Proceedings of the ASME 2009 Summer Bioengineering Conference (SBC2009)
June 17-21, Resort at Squaw Creek, Lake Tahoe, CA, USA

SBC2009-204916

VALIDATION OF SANTOS BIOMECHANICS

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ABSTRACT
A validation methodology for an optimization-based predictive dynamics framework for digital human motion simulation is presented in this work. The proposed validation methodology has been implemented in time and frequency domains on a predicted walking task. The methodology uses selected critical key frames in the comparison process in the time domain, as against the full profile of all joint angles. In the frequency domain, the methodology considers using fast Fourier transform and power spectrum density. In addition to human kinematics, the methodology compares inertia and ground reaction forces, a key kinetic parameter for motion validation. The results have shown considerable correlation and insight information between the predicted and the measured data.

INTRODUCTION
Approaches that attempt to solve for human walking motions based on performance optimization are very promising and have shown to be suitable for prediction of realistic human motions. In this case, objective functions are used to represent human performance measures, and optimization schemes are developed to solve for the feasible joint motion profiles that maximize the performance measures.

Predictive dynamics [1] is one such approach for predicting and simulating human motion. This optimization-based approach avoids solving typical differential algebraic equations (or ordinary differential equations) in order to create the resulting simulations for highly redundant systems. Detailed and anatomically correct joint-based full-body human models with high degrees of freedom can thus be used to create more realistic simulation of tasks with relatively less computation. Various tasks like lifting [2], running, and stair climbing have been simulated using this approach. In this paper, we present a validation methodology for such an approach.

In the validation process, the motion time series can have a tremendous amount of information, and it becomes very tedious to consider frame-by-frame comparison with the model over the whole interval of time. Predicting and comparing the whole time history of various tasks is troublesome since different people perform tasks, including the walking task, in different ways. Therefore, in this work, we propose to base the comparison on selected key frames that a majority of experts should agree on.

Another issue of concern with the validation process for digital human motion prediction is the large number of degrees of freedom that defines human kinetics; therefore, in this work, we introduce motion parameters that represent key degrees of freedom that contribute to a certain tasks. Fortunately, in normal walking these parameters are well defined in the literature and will be selected and used in this work. However, motion parameters are considered vectors, and therefore they should be tested for magnitude and phase. In this regard, the motion time series was transformed to the frequency domain to better understand the signature of the signals.

EXPERIMENTS
A twelve-camera Vicon motion capture system was used to collect the time history of the Cartesian location of reflective markers attached to well-defined anatomical spots on the human subjects, while they walked normally. All motion data were captured at a rate of 100 frames per second and were filtered with a Butterworth filter with a cut-off frequency of 8 Hz. Four male subjects, with a mean height of 5’7” and a mean weight of 143 lbs, participated in this study. The average age of the participants was 34 years. Written informed

consent, as approved by the University of Iowa Institutional Review Board, was obtained prior to testing.

METHODS

In this work, we propose using a minimum number of parameters that define the motion of a certain task and considering these parameters as determinants. Based on the literature and a fair understanding of human walking, a total of six parameters, that include angles and displacements, were chosen as determinants for forward walking. These determinants consist of the lower extremities and pelvic motion of the human and include hip flexion/extension, knee flexion/extension, ankle plantar/dorsiflexion, pelvic tilt, pelvic rotation, and lateral pelvic displacement.

DETERMINANTS AT KEY FRAMES

While the time history of the walking determinants contains valuable information about the signature of each subject at each time frame, in this article, we propose using selected key-frames instead of considering the whole time history of each determinant. For example, at mid-stance, the trend of the knee flexion angle for normal subjects has a clear signature and a recognizable magnitude; therefore, it can be selected as a key-frame. Analogous characteristics can be noticed for other determinants. Also, similar determinants can be derived for other tasks like running, stair climbing, etc.

