[Upper body exercise pose labeling system for injury reduction]

Sensor Readings Interpretation Documentation

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Revision: [01]

Revision History

Revision Number	Date	Comment
1.0	2018-08-21	First version

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Document Overview

In this document we will explain and demonstrate how to interpret and visualize the readings obtained from the data acquisition unit. This will be done by explaining the cardinal planes, axes of movement for the human body and the description of movement across these planes.This will give the user a reference of the accelerometer and gyroscope X,Y, and Z axes. For more information regarding the software being used and the hardware proposed, please reference to the Hardware Document and Software Document respectively.

Cardinal planes and axes of movement for the human body

Anatomical position

In order to interpret the sensor readings, it is first important to understand the 3 axes which a human being can move around, as well as the starting position for any movement. The starting position is called the anatomical position. The anatomical position, is the position in which the user is standing upright, with palms and toes facing forward, and which contains a total of 3 anatomical (Cardinal) planes, as seen in the pictures below:

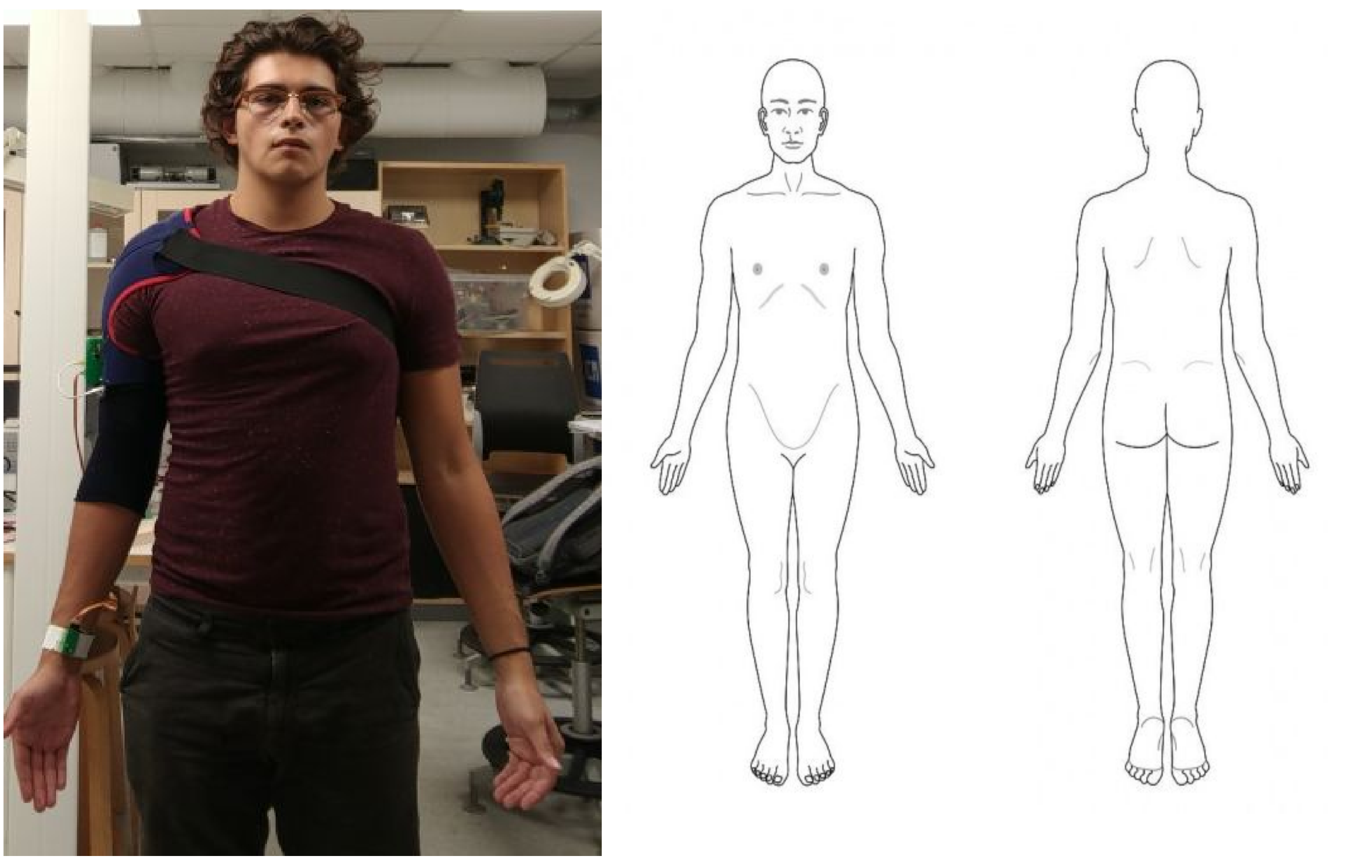

Figure 1: Anatomical Position and starting position for movements [1]

From this starting position, all sensors readings can be interpreted and mapped to their corresponding cardinal plane and axis of movement.

Cardinal Planes

Three basic reference planes are used in anatomy, as seen below:

Sagittal plane

This plane divides the body into left and right. In this plane motions of extension and flexion occur.

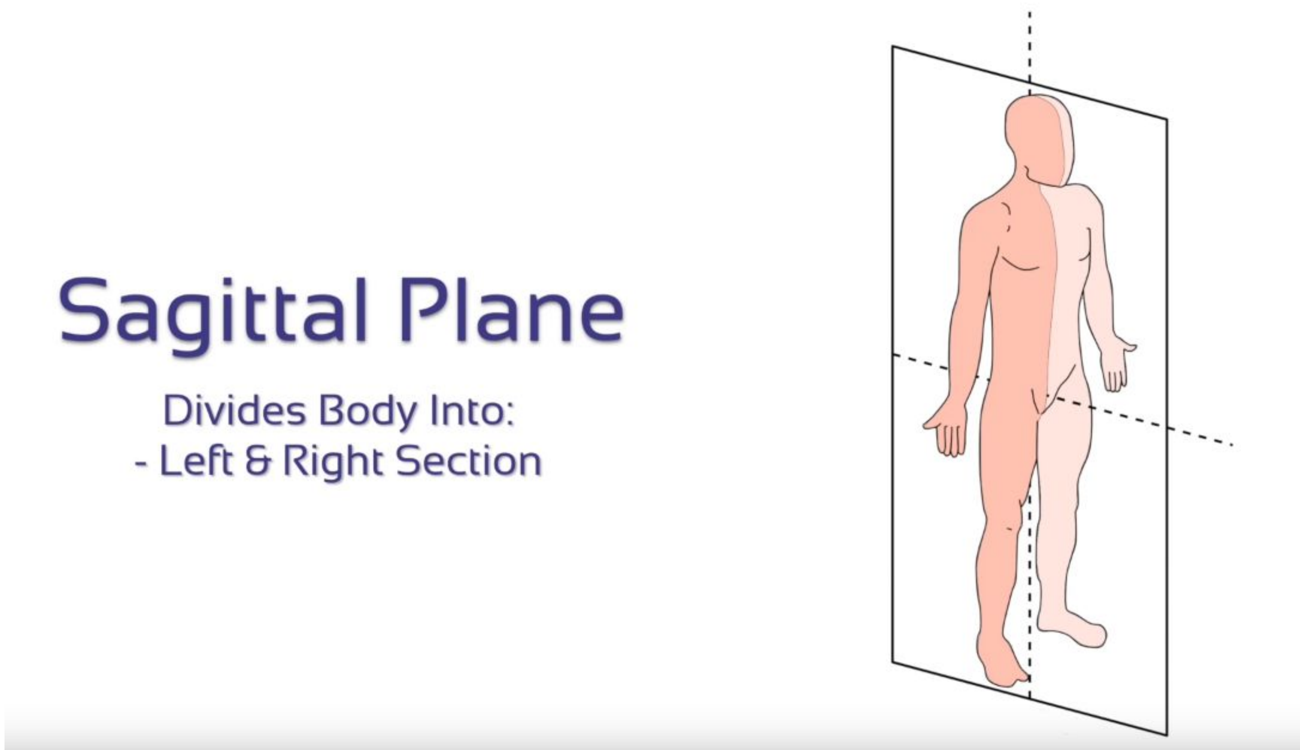

Figure 2: Sagittal Plane [2]

Frontal plane

This plane bisects the body into front and back portions. Motions of Abduction and Adduction occur in this plane.

