Development of A Dynamic Human Movement Analysis Platform

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Abstract: In this paper, we developed a dynamic motion analysis platform to analyze the nature of human movement. This system contents a 3D motion capturing system, which has 6 high-speed cameras, 8 force plates, 32ches EMG sensors and 30ches acceleration sensors. Moreover, a dynamic simulation model of human muscle-skeletal body is constructed. Unlike usual systems that approximates the human motion forces from the numerical differentiation of the calculated angle information, this system can obtain more precise human motion control force by measuring the motion acceleration information directly with all other inputs, which makes it possible for analyzing human dynamic motion control functions more precisely and is thus useful for biomimetic robots. By using the redundant human body model, we are studying the brain motor control functions through the dynamic simulations.

Keywords: Motion capturing, Musculo-skeletal simulator, Redundant muscle force, Mechanical impedance, Biomimetics

1 Introduction

Bio-mimetic research to obtain more dexterous and skillful motion like human movements has become one of the most important subjects in robotics. The objective of this research is not only for developing human friendly robots but also to clarify the brain motor control mechanism. To measure and analyze the real human motions, motion capturing systems are used widely. By integrating optical measurement and force plats, the joint torques can easily be calculated, however most of the existing systems use numerical differentiations in order to calculate the joint accelerations, which makes it impossible to obtain the precise joint torques [1, 2]. In order to simulate the dynamic human motions, there are also many researches and products, however, to obtain the redundant muscle forces from the calculated joint torques, the previous approaches mainly use mathematical optimization like a linear programming [1, 2] without any physical meaning nor biological investigations.

This paper proposes a novel platform for studying dynamic human motions. In the following sections, we first describe our dynamic motion capturing system and then show our 3D dynamic simulator of a whole body human musculo-skeletal system model. This platform has mainly two advantages. Firstly, this platform measures the acceleration information directly using accelerometers instead of 2nd numerical differentiation of angle information. Secondly, unlike the mathematical optimization approach to solve the redundant torque-muscle transformation, we apply "bilinear model" [3] of the muscle and solve this problem through a impedance control approach from the task realization point of view.

2 3D Motion Capturing System

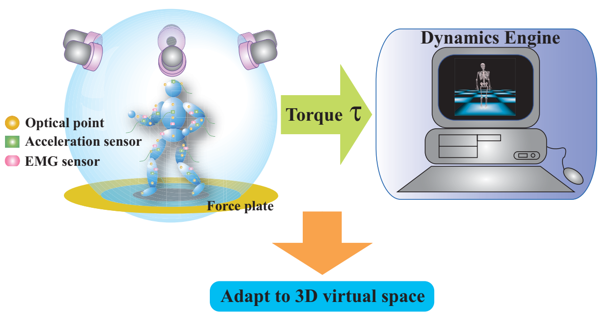

Fig. 1: A 3D motion capturing system

The overall motion capturing system developed in this research is shown in **Fig. 1**. This system has 6 high-speed cameras, 8 force plates, 30ches accelerometers and 32ches EMG sensors. As the most advantage of this system, the system measures the accelerations directly using accelerometers and also the myoelectric activities using EMG sensors synchronized with the high-speed cameras. Usually, the human acceleration information for calculating joint torques are obtained approximately only by 2nd numerical differentiation of the measured position data, which results in a large numerical error especially in quick motions. By measuring the accelerations directly, even for the fast dynamic human motions, it can be expected to obtain joint torques more precisely, which will be important for the dynamic simulation described in the next section. Experimental results of the calculated

