An Open Biomechanics System using Commodity Hardware

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Abstract— Biomechanics is the study of the forces exerted by muscles and gravity on the skeletal structure on body using mechanics. It has applications in both medicine and sports, but the systems used are costly and complex. Our system for studying biomechanics uses off the shelf hardware and open software. We describe how skeletal joint coordinates captured using a Microsoft Kinect are fed into Stanford University's OpenSim system to visualise movement. A rigid body analysis of the arm has been done as a preliminary step towards a full musculoskeletal analysis of motion.

Keywords—Motion capture, Biomechanics, Microsoft Kinect, OpenSim simulator

I. INTRODUCTION

Recently a biomechanical analysis of human motion has caught the interest of scientists, researchers, and engineers throughout the world, as it can be used not only in medical treatments but also in sports. Our aim is to implement a biomechanics system at low cost and low complexity that is capable of analyzing the forces acting on the human body. We are using the Kinect device from Microsoft to capture human motion and analyze the forces using a musculoskeletal model (a model of a human skeleton with muscles) in the OpenSim simulator. We are currently focusing on the human right arm.

II. BACKGROUND

The biomechanical analysis is the analysis of parts of the human body in a scientific manner [1]. It is widely used in: (1) sports to identify causes of injuries so that they can be prevented and to monitor athletes' movements so that they can master techniques, and (2) medical applications to detect deviations in human movement patterns [2]. Biomechanical analysis can be done in two approaches, to do a rigid body analysis considering the human as a rigid body or consider the skeleton and muscles too in calculations. The former can be done using standard free body diagrams, but the latter requires some knowledge in human anatomy, string and damping constants of muscles and have to consider about effect of vibration that take place in body in motion. Therefore often in the field of biomechanical analysis simulators are used to simulate and analyze forces.

In rigid body analysis, the arm is considered as a rigid body and standard free body diagrams & mass acceleration diagrams are used to calculate forces as shown in Figure 1. Moreover, for simplicity, the effect of the muscles is assumed to be negligible. One bone will be considered at a time, and with acceleration data and mass data, it is possible to calculate forces acting on the joint. For an example, if we consider the forearm, if we have the acceleration data of wrist, and by approximating the mass of the arm and center of mass, we can calculate forces acting on the elbow. Using those results, in the same way, we can calculate forces acting on shoulder [3].

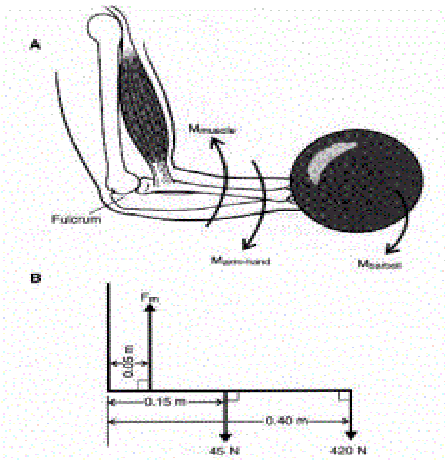

Figure 1. Force diagram of a hand lifting a weight [17]

OpenSim simulator [4] is a professional open source biomechanical analysis software. OpenSim mainly consists of models where users can analyze existing models and simulations and also develop new models and simulations. A model in OpenSim can represent a part of the human body or entire human body. A model is simply an XML file where each component (bones, muscles, etc.) is represented in XML tags. The software can perform inverse kinematics and forward dynamic simulations on these models [5]. Since we are focusing on the human arm, we are using the Arm26 and upper extremity models in Opensim. The Arm26 model has the capability of representing up to 6 muscles. This is a simplified model of upper extremity model that has the capability to analyze entire arm with up to 15 muscles [6].

Biomechanical analysis heavily depends on quantitative motion capturing techniques. To diagnose and treat various movement disorders, much movement should be captured and analyzed. Motion capturing is also widely used in various applications such as virtual reality for training simulations (military applications), 3D animated movies & video games and robotics.

Motion capture technologies can be broadly categorized as optical and non-optical. Non-optical methods include inertial systems, mechanical systems, and magnetic systems. However, optical motion capture systems are the most common.