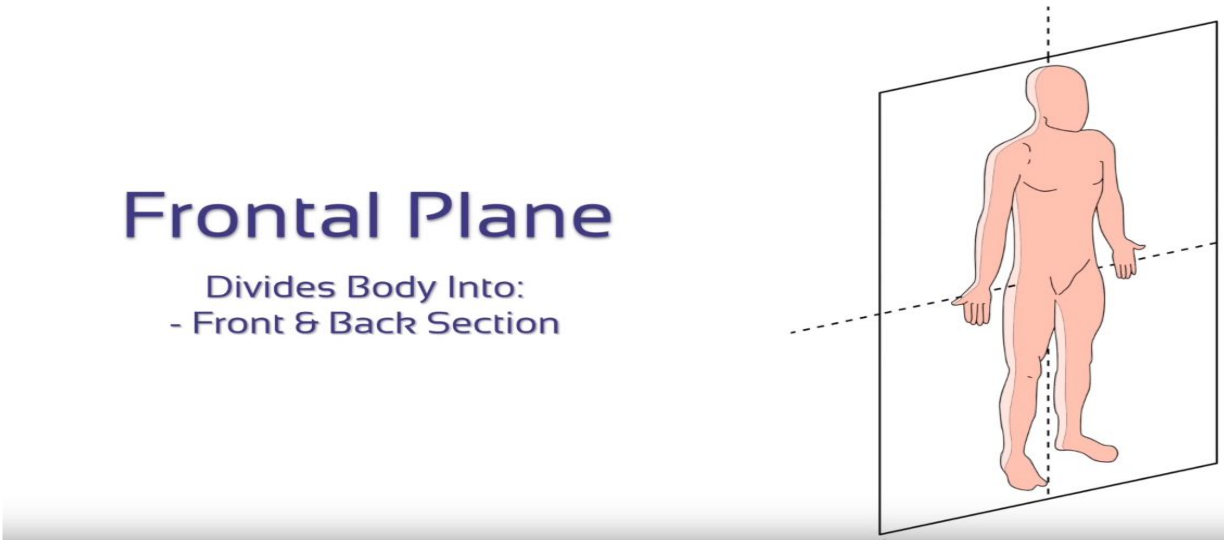

Figure 3: Frontal Plane [2]

Transverse plane

This plane divides the body into upper and lower portions. All movements of rotation (Internal and external) occur here.

Figure 4: Transverse Plane [2]

Anatomical Axes

An axis is a straight line around which an object rotates. In human anatomy we have the following 3 axes of movement, as seen below:

Transversal (Frontal) axis

When a movement takes place in the sagittal plane we are seeing a rotation around or perpendicular to the transversal axis

