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Biomechanics Analysis: Development of Biomechanics Analysis Algorithm with OpenPose Motion Capture System

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Abstract: This research is about to develop a biomechanics analysis algorithm to do quantitative biomechanics analysis on the movement of a person. This research is conducted because the analysis done by the coaches to their athletes is a qualitative analysis. This kind of analysis may not be understood clearly by non-experts. The objective of this research is to retrieve motion captured data from OpenPose open source code, to develop biomechanics analysis algorithm from the captured data and to perform distance, velocity, acceleration and angular biomechanics analysis with developed algorithm. The motion capture in this research will be performed by using OpenPose Demo. The coordinate data of the keypoints analysed by using OpenPose Demo is only x and y axes which refer to the pixels of the screen and the origin is the right bottom corner of the screen. This also means that the coordinate data of the keypoints is in 2 dimensiona (2D). The obtained 2D coordinate of keypoints will be analysed by the developed biomechanics analysis algorithm to obtained angle, distance travelled, velocity and acceleration of the keypoints. The algorithm developed is for biomechanics analysis. The biomechanics analysis algorithm only analyses kinematic such as velocity and acceleration and displacement and angle. In this research, the source code of the OpenPose Demo is first downloaded from GitHub and installed into laptop. OpenPose Demo is used to do motion capturing and collecting data of the keypoints of the body. The MatLab is also installed for developing an algorithm for retrieving coordinate data from the data of motion captured and it is also used to develop algorithm for biomechanics analysis. Then, the developed algorithm will be tested. The angle analysed by using the developed biomechanics analysis algorithm is smooth. However, the displacement, velocity and acceleration analysed by using the developed biomechanics analysis algorithm are fluctuating. The results of the displacement, velocity and acceleration is fluctuating because of the inconsistent of the frame per second (fps) of the OpenPose Demo. Furthermore, the coordinate of the keypoints analysed by OpenPose Demo is 2 dimensional coordinate and the pixels are the reference of the coordinate. Hence, OpenPose Demo required to be replaced by a more advanced motion captured system in order to collect more accurate motion data.

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Keywords: Develop, Biomechanics Analysis Algorithm, Motion Capture System, OpenPose Demo, Coordinate, Keypoints, Kinematic, Angle, Displacement.

1. Introduction

Biomechanics is the study of the structure, function and motion of the mechanical aspects of biological systems, at any level from whole organisms to organs, cells and cell organelles using the methods of mechanics. Biomechanics is a branch of biophysics. Basically, biomechanics is the mechanism that limit the movement and also allow some specific movement of a living body.

Every species of living things have his own biomechanics and these biomechanics can also be one of the elements that used to differentiate the species of living things. For an example, the biomechanics of humans allow humans to walk with the longest time in Earth compared to other species of living things. Although primates do not have much different on biomechanics compared to humans and they can stand upright, they still cannot walk with longer time compared to humans. Therefore, different species have different body movement abilities although they have a bit different on biomechanics.

Biomechanics of humans allow humans to stand upright, walk, run, jump, swim, carry and throw objects. The biomechanics have assisted humans on doing tasks in daily life. It is also limit movement of the body to prevent humans to do some movements that may injure their bodies. Furthermore, biomechanics also play an important role in sports for humans. There are many sports have been created for humans to allow human to perform their ability of biomechanics in the sports competitions. Humans will train their body to utilize their biomechanics effectively in order to have better performance in the sport competitions..

1.1 Biomechanics analysis in sport

In sports, athletes' performance has no limit and could be improved through training. Athletes are always have to follow the instructions and suggestions from their coaches or instructors in order to improve their performance. The suggestions and instructions given by coaches are based on the qualitative analysis on athletes' performances. The qualitative analysis done by couches with their experiences by observing the biomechanics of the athletes and getting the qualitative results and do analysing. According to the qualitative analysis, athletes will be suggested to improve their muscles' capability and do some specific repetitive training in order to improve their performance. However, the qualitative results cannot be understood easily by the non-experts.

