Utilization of Minimum Set of Inertial Parameters Identification Method Using Free Vibration Measurement to Improve the Accuracy of Ground Reaction Force Estimation

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Abstract

In motion control and motion simulation, the inertial properties (mass, center of gravity, inertia tensor) of an object are fundamental and important parameters that serve as input values and have a significant influence on the accuracy of the results. The inertial properties of machines such as robots can be identified part by part or calculated theoretically from CAD data. However, the inertial properties of human body segments cannot be identified separately. So, they are generally estimated using regression equations based on body weight, height and the representative length of each part [1]. However, the data used to create the regression equation is limited and the results of the estimated inertial properties are inaccurate due to rough comparisons. They also can be calculated from human shape data using the density of muscles and bones. But it is difficult to accurately obtain the density of muscles and bones.

Thus, there is a demand to identify the inertial properties of the human body segments in the connected state. But the inertial properties of individual links cannot be identified from link motion and inter-joint torque or external force data, because they are redundant to the multi-body dynamics model. Therefore, the minimum dynamic parameters necessary to represent the multibody dynamics model has been defined and identified. These dynamic parameters are obtained by combining the geometric parameters and the inertial properties of the counterpart elements and are called the minimal set of inertial parameters.

Numerical and analytical methods for calculating the minimal set of inertial parameters have been proposed [2] and various experimental identification methods have been developed. The conventional identification methods utilize a set of measured link motion and inter-joint torques [3] or a set of measured link motion and floor reaction forces [4]. The former requires a torque sensor for every joint. Thus, it cannot be used in cases where it is difficult to estimate or measure joint torque, such as humans and humanoid robots. The latter can only identify the minimal set of inertial parameters for a plane in the direction of travel from movements such as walking. It has problems such as the difficulty in selecting an effective motion for identifying all minimal set of inertial parameters and the large measurement error and has not yet applied to the identification of individual human bodies.

A new method for identifying the minimal set of inertial parameters of multi-body system is developed by expanding and applying the identification method based on free vibration measurements, which is a method for identifying the inertial properties of a single-body [5]. This method enables the identification of the minimum set of inertial parameters in three dimensions with high accuracy, and its validity has been assessed by actual identification of body segments and comparison with the results obtained from regression equations. However, the effect of using the identified values on the accuracy of motion simulation is not yet known.

Ground reaction forces and moments are important measures used as input in biomechanical analysis to estimate joint kinetics, which often are used to infer information for many musculoskeletal diseases. Therefore, there is a demand for accurate estimation of these by motion simulation. In a previous study, the influence of inertial properties on the ground reaction force estimation results was investigated for a simple walking motion [6]. However, these verifications are limited to walking motion and have not been verified for other motions. If the motion to be evaluated changes, the affected inertial characteristics will also change. So, when using motion simulation for general purposes, it is necessary to verify various motions.

This study focuses on ground reaction force estimation and aims to investigate how the ground reaction force estimation results change with the identified minimum set of inertial parameters. It also aims to clarify how inertial properties influence the ground reaction force estimation in three-dimensional

motion, including not only in the sagittal plane but also in the frontal plane.

The human body was modelled with 10 rigid bodies and 19 degrees of freedom as shown in Fig. 1. The model consists of rigid bodies for the head, forearm, upper arm, torso, thigh and lower leg, with the shoulder, hip and neck joints represented by spherical counterparts and the elbow and knee joints by rotational counterparts.

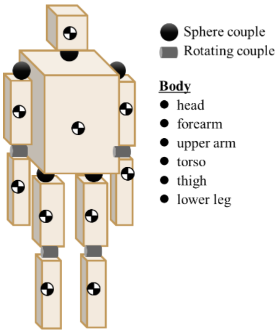

Figure 1: Human body model.

The results of the minimum set of inertial parameters obtained using the regression equation and the results identified by the minimum set of inertial parameters identification method using free vibration measurements of a subject are substituted into the model to create a human body model to the subject.

On the other hand, a motion capture system and a floor reaction force sensor are used to measure the subject's movement and the floor reaction force during the exercise. From the human body model given the motion and minimum dynamic parameters, the external forces acting on the person can be calculated using the equations of motion of the multibody system shown in Equation (1) [7]. Assuming that the external force exerted on the person is the only floor reaction force. For simplicity, the results of the estimation in the case of single support are compared with the results of the experimental measurement of the floor reaction force.

$$\mathbf{H}\begin{bmatrix}\ddot{\mathbf{q}}_0\\ \ddot{\mathbf{q}}_C\end{bmatrix} + \mathbf{b} = \mathbf{F}, \quad (1)$$

where $\mathbf{H}$ is the inertia matrix, $\mathbf{b}$ is the sum of the Coriolis force, centrifugal force and gravity force, $\mathbf{F}$ is the external force, $\mathbf{q}_0$ is the generalized coordinates of the base link and $\mathbf{q}_C$ is the joint angle vector.

This comparison confirms that the ground reaction force estimation accuracy is remarkably improved by using the results identified by the minimum set identification method of inertial parameters using free vibration measurements. The changes in the ground reaction force estimation results when the mass, center of gravity, and inertia tensor are changed from the identification results are precisely shown by using numerical simulations with identified parameters and the body model. This clarifies the influence of inertial properties on ground reaction force estimation results in three-dimensional motion, including not only in the sagittal plane but also in the frontal plane.

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