Modeling Muscle Activities of Squat Motion using OpenSIM

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Abstract

Human beings need to be able to monitor their muscle health. Muscle health can be assessed by directly measuring its signal using an electromyography sensor or, recently, from a musculoskeletal modeling software such as OpenSIM. OpenSIM is an open-source platform for modeling, simulating, and analyzing the neuromusculoskeletal system. This work aims to simulate muscle forces during squat movement using OpenSIM simulation and validate the results using electromyography sensors attached to the body. The squat movement data generated from the optical motion capture system and the force plate will be used as inputs for the OpenSIM software. OpenSIM can provide output, such as a graph of the working muscle forces. That graph will be compared and analyzed with a surface electromyography sensor results graph. Based on the analysis results, the chart of working muscle forces generated by the OpenSIM software has shown a similar trend to the graph of muscle activity resulting from surface electromyography sensor reading. Therefore, the results from the OpenSIM software were validated, and it implied that the data collection process was done correctly.

Keywords: optical motion capture, force plate, surface electromyography, OpenSIM, musculoskeletal activities

1. Introduction

Health is an essential thing for humanity in survival. The human body consists of many parts that need to be cared for. One such part is the muscles. Muscles are parts of the human body that move the body [1]. Measurement of muscle activity is one of the routine checks in medical science to determine whether there is a disorder or abnormality of the muscle tissue in the patient. Muscle activity can be measured in several ways, but the most used is surface electromyography [2].

In this study, the movement that became the focus was the standing squat movement. This movement is used in daily basic activities such as walking, ascending and descending stairs, sitting down and standing up [3-4]. In this squat movement, the focus muscle is the rectus femoris. This standing squat movement was chosen because it is the most straightforward exercise in evaluating the fitness or health of the people who are the background of this study [5]. This movement also requires a large enough muscle force that can be easily read by the sEMG sensor [6].

Over the past ten years, OpenSIM, an open-source platform that models, simulates, and analyzes the neuromusculoskeletal system [7], has been extensively utilized to measure and simulate muscle forces. The objective of this study is to simulate muscle forces during squat movement using OpenSIM simulation and validate the results by attaching electromyography sensors to the body.

2. Methodology

Participant

A total of 1 participant was recruited for this study. The subject is an Asian, with a height of 173 cm and a mass of 68 kg (BMI: 22.7 kg/m2). The subject recognized the movement needed because the subject had a history of physical exercise in the gym or outdoors for the past year. The participant was physically active without lower extremity disorders or injuries in the past six months before the test. The subject was informed of the objectives and requirements of this study with consent.

Experimental Protocol

There are three systems that run synchronously during the subject's data retrieval: the motion capture system that measures the subject's movement, the force plate system that measures ground reaction forces, and the surface electromyography that measures the subject's muscle activities.

The Biomechanics Research Team at the Mechanical and Aerospace Engineering Faculty Institut Teknologi Bandung has developed a motion analyzer system using four GoPro cameras as its recording visual for motion capture research. These four cameras will synchronously record activities that the subject performs. Subject was attached with 12 markers as shown in Figure 1. Recording of squat movement will be done simultaneously with the ground reaction forces measurement. The experimental layout illustration is shown in Figure 2a. A force plate with a frequency of 2000 Hz is used to measure ground reaction forces of one leg (right leg). To record muscle activities during squat, a surface electromyography was used to retrieve the Rectus Femoris muscle signals (as shown in Figure 2b) with a 50 Hz frequency. The recording results from cameras will be further processed using a motion analyzer system to get markers' trajectories in real coordinate.

Before taking experimental data, calibration process should be done to the force plate, the cameras, and surface electromyography. After calibration, the subject was given some time to exercise the squat movement to get used to it.