Optical systems can be further classified as marker based and marker-less motion capturing. In marker based systems, the motion is captured by tracking markers that are attached to the body. This is the most popular method for capturing motion data at present, which has been used in the industry for a long period and has high accuracy with the results. However, the marker-based system needs special purpose cameras, and it requires special software and specially trained staff to work with the whole set up which leads to high operating cost. There are two types of markers: passive markers, where markers are coated with a reflective material, and active markers, which are powered to emit their light.

Marker-less motion capture is a lot cheaper and more convenient than marker based because it does not require any special equipment for tracking. Instead, algorithms needed to be designed to analyze multiple streams of optical input to identify human motion as a general marker-less motion capturing system consists of multiple cameras [7].

We are using the Kinect device, which is already designed to capture motion so that we can get the required data using the only single device. The theory behind the Kinect sensor is to use its video sensor and depth sensor to recognize the positions of human joints of a human in 3D space. The depth sensor continuously captures the depth differences and detects the particular skeleton [8].

III. Methodology

Figure 2 gives an overview of the entire project. The Kinect sensor is used to track the skeleton and capture the movement. Two outputs are given from the Kinect, a video of the motion and 3D coordinates of joints. Matlab is used to post process those captured data and visualize the motion and acceleration data graphically. Post processing includes averaging 3D coordinates to smooth out small variations. We then derive acceleration and convert 3D coordinates to Opensim format. We visualize the motion using the human arm model in OpenSim. At present, we are performing rigid body analysis using the acceleration data outside the Opensim.

A. *Motion capture and visualization*

To calculate forces, we need the acceleration at each joint. Since the Kinect device does not provide acceleration data directly, as in any optical motion capturing method, the motion data had to be captured as 3D coordinates. The Kinect sensor is capable of capturing 25 joints of human body and return the 3D coordinates of particular joints [9]. In order to make the coordinate data independent from the Kinect sensor's 3D coordinate system, coordinates of the wrist were taken with respect to elbow's position. Kinect APIs were used to track the skeleton and to get the video stream, and inbuilt functions were used to select relevant joints and get their 3D coordinates.

The default rate of thirty frames per seconds was used to capture data. Tracked skeleton was drawn on top of the video stream, with an indicator to mark the movement of the wrist. Then the coordinate data were written into a text file with a timestamp [10] [11].

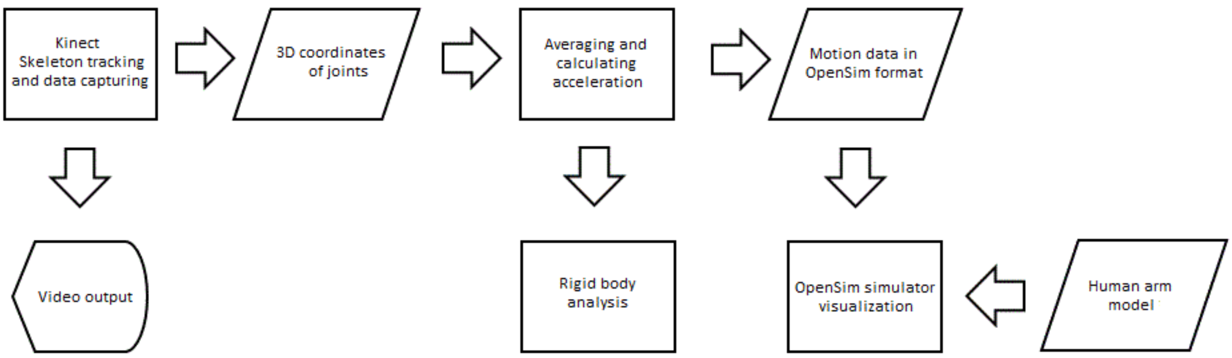

Figure 2. Abstract overview of the project

The collected position data had small fluctuations that affected the visualization of the motion. Therefore, they had to be smoothed. Figure 3 shows the effect of averaging. This was accomplished by calculating the moving average of position data at each point, resulting a more accurate motion visualization.

To visualize the motion, we used Arm26 model in OpenSim. Arm26 is a model of the human right arm, which has two variable parameters. We calculate the angle at the elbow and feed it with the timestamp to visualize motion. The calculated angle results are saved in motion file (.mot file) and then loaded into OpenSim.

