is applied to a human model without stilts. Figure 4 shows the contact forces between patella and femur with and without stilts. There is no significant difference (less than 2% in peak values) based on the parameters provided for this contact forces. Similar observations can be found in the muscle forces in the knee joints (shown in Figure 5). However, the main purpose of this paper is not to interpret the simulation results but to demonstrate the application and benefits of using the human model tools.

Summary

This study provides an example of building a human model augmented with stilts using FIGURE. With the inverse/forward dynamics approach, the loads in joints and soft tissues can be evaluated. The same process can be used in study human operating other types of tools in the work environment. The finding of these studies can help improvement in the working tool designs and thus improvement in work performance or safety.

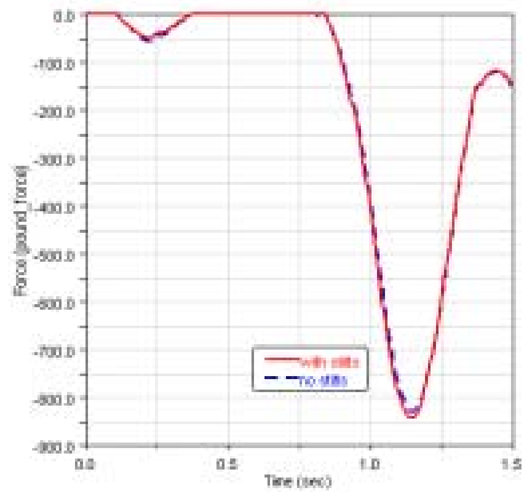

Figure 4 A comparison of (right) contact forces between the patella and the upper leg in two cases (with and without stilts)

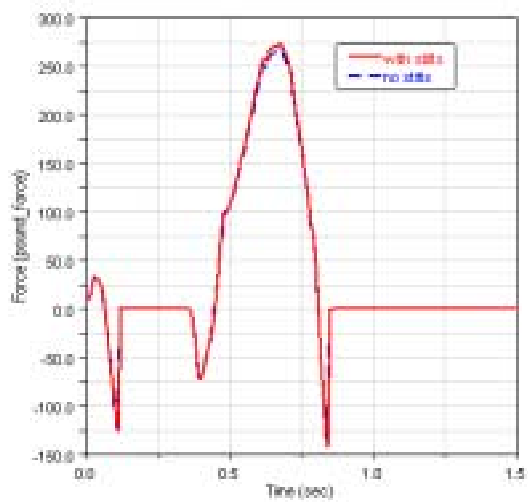

Figure 5 A comparison of the hamstring loads (left strand) in two cases (with and without stilts)