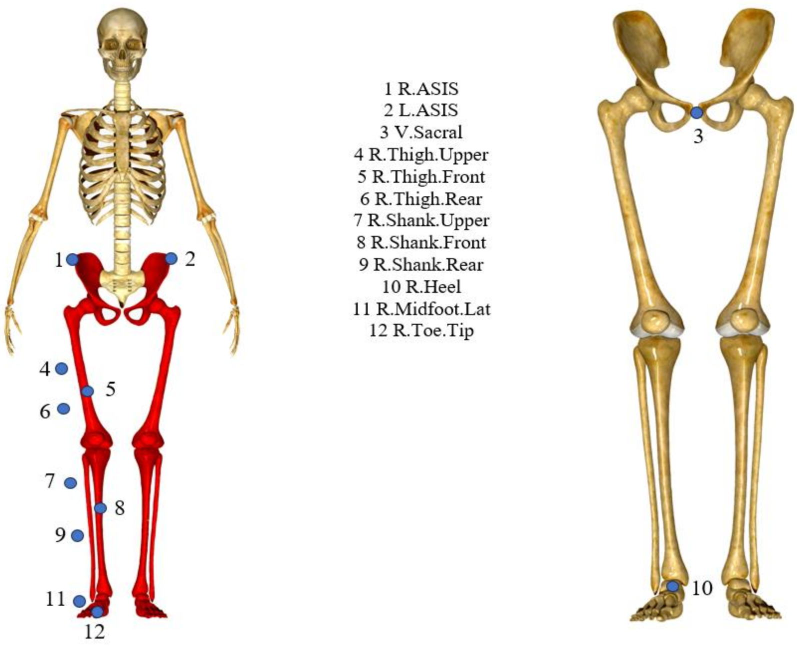
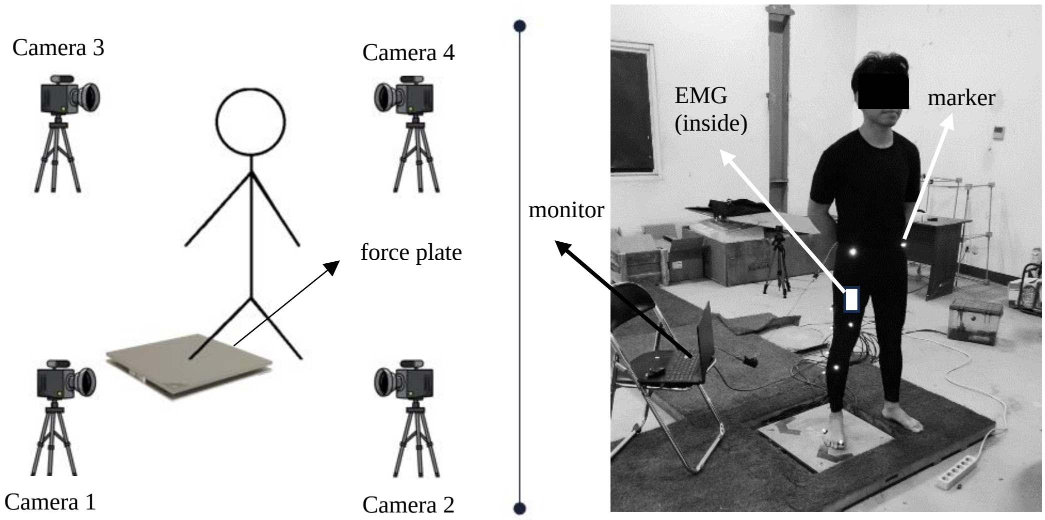