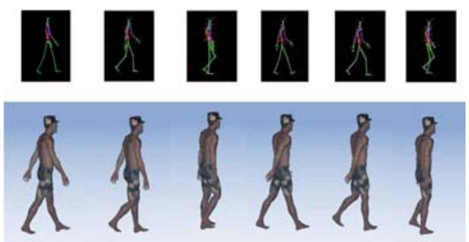

Figure 1: Selected critical key-frames; upper pictures depict the key-frames using motion capture skeleton; lower pictures demonstrate that using Santos

VALIDATION

Key Frames in Time Domain

Figure 2 depicts the coefficient of determination (R^2) plot for the six walking determinants for the selected key-frames of Fig. 1. In Fig. 2, the red diamond shape, for example, represents the relationship between the simulation data (vertical axis in degrees) and the experimental data (horizontal axis in degrees) of the hip flexion of each subject. A total of 24 points were constructed for each determinant, representing six key-frames (shown in Fig. 1) for four subjects. It can be seen that most determinants show a significant agreement between the simulation and the experiments. Nevertheless, there are some determinants that showed weaker correlation, which may be due to the inconsistency between the Santos model and the experiment model and the small range of these determinants.

Frequency Domain:

In this work, walking determinants were transformed into the frequency domain and the power spectral densities are demonstrated in Fig. 3. It is obvious that frequency components greater than 3 Hz have no major role in the process and that most of the activity is contributed to the lower frequencies. It is obvious from Fig. 3 that most of Santos's predicted determinants (in red) have shown comparable behavior with that of the human subjects.

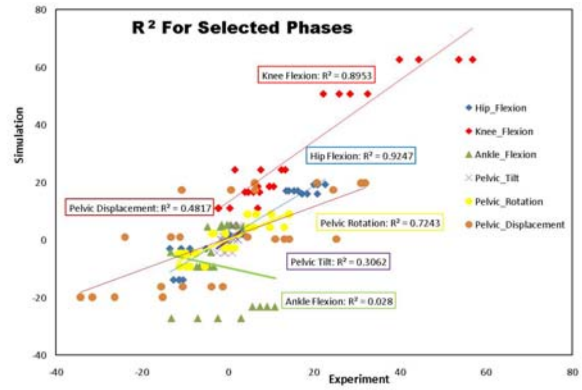

Figure 2: R^2 for walking determinants for the selected key-frames; each determinant comprises 24 points, representing four subjects and six key-frames

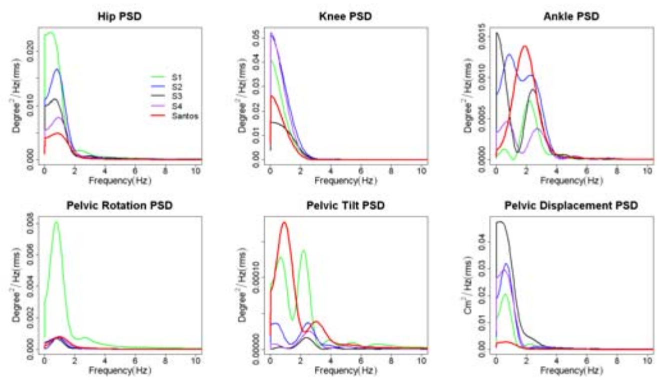

Figure 3: Power spectral density of the six walking determinants; Santos determinants are in red

CONCLUSIONS AND DISCUSSIONS

A methodology of validating a predictive dynamics framework for digital human motion simulation is presented in this work. Quantitative statistical analyses were used as metrics to measure the correlation between the simulation and the experimental data in time and frequency domains. Inertia and ground reaction forces were also considered in the validation and showed a considerable correlation.

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ACKNOWLEDGMENTS

This research is funded partly by Virtual Soldier Research (VSR) partners. They include US Army TACOM, Caterpillar Inc., Natick Soldier Research Center, Honda R&D Americas Inc., and USCAR. We would like to thank all other research members within VSR for their contributions.