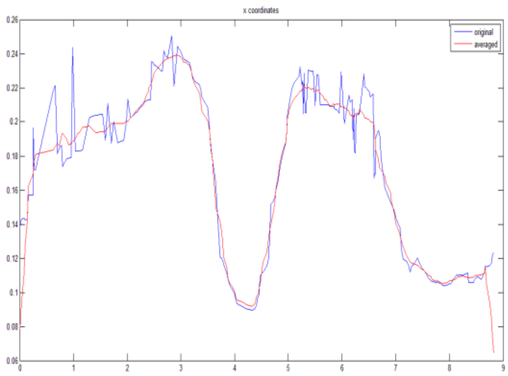

Figure 3 Averaged position data

B. *Deriving acceleration and rigid body analysis*

To derive acceleration from position data, numerical differentiation was required. Therefore, the set of X, Y and Z coordinates were interpolated to get position functions of time (x(t), y(t) & z(t)). By differentiating each function with respect to time, acceleration functions of time were derived (x''(t), y''(t) & z''(t)). These acceleration data also were visualized along with position data as shown in Figure 4. However, the process of obtaining the continuous functions by interpolating and then differentiating them twice has caused the accuracy of acceleration data to decrease. This lack of accuracy is a limitation of the system.

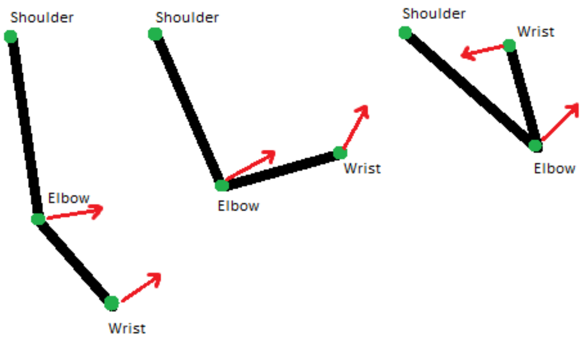

Figure 4. Acceleration on wrist and elbow with respect to shoulder

We then do a rigid body analysis to calculate forces at joints. Calculations are done using the derived acceleration data and approximated mass values for arm using standard values available. For the time being, forces at only elbow and shoulder are calculated.

IV. Related Work

Human movement capturing, and biomechanical analysis of human motion has been researched over the years. A comparative study about different methods and tools used for motion capture and analysis has been done [12]. This research is based on two motion capturing systems, Kinect, and Vicon. Vicon is a marker-based motion capturing system consist of eight high-speed digital cameras to compare with a Kinect system. They have assessed the accuracy of the Kinect system with respect to the Vicon system. According to their study, the Kinect system has good repeatability in its central region although there are some residual errors in data which can be fixed after calibration.

Another approach to motion capture using a single camera is real-time motion capturing using a single time-of-flight camera [13], which gives a stream of depth images. It requires processing the depth image stream to get the motion data, and further they have used GPU-accelerated filtering for processing to make it real-time. In the Kinect, a depth image stream is used together with the video stream to capture motion, but the processing is done on the device and we can directly get the motion data.

A simulation of one-handed handstand was done using a full body model in OpenSim simulator. In this research tools such as Static Optimization and Inverse Dynamics were run on the model to find what kind of forces were needed to hold the model up and to find moments on the wrist, elbow and shoulder joints respectively [14]. A similar biomechanical analysis has done using the above mentioned tools in another research, Muscular strategy shift in human running: dependence of running speed on hip and ankle muscle performance [15]. Although the motions are not similar to ours, the force analysis done in these research are considerably similar to our project.

Another project has been done on multimodal movement capture, used the Kinect and a smartphone accelerometer to capture position and acceleration data [16].

V. Conclusions and Future Works

So far, we have captured motion using the Kinect device and smoothed out small variations. We have then transformed position data into joint angles to visualize motion in Opensim. Also, we also derived acceleration from position data, to do a simple rigid body analysis. In future, we will perform a full musculoskeletal analysis of motion using OpenSim.

VI. ACKNOWLEDGEMENTS

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