Figure 1. Marker placement illustration



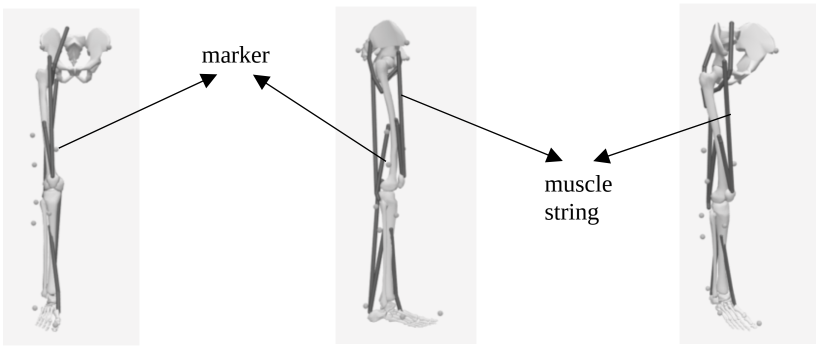
(a) experiment layout illustration

(b) subject with markers and EMG

Figure 2. Experiment layout

Muscuskeletal model

An OpenSIM musculoskeletal model of 1 leg with 12 markers was used in this research. This musculoskeletal model provided by OpenSIM was enough considering this research only focuses on the lower extremity body and is based on the subject medical history with no prior abnormalities with his legs and also based on the assumption either the movement or the muscle of the subject's legs were identical. Thus, conducting research with one leg musculoskeletal model was adequate as shown in Figure 3.

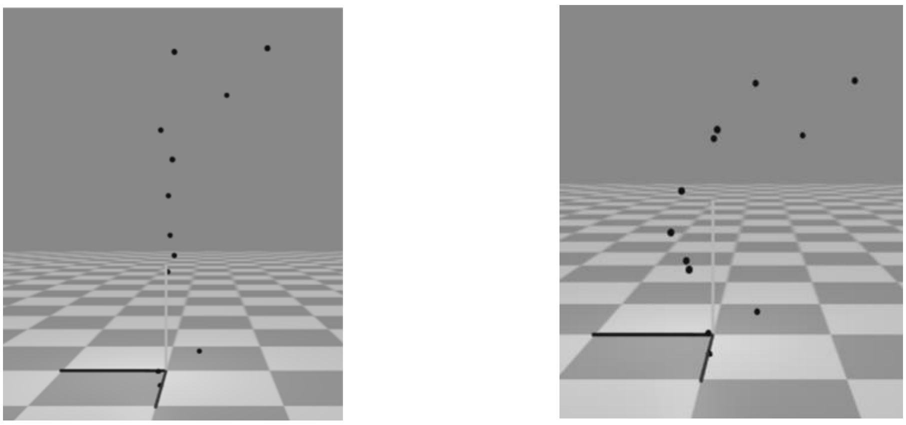


(a) front view (b) right view (c) isometric view

Figure 3. One leg model provided by OpenSIM

3. Result and Discussion

Marker trajectories and ground reaction forces data obtained from the experiment as shown in Figure 4 and 5, respectively, were fed as input to OpenSIM v4.4. A standard OpenSIM workflow was used in this research [7]. Firstly, the subject's static marker position and body mass were used to scale the model to achieve a participant-matched model, as shown in Figure 6. Secondly, the Inverse Kinematics tool was used to simulate movements using subject’s marker trajectories to the participant-matched model. (shown in Figure 7).