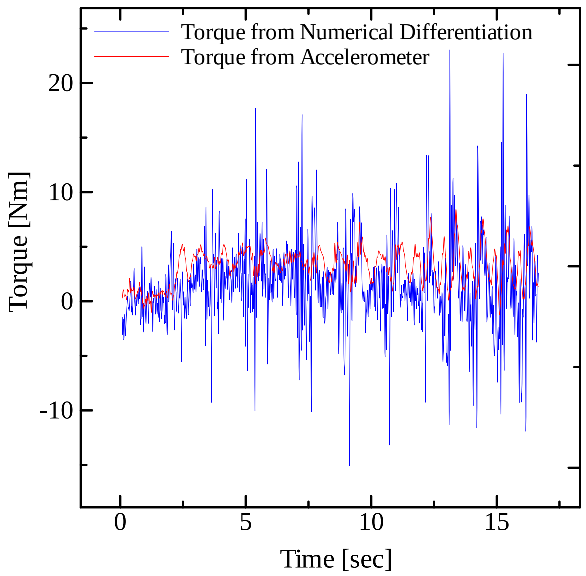

Fig. 2: The comparison of joint torques calcurated from numerical differenciation of position and from directly measured acceleration

torques for human shoulder movement is compared in **Fig. 2**. The blue line is the result of the numerical differentiation, while the red one is the result from directly measured acceleration. As seen from this figure, obviously, the torque data calculated from the numerical differentiation of the position has high frequency noise. However, the torque from the acceleration data is smoother.

3 Dynamic Musculo-Skeletal Model

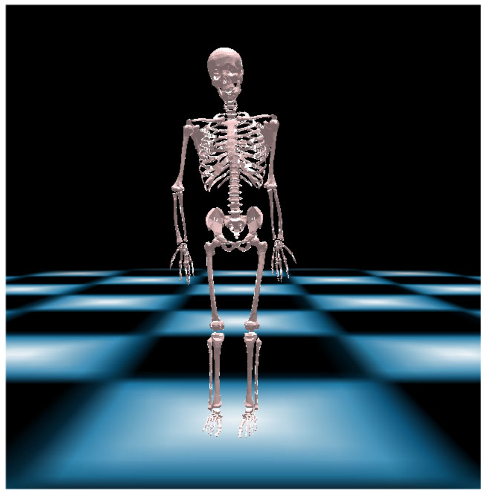

Fig. 3: Whole body skeletal system

In order to simulate and analyze the human motions, a dynamic simulator of whole body musculo-skeletal system is developed as shown in **Figs. 3** and **4** using programming library "Vortex". By input muscle forces, this simulator can easily calculate collision between each body parts as well as dynamic body movements within real time.

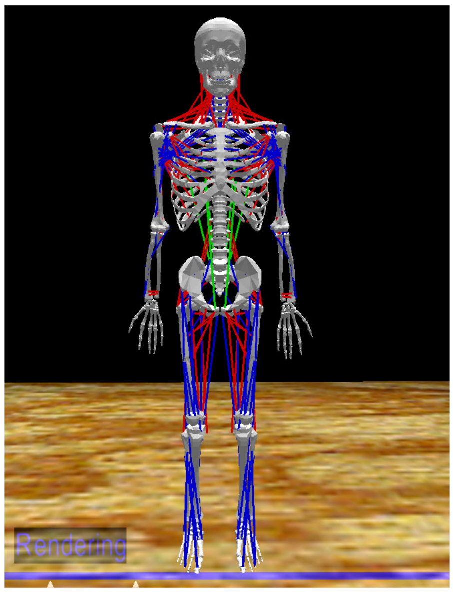

Fig. 4: Dynamic simulation of whole body musculo-skeletal system

Fig. 3 shows only a skeletal model, in which bones of the whole body are classified into 100 segments. The total motion degrees of freedom of the whole body have 105 D.O.F., which connect each body segments and drive the joint motions. **Fig. 4** shows the whole body musculo-skeletal model. In this model, 300 muscles are defined to attach between each bone segments. Since each muscle is defined as a line model, which starts from some body segment to the insertion point of another segment, the muscle via points should be defined in the model so as to realize more exact motion. As an example, we define the muscle via point about elbow joint as shown in **Figs. 5** and **6**. These via points only transmit the muscular force and change the force directions.