For an inexperienced people, they will have more understanding on the quantitative analysis compared to qualitative analysis. Quantitative analysis will have more detail analysis on the biomechanics parameters such as movement distances, angles, movement speed and acceleration. Quantitative measurement can also assist the coaches to give more accurate and clear instruction to the athletes. Therefore, this research will develop a biomechanics analysis algorithm to do quantitative analysis on biomechanics of human body. The biomechanics analysis algorithm is not only develop for the non-experts, it is also developed to assist the coaches in their decision making by providing quantitative measurement of athletes' performance.

1.2 Motion capture (MOCAP)

Motion capture also known as MOCAP which is the process on recording the movement of people digitally. MOCAP will be used in entertainment, sports, medical applications, ergonomics, and robotics. MOCAP is normally used in entertainment for film making and game development [1]. The motions of the actors will be digitally recorded by MOCAP and then the motion captured will act as the base structure of the animation and visual effects which will be added on the motion captured. Furthermore, motion capture is also play an important roles on sports biomechanics and also medical application. There are also many studies and researches are about the biomechanics analysis which have been done by using motion capture. In the study of biomechanics, Motion captured (MOCAP) system is also provide kinematic data as an output [1].

Motion captured can be done by using many different ways. This means that there are many types of motion capture such as optical-passive, optical-active, video (markerless), and inertial sensors. Optical-passive motion capture is the technique that uses retroreflective markers which can be tracked by infrared cameras. For Optical-active motion capture, the LED markers which can emit light will be used and tracked by a special camera in order to capture the motion. For video or markerless motion capture, the motion captured does not required any markers and it is relying on software, algorithm or system to track the movement of a subject. For inertial sensors motion capture, cameras are not necessary required in this type of motion capture except as a localization tool. Inertial sensors are also now as IMUs which are worn by the subject and the data collected by the sensors will be transmitted to the computer wirelessly. From the types of motion capture explained before, the types of motion captured can be classified by inertial sensors, maker-based and markerless-based motion capture. Optical-passive and optical-active motion capture are the types which can be classified as the marker-based motion capture.

2. Materials and Methods

In this research, this first step is to obtain the motion data as an input data for the algorithm to anlyse the angle, displacement, velocity and acceleration of the keypoints of the motion. In this research, the motion capturing system used to obtain the motion data is OpenPose Demo. Then, the motion data obtained from OpenPose Demo will be put into the biomechanics analysis algorithm developed in this research. The biomechanics analysis algorithm is developed by using MatLab. There are some theories have been included into the developed biomechanics analysis algorithm. The theories applied in the algorithm are theory of calculating angle between two vectors and the theory of calculating velocity and acceleration. In this research, the developed biomechanics analysis algorithm will be used to analyse angle, displacement, velocity and acceleration.

2.1 Materials

The material will be used to run this research and develop the biomechanics analysis algorithm are OpenPose Demo and Matlab. OpenPose Demo is used to analyse the coordinate of the 25 keypoints such as ears, eyes, nose, neck, shoulders, elbows, wrists, hips, knees, ankles, heels, big toes and small toes. The interface of the OpenPose Demo is shown in Figure 2.1. The coordinate of the keypoints is estimated by referring to the pixels of the screens. For the MatLab, it is used to develop the biomechanics analysis algorithm.

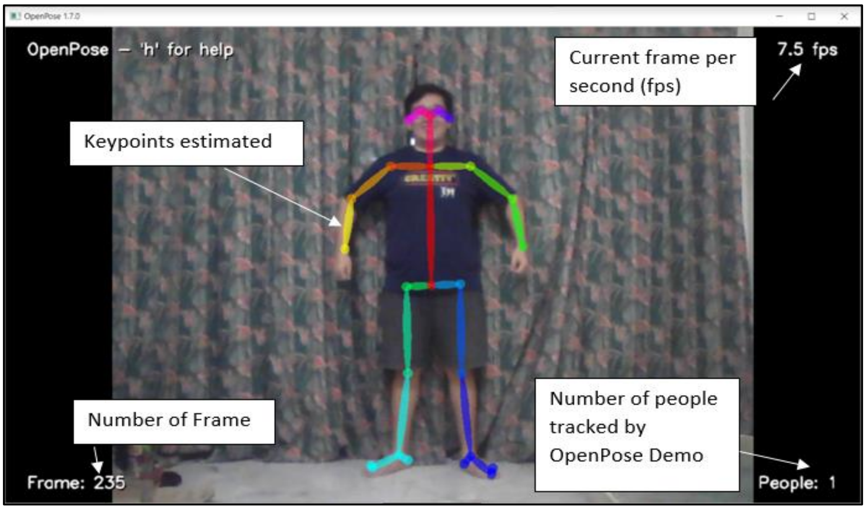


Figure 2.1: The interface of the OpenPose Demo.