(a) standing position (b) squat position

Figure 4. Marker position illustration in real-world coordinates

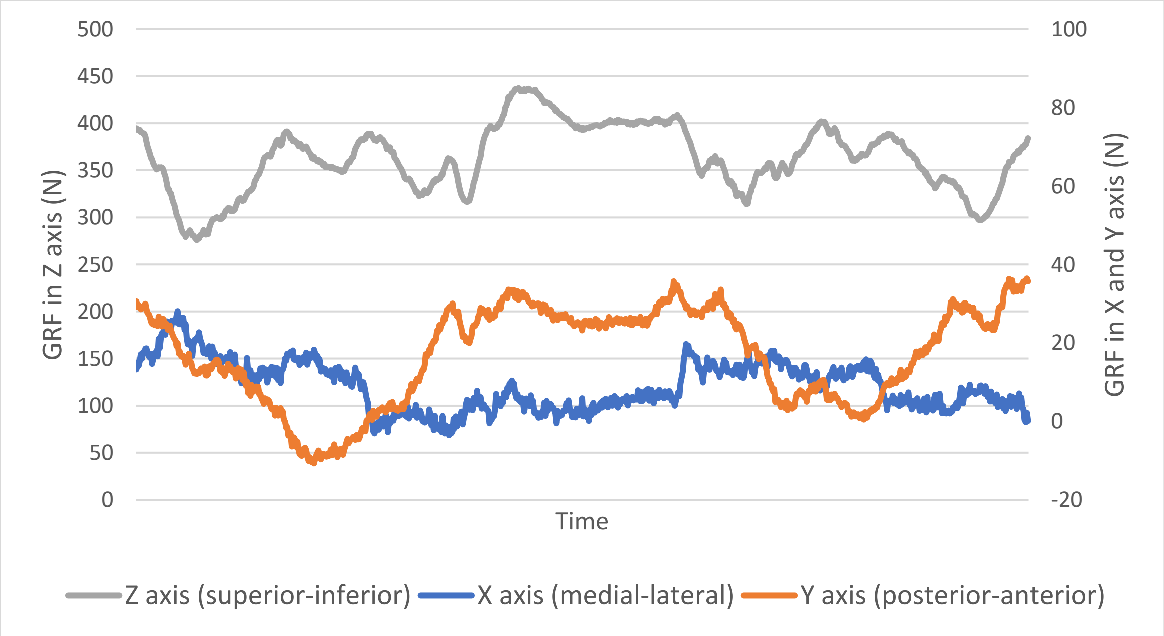


Figure 5. Graph of results from force plate recording

(a) before scaling (b) after scaling

Figure 6. Leg model before and after scaling process

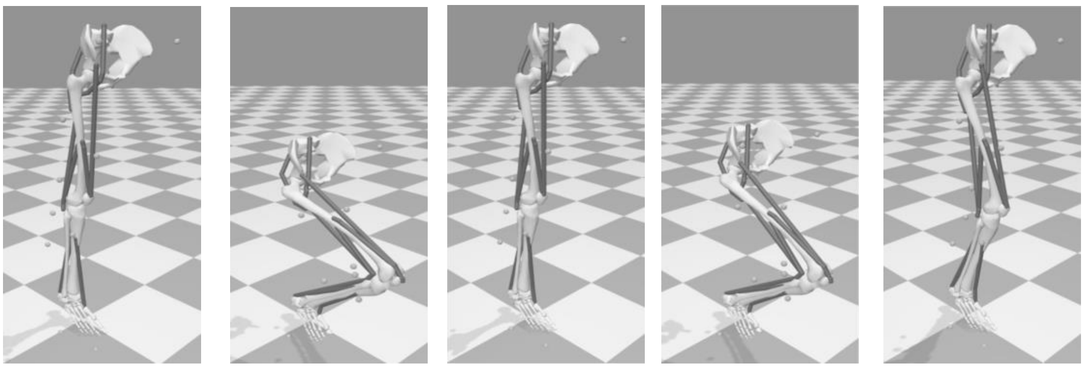


Figure 7. One cycle of standing squat movement

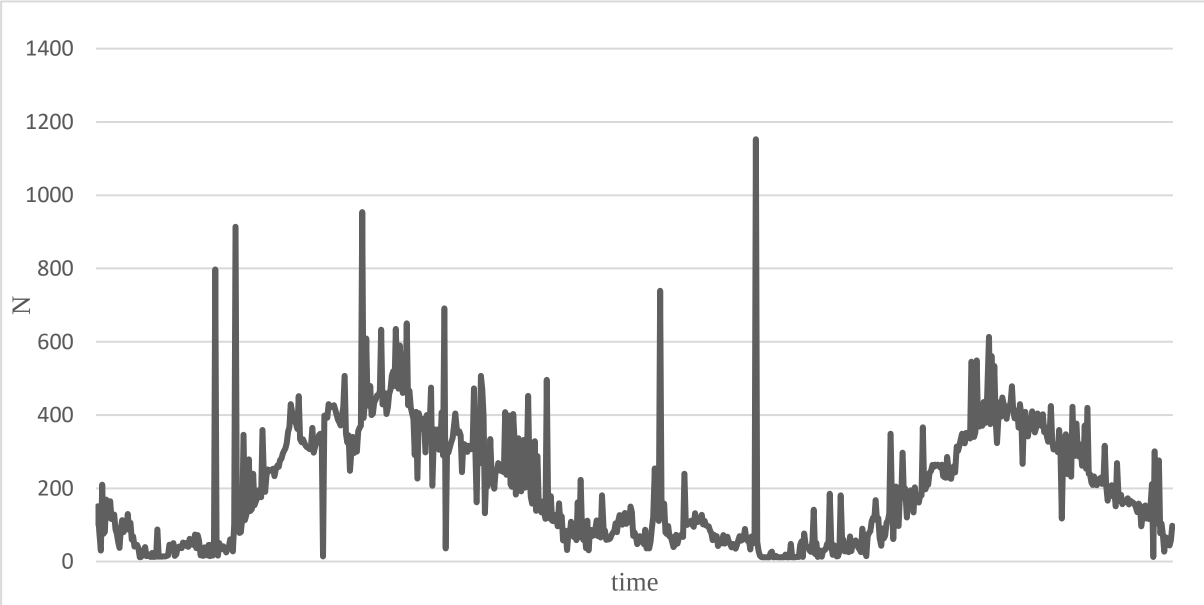


Figure 8. Graph of muscle force after static optimization

After the model has been integrated with the movements following the data retrieval results, the Static Optimization tool was used to estimate the The resulting graph from OpenSIM software is then exported into Excel and combined with the data from electromyography sensor readings. Then the two data are plotted in the exact figure, with two different graphs to compare and see for compatibility. Even though the measurement unit between the two graphs are different, where the muscle force unit from muscle force in graphical form, as seen in Figure 8 [7-10].

simulation is in Newton and the muscle signal from surface electromyography is in mV, those graphs are measuring the same muscle activities. These two graphs can be seen in Figure 9. However, these graphs contain so much noise and must still be smoothed. Figure 10 shows the smoothed graphs.