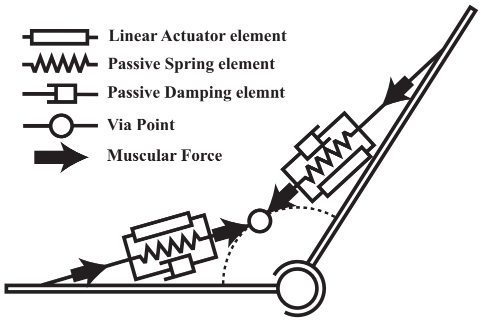

Fig. 5: Definition of muscle's via point

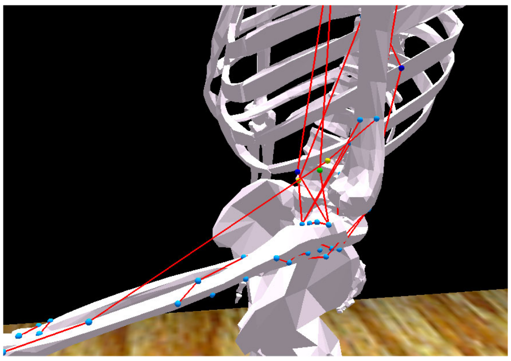

Fig. 6: The left elbow joint which defined via points

4 Determination of Muscle Forces

It is well-known that there are many muscles contributed to the motion of one joint. In order to move the musculo-skeletal system from the muscle space, we should solve the redundancy problem from the joint torque obtained in motion capturing system to each muscle forces. In this research, we apply bilinear model of the muscle and solve the above redundancy problem from the point of view of impedance control. For simplicity, let us consider a one link arm system which performs horizontal rotation with a pair of antagonistic muscles as shown in **Fig. 7**. The dynamics of this model is expressed by [3]:

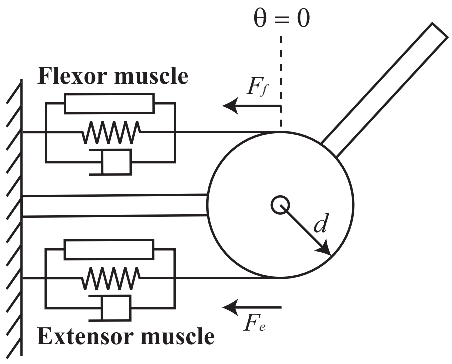

Fig. 7: Bilinear muscle model

$$\frac{M}{d}\ddot{\theta} = u_f - u_e - (u_f + u_e)(k\theta + b\dot{\theta}) \tag{1}$$

where ($\ddot{\theta}$, $\dot{\theta}$, θ) are joint acceleration, velocity and angle respectively. M is the inertia of link, d is the rotation radius. u_f and u_e are exerted forces from flexor and extensor muscles, respectively. k and b are positive elastic and damping coefficients. Eq.(1) denotes that, the difference of the flexor and extensor muscle force $u_f - u_e$ determines the joint torque and the sum of the two muscle forces $u_f + u_e$ determines the joint impedance. Therefore, joint impedance can be changed independently by internal force of the antagonistic muscles for the same joint torque. To show the effectiveness of this model, we consider a task to hole up an object from the floor. The object is connected with the floor by a spring. In this example, the differences between the flexor and the extensor muscle forces $(u_f - u_e)$ are the same, however the sums of the two forces $(u_f + u_e)$ are different. The resultant object's position responses are given in **Fig. 8**. From this figure, it is clear that, if the summed muscular force is relatively small, oscillation may happen. Therefore, in order to improve the task performance it is necessary to adjust the joint impedance by changing this summed muscular force. The redundant muscle force distribution problem can thus be solved from the task realization point of view. The results are compared in **Fig. 9**.