2.2 Methods

The data analysed by the OpenPose Demo will be saved into JSON files where each JSON file will saved the keypoints data from each frame estimated by OpenPose Demo. Then, the coordinate data of keypoints will be retrieved from the data of the keypoints from JSON files by using the algorithm developed in this research. After the coordinate data has been retrieved, the data retrieved will be put into the biomechanics analysis algorithm for analysing angle, displacement, velocity and acceleration. There are two method will be applied in the developed a biomechanics analysis algorithm. The first method is calculating angle between two vectors. The second method is the physics theory on analysing velocity and acceleration.

2.3 Method calculate angle between two vectors

The method used to find the angles is the method calculating the angle between two vectors. Figure 2.2 has shown the example of two different vector and the angle between two vectors with the coordinates of each points.

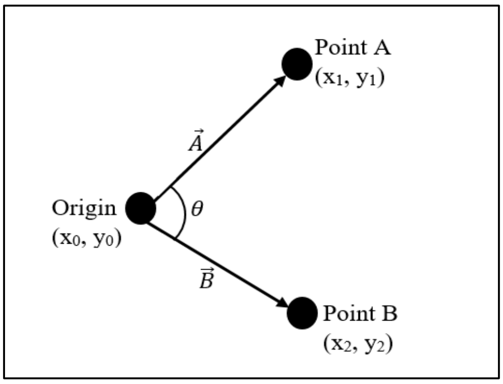


Figure 2.2: Vector A from origin to point A and Vector B from origin to point B.

The vector A and B can be obtained by using the coordinate of the points with the equations:

$$\vec{A} = \langle (x_1 - x_0), (y_1 - y_0) \rangle = \langle x_A, y_A \rangle \ldots\ldots (1)$$

$$\vec{B} = \langle (x_2 - x_0), (y_2 - y_0) \rangle = \langle x_B, y_B \rangle \ldots\ldots (2)$$

After the vector of A and B is obtained, vector A dot vector B and magnitude of vector A and vector B will be calculated by using the equations:

$$\vec{A} \cdot \vec{B} = (x_A)(x_B) + (y_A)(y_B) \ldots\ldots (3)$$

$$Magnitude\ of\ \vec{A} = \|\vec{A}\| = \sqrt{{x_A}^2 + {y_A}^2} \ldots\ldots. (4)$$

$$Magnitude\ of\ \vec{B} = \|\vec{B}\| = \sqrt{{x_B}^2 + {y_B}^2} \ldots\ldots. (5)$$

Finally, the angle θ can be obtained by using the equation:

$$\theta = \cos^{-1}\left(\frac{\vec{A} \cdot \vec{B}}{\|\vec{A}\|\|\vec{B}\|}\right) \ldots\ldots (6)$$

Therefore, the angle can be obtained by using coordinate of three points. Hence, the coordinates of shoulders, neck and elbows is enough for calculating the angle of joints at shoulders. If the shoulder acts as the original point, neck act as point A and elbow acts as point B as shown in Figure 2.2, the angle of the joints at shoulders can be obtained by using the equations from (1) to (6). Hence, this is the method to find the angle of joints. Each numbered equation should be in its line and be separated from the surrounding text by the default line spacing. Eq. 1, as are all equations, should be referenced in the text.

2.4 Method of analysing velocity and acceleration

In order to calculate the velocity and acceleration of the key points, the collecting of the data of displacements of the key points is necessary. The displacements of the key points can be measure by the number of pixels travelled by the key points. The displacement of the key points can be calculated by using the coordinate of the key points of current frame (x_n, y_n) minus the coordinate of the key points on the first frame (x_0, y_0). Then, the magnitude of the vector of the displacement will be calculated by using equation (7):

$$Displacement\ (pixels) = \sqrt{(x_n - x_0)^2 + (y_n - y_0)^2} \ldots\ldots (7)$$

The magnitude of the displacement of key points in the video can be obtained by using equation (7). After the magnitude of the displacement in the unit of pixels obtained, the time also need to be calculated before calculating velocity and acceleration. The frame per second (fps) will be calculated by using equation (8).

$$Frame\ per\ second\ (fps) = \frac{Number\ of\ frame}{(Time\ different\ between\ last\ frame\ and\ first\ frame)} \ldots\ldots (8)$$

Then, the velocity of the key points travelled from a frame to next frame will be obtained by the product of the magnitude of the displacement of the keypoints travelled from a frame to the next frame and the frame per second (fps). The equation will be:

$$Velocity = Displacement\ (Pixels) \times Frame\ per\ second\ (\frac{1}{s}) \ldots\ldots (9)$$

When the velocity of obtained, the acceleration will be obtained by calculating the product of the change in velocity and the frame per second. The equation for calculating the acceleration is:

$$Acceleration = Change\ in\ velocity\ \left(\frac{Pixels}{second}\right) \times Frame\ per\ second(\frac{1}{s}) \ldots\ldots (10)$$

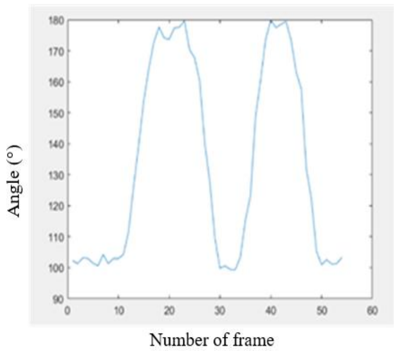
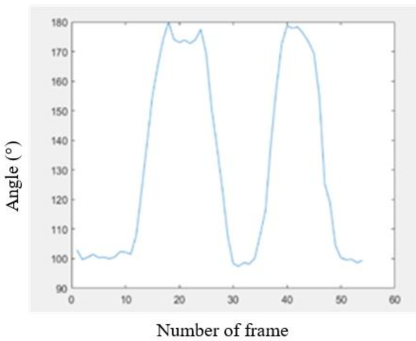
Therefore, these are the methods which will be used to calculate the velocity and acceleration of the key points.

3. Results and Discussion

After the algorithm of biomechanics analysis has been developed, the developed algorithm will be used to analyse the angle of the shoulders, displacement, velocity and acceleration of shoulders, elbows and wrists when doing two repetition of hand side lifting as shown in Figure 3.1. From Figure 3.1, one completed hand side lifting is starting from the first position to second position when hands are horizontally aligned and then going back to position where hands is putting down.

Figure 3.1: Hand side lifting.

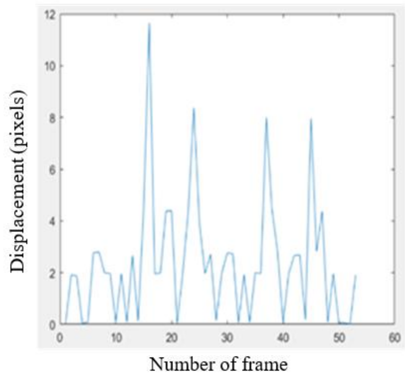
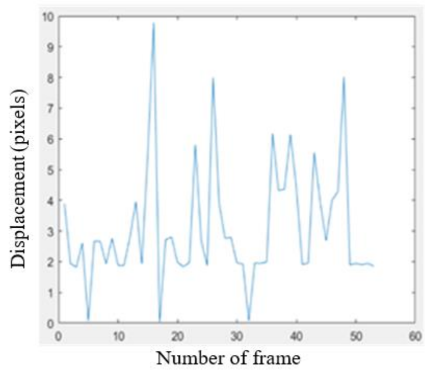
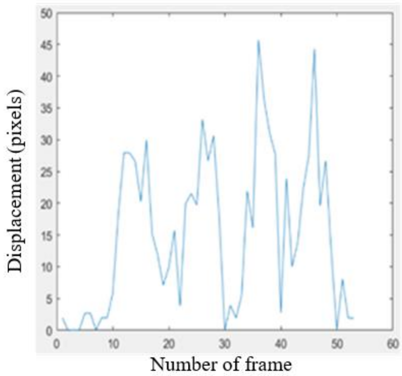
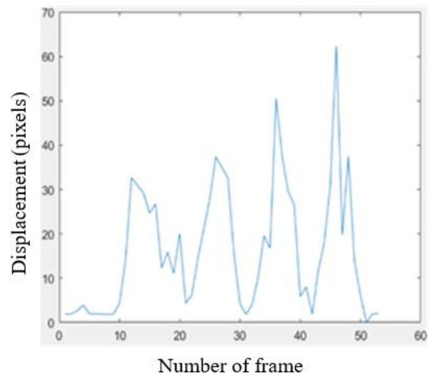
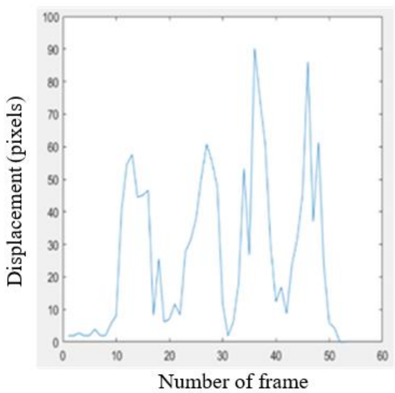
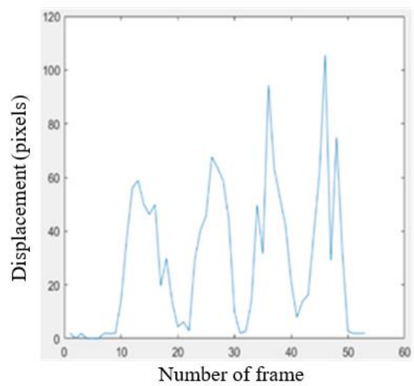
Table 3.1: The graph of the angle of shoulder of doing side lifting as shown in Figure 3.1 against the number of frames.

Set	Right Shoulder	Left Shoulder
1		

From Table 3.1, the graphs show the same trend which have two upward curve. The maximum of the graphs as shown in Table 3.1 are in between 170 degree to 180 degree and the minimum of the graphs are around 100 degree. If the maximum angle of shoulders represent 2 and the minimum of the angle of shoulder represent 1, the trend of the graphs will be 1,2,1,2,1. The trend of the graph is same with the sequence of doing side lifting as shown in Figure 3.1.

When the maximum angle of the shoulder is represent the second posture of side lifting as shown in Figure 3.1, the angle of the shoulder of second posture of side lifting will be 170 degree to 180 degree. When the minimum angle of the shoulder is represent the first posture of side lifting as shown in Figure 3.1, the angle of the shoulder of first posture of side lifting will be around 100 degree. From here, the testing has proven that the algorithm to analyse angle can be used to analyse angle from the data of keypoints obtained from OpenPose Demo.

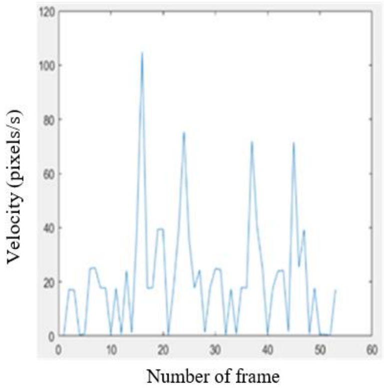
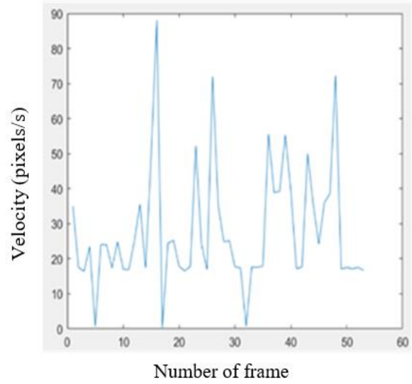
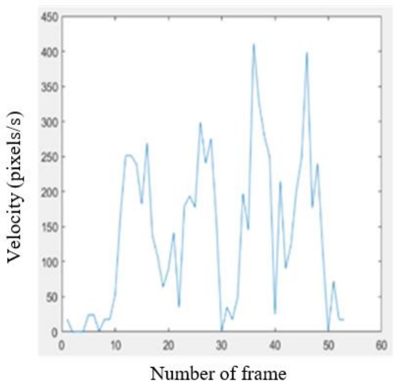
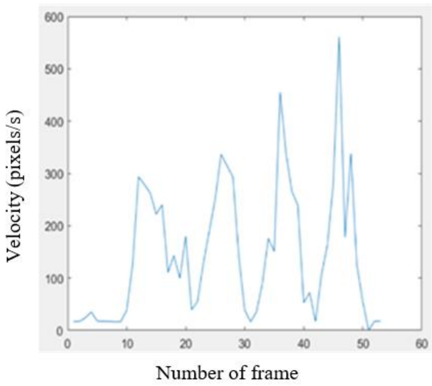
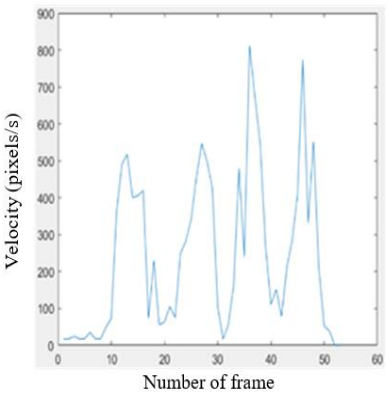
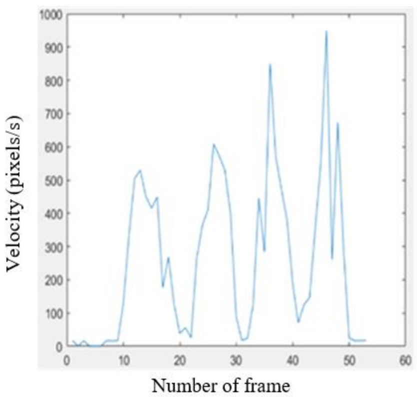
Table 3.2: The graphs of the displacement against the number of frame.

Keypoints	Right side	Left side
Shoulder		
Elbow		
Wrist		

From Table 3.2, the displacement obtained for the keypoints of right and left shoulders, elbows and wrists travelled from a frame to the next frame have been plot into the graphs of the displacement against the number of frame. The displacements of the keypoints of shoulders are within the range of 0 pixel to 12 pixels and the displacements of shoulders are the smallest compared to the displacement of the elbows and wrists. This is because shoulder do not have great movement when doing side listing as shown in Figure 3.1.

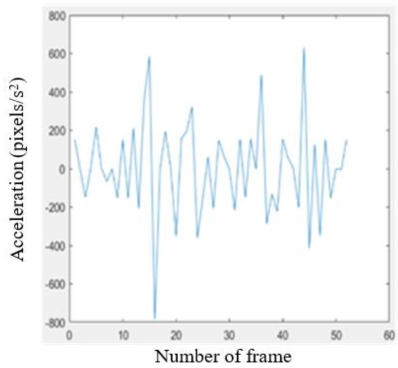
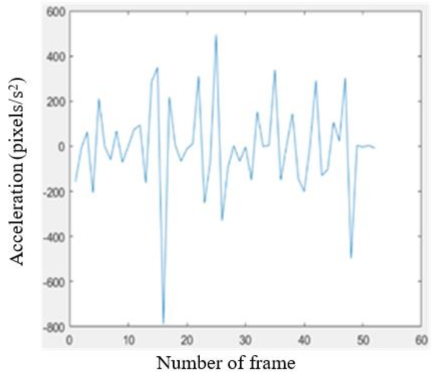
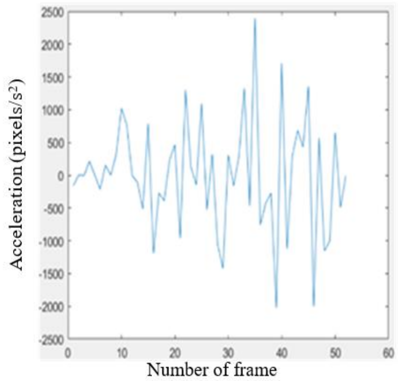
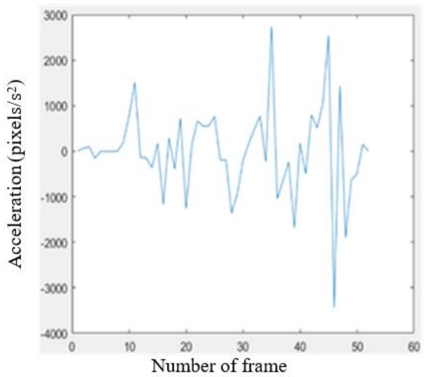
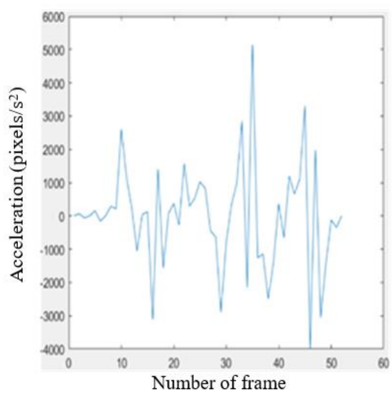
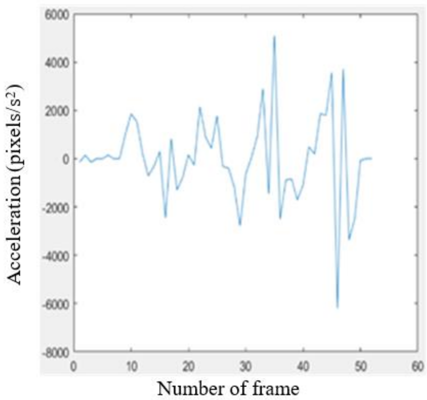
Then, the displacements of the wrists are within 0 pixel to 100 pixel and the displacements of the wrists are the largest compared to shoulders and elbows. This is because the wrists are on the outer layer of the angular movement when doing side lifting as shown in Figure 3.1. The arms are moving with the same angular velocity when doing side lifting as shown in Figure 3.1, so the wrists will require to travel more distance compared to elbow when doing the side lifting as shown in Figure 3.1. This because wrist located at further place from shoulder compared to elbow. The trends of the graphs of elbows and wrists as shown in Table 3.2 are almost the same because they are move in the same angular velocity.

Table 3.3: The graphs of the velocity against the number of frame.

Keypoints	Right side	Left side
Shoulder		
Elbow		
Wrist		

For the graphs as shown in Table 3.3, the graphs of velocity against the number of frames is plotted for the keypoints shoulders, elbows and wrists. The trends of the graphs shown in Table 3.3 are same as the trends of the graphs as shown in Table 3.2. This is because the velocities of the keypoints are the product of displacement of the keypoints with frame per second (fps).

Table 3.4: The graphs of the acceleration against the number of frame.

Keypoints	Right side	Left side
Shoulder		
Elbow		
Wrist		

For Table 3.4, the graphs of change in velocity against the number of frame have been plotted for the keypoints of shoulders, elbows and wrists. Form Table 3.4, the range of the acceleration shown in the graphs is between negative values and positive value. This is because the velocity is fluctuating as shown in the graphs in Table 3.3. Hence, the value of the acceleration will fluctuate between positive value when velocity is increasing and negative value when velocity is decreasing. Therefore, the displacement, velocity and acceleration of the keypoints such as shoulders, elbows and wrists analysed by using the biomechanics analysis algorithm developed in this project have been shown in the graphs in Table 3.2, Table 3.3 and Table 3.4. The graphs in Table 3.3, Table 3.4 and Table 3.5 have shown the results of the displacement, velocity and acceleration analysed by the biomechanics analysis algorithm developed in this research.

4. Conclusion and Recommendation

The data obtained from the motion captured system OpenPose Demo as an input for the developed algorithm can be improved to 3D coordinate data. Since the data obtained from OpenPose Demo is in 2D form, the output data of the displacement is in the unit of pixels, velocity is in the unit of pixels per second and acceleration is in the unit of pixels square per second. Hence, the data of displacement, pixels and acceleration may not be much accurate. If the input data is in 3D form, the analysing of the displacement, velocity and acceleration may be more accurate.

In conclusion, this final project has achieved all the objectives. The data can be retrieved from the motion captured system OpenPose Demo. The algorithm for biomechanics analysis has been developed and it is able to perform displacement, velocity, acceleration and angle analysis. This retrieved data can be improved from 2D to become 3D to increase the accuracy on analysing the displacement, velocity and acceleration data.

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