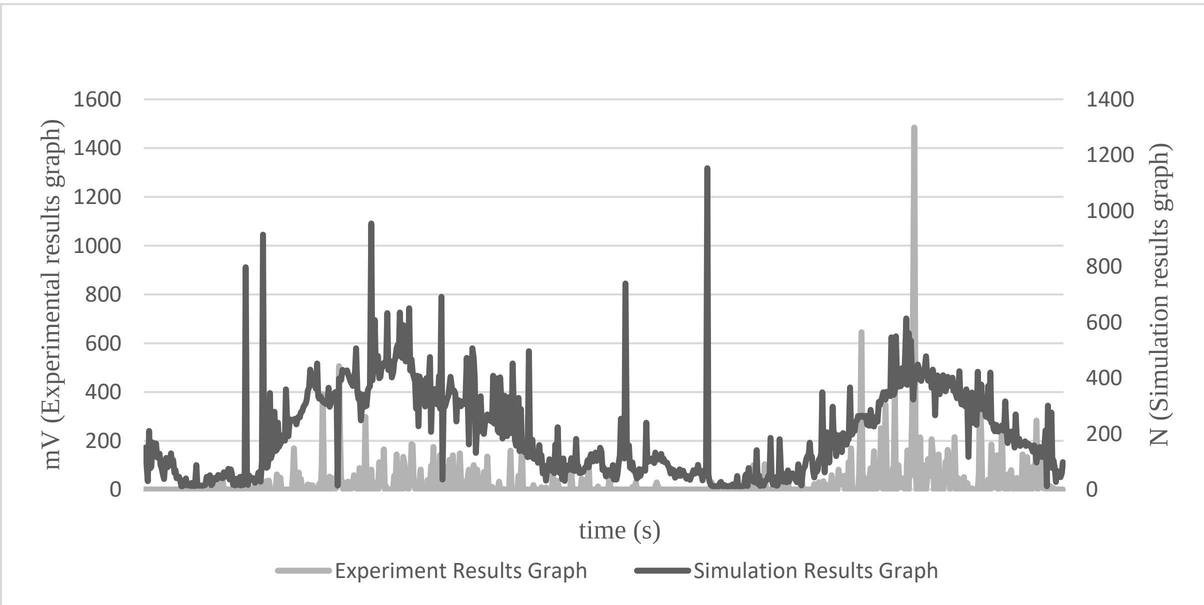


Figure 9. Comparison Graph Between Experimental Results and Simulation Results

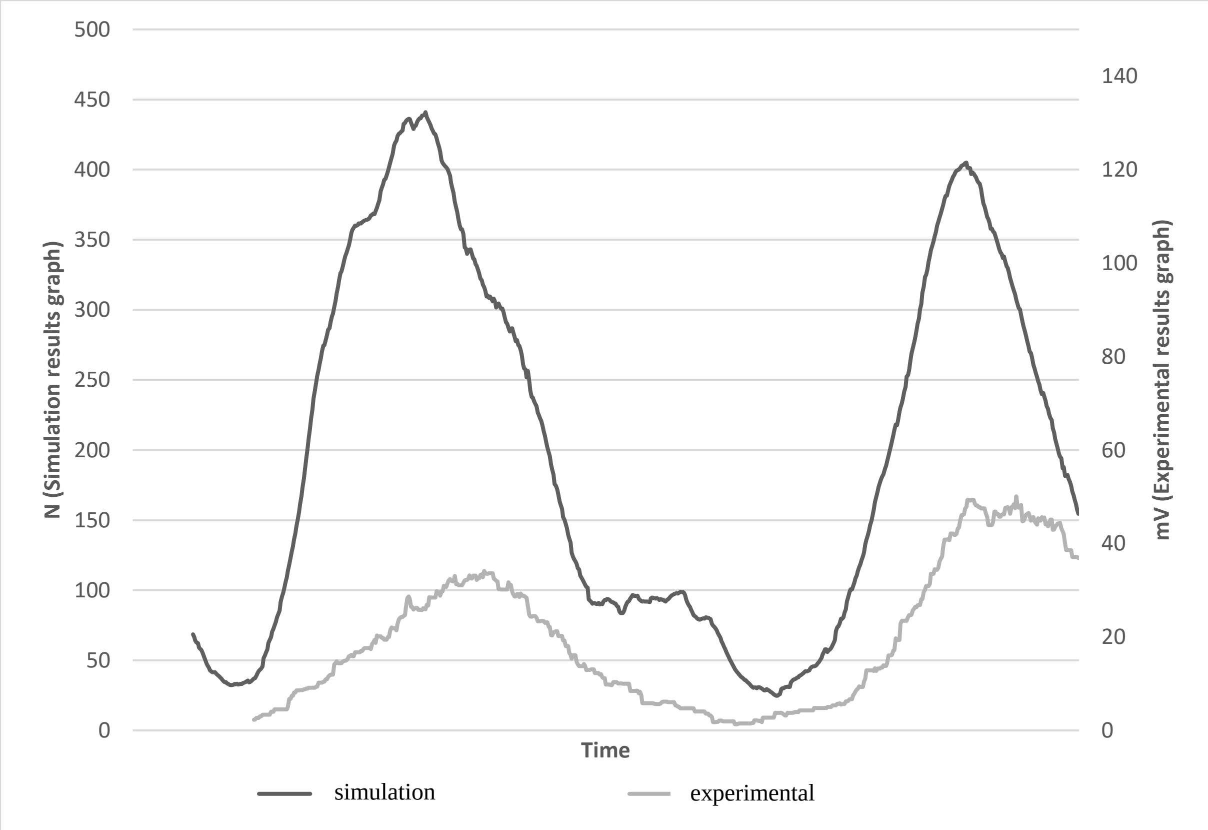


Figure 10. Comparison of the smoothed graph of experimental and simulation results

From the comparison above, the two graphs are seen as identical. Therefore, it shows that the OpenSIM simulations could measure the same muscle activities in the standing squat movement as measured by surface electromyography.

4. Conclusions

This work used OpenSIM, an open-source platform for modeling, simulating, and analyzing the neuromusculoskeletal system, to simulate muscle forces during squat movement. In order to do that, the squat movement data generated from the optical motion capture system and the force plate were used as inputs for the OpenSIM software. Muscle activities during the squat movement were recorded simultaneously with surface electromyography attached to the rectus femoris muscle to validate the results. A comparison between muscle force results obtained from OpenSIM and muscle activity signals from surface electromyography shows that both graphs are identical. This result shows that OpenSIM was simulating the same signal activities measured by surface electromyography. Using similiar procedures, muscle activities in other body parts can also be simulated with the OpenSIM software.

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