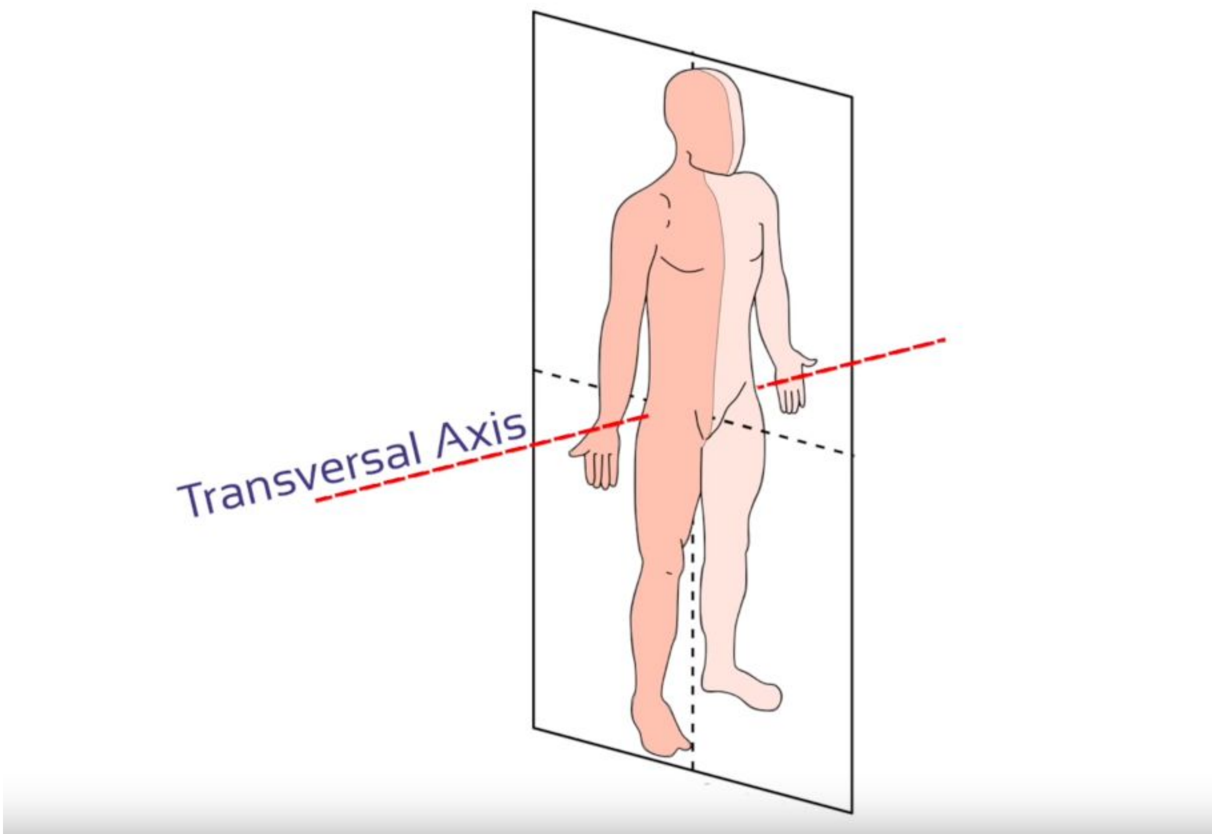

Figure 5: Transversal Axis [2]

Sagittal axis

When we see a movement in the frontal plane we are describing a rotation around the sagittal axis

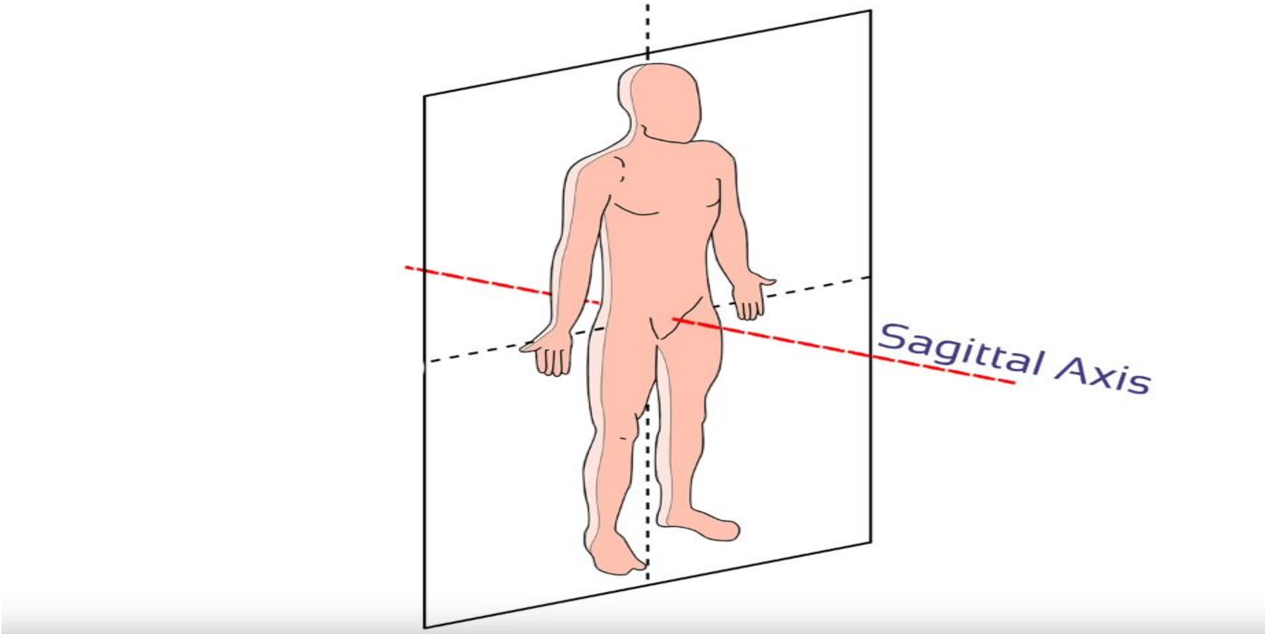

Figure 6: Sagittal Axis [2]

Longitudinal (Vertical) axis

When we see a movement in the transversal plane, we are describing movement around the longitudinal (vertical) axis

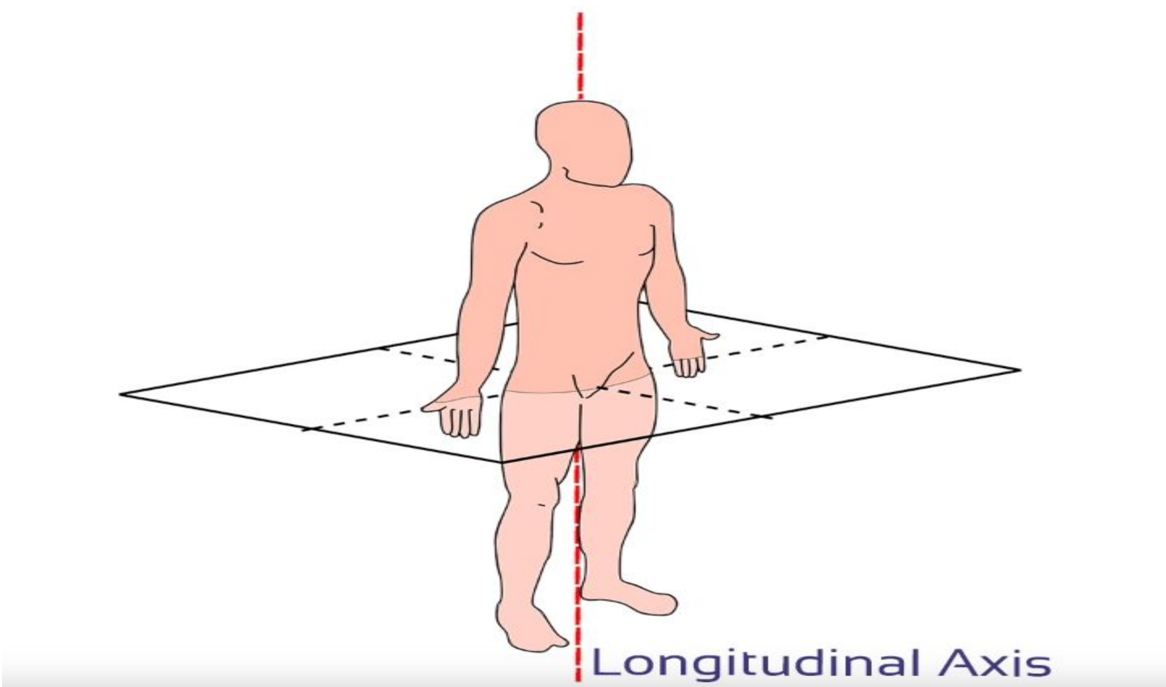

Figure 7: Longitudinal Axis

Describing movement

When performing an exercise, movements will occur across 1, 2 or all 3 cardinal planes. Here we will describe 3 basic movements: Flexion and Extension, Abduction and Adduction, and Rotational movements.

Flexion and extension

Flexion and extension are movements in the sagittal plane about the frontal axis, as seen below:

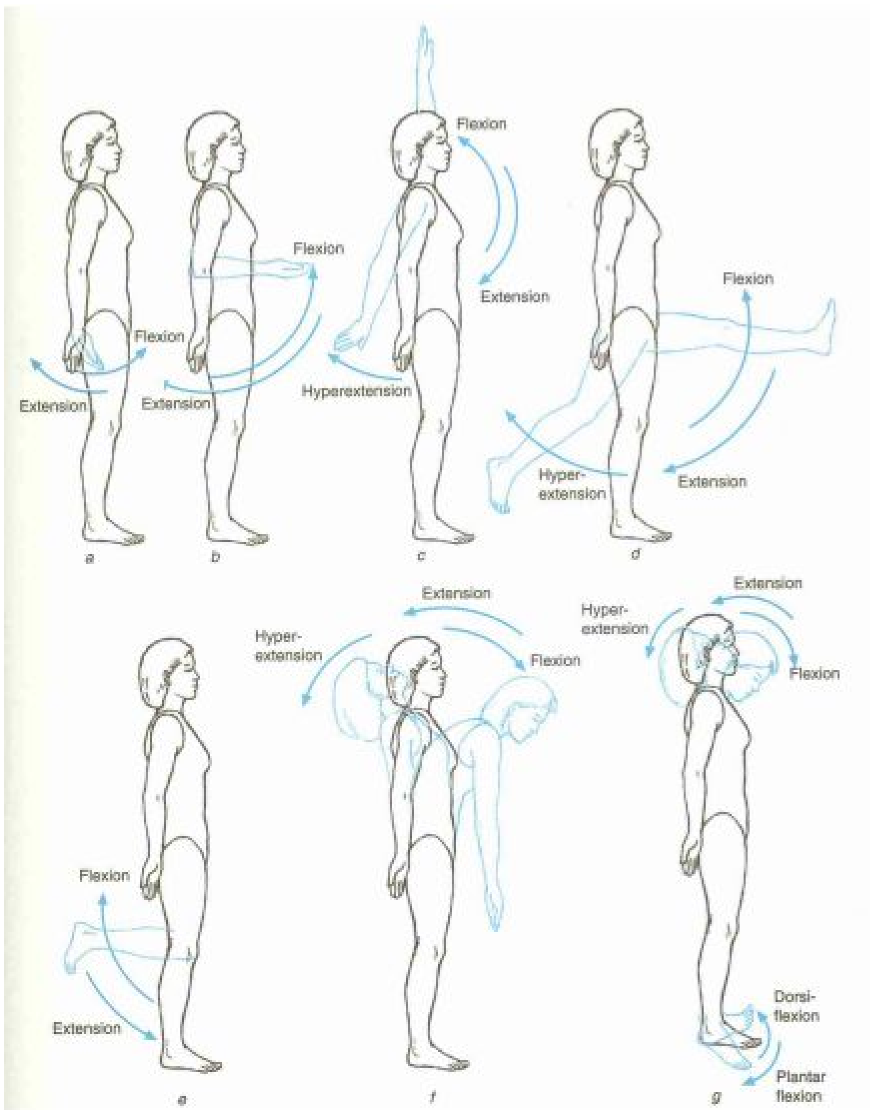

Figure 8: Movements in the sagittal plane about the frontal axis [1]

ABDUCTION AND ADDUCTION

Abduction and Adduction are movements in the frontal plane about the sagittal axis, as seen below:

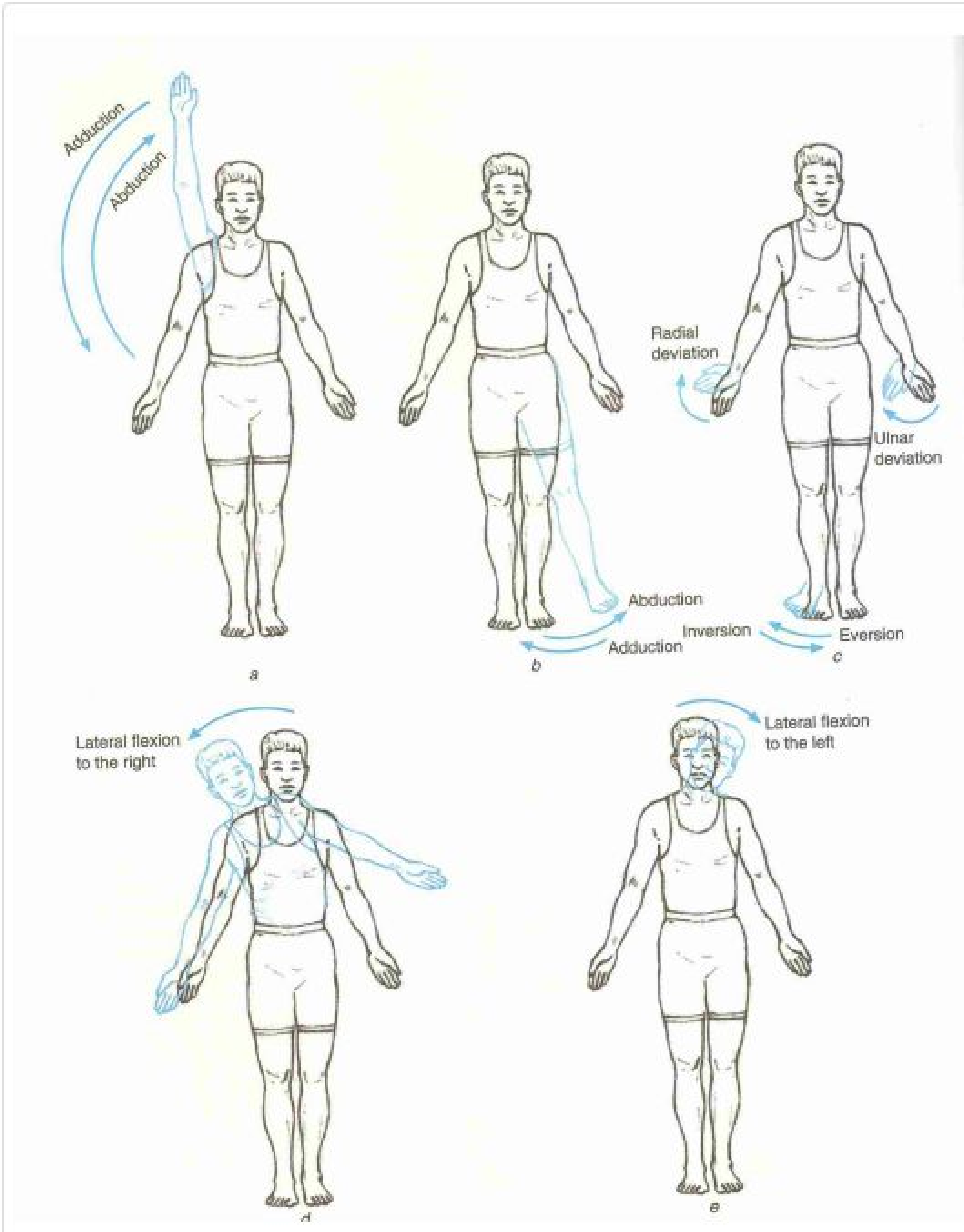

Figure 9: Movements in the frontal plane about the sagittal axis [1]

Rotation

Rotation movements occur in the transverse plane about the longitudinal (vertical axis), as seen below:

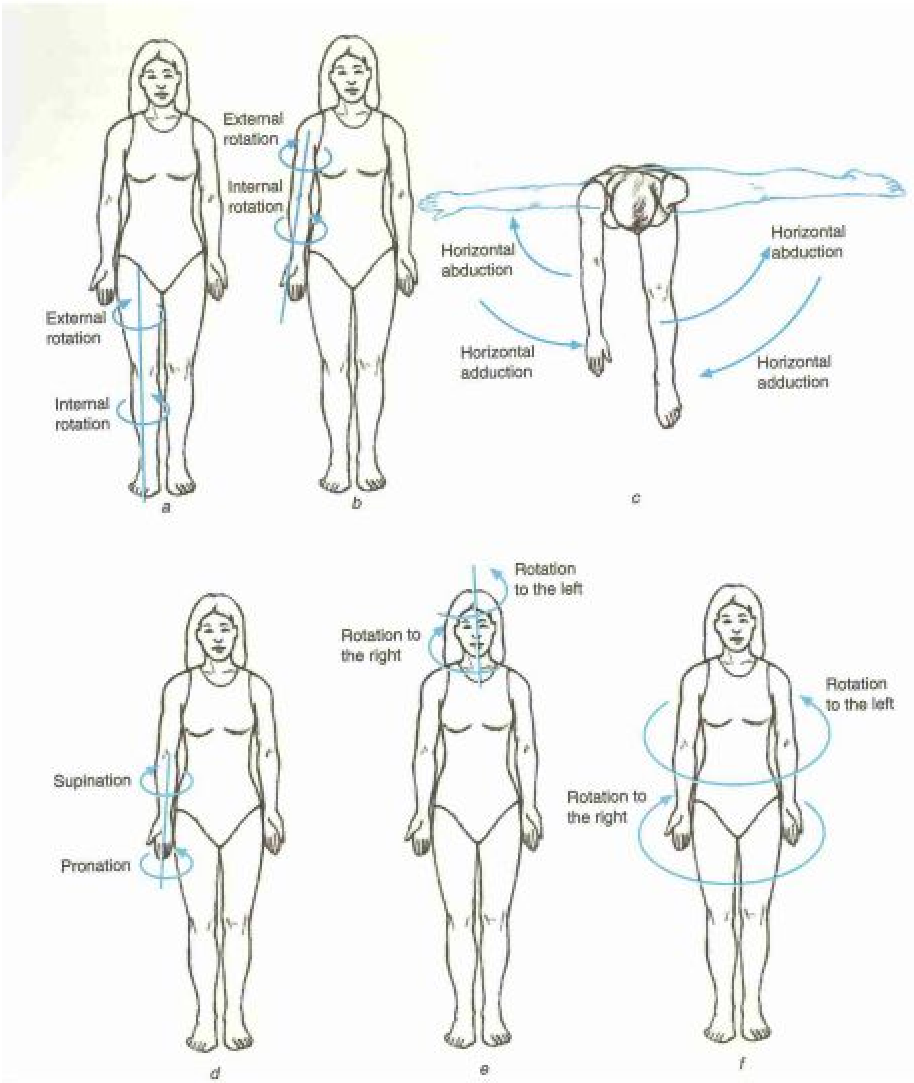

Figure 10: Movements in the transverse plane about the longitudinal (vertical) axis [1]

Shoulder/wrist, gyro/accel x,y and z readings interpretation

Shoulder and wrist x, y and z mapping

In our system we have 2 gyroscopes; 1 located in the shoulder and another in the wrist, and 1 accelerometer located in the wrist. All of these sensors give out readings in their respective X, Y and Z axis. In order to understand what these values mean, tests were performed in order to map the 3 axis of the sensors to the corresponding anatomical axes they rotate about.

Shoulder Gyroscope x,y and z readings

Starting from the anatomical position, the shoulder gyroscope X, Y and Z axes move along the following anatomical axes and cardinal planes:

-***X*** axis: The X axis represents movements in the transverse plane about the vertical axis. When movements of internal and external rotation take place, the shoulder gyroscope X axis readings will change accordingly.

-***Y*** axis: The Y axis represents movements in the frontal plane about the sagittal axis. When movements of Abduction and Adduction take place, the shoulder gyroscope Y axis readings will change accordingly

-***Z*** axis: The Z axis represents movements in the sagittal plane about the frontal axis. When movements of