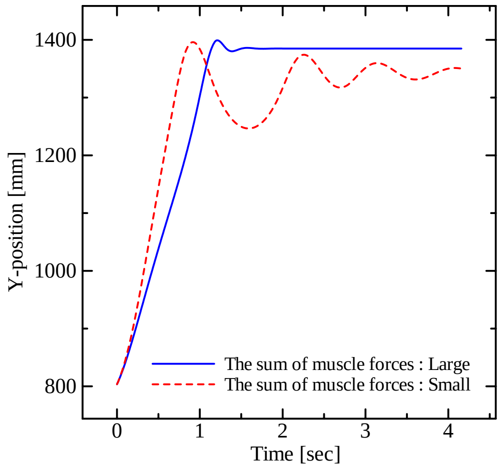

Fig. 8: Comparison of the object position response for the large and small sum of muscle forces

5 Conclusions

A dynamic motion capturing system that uses force plates, accelerometers and EMG sensors, and a dynamic human motion simulator are developed. Accelerometers may increase the accuracy when calculating the human joint torques.

In the future, to approach a redundancy problem between a muscle space and joint space from the point of view of mechanical impedance, the information of myoelectric activity should be applied. By this platform, we hope to clarify the mystery motor control mechanism of the brain in controlling such redundant and complex musculo-skeletal system.

References

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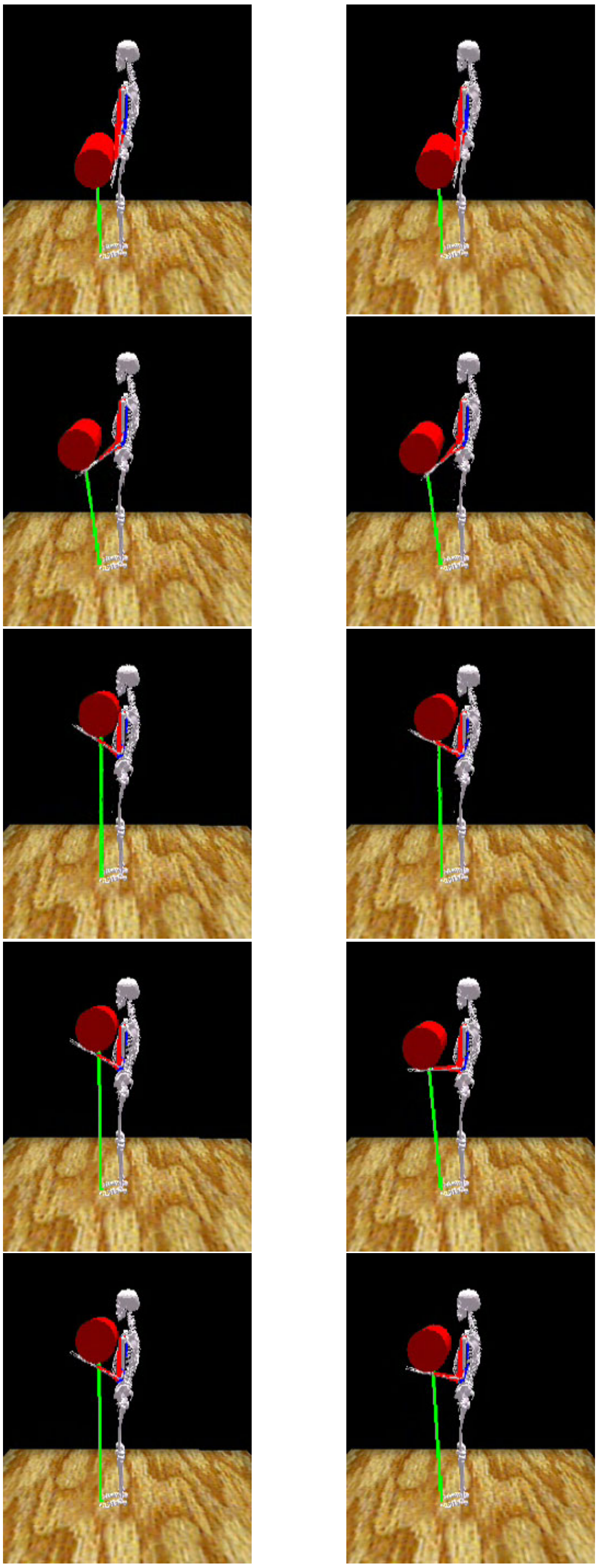

(A) (B)

Fig. 9: The results of holding up an object with large (A) and small (B) sum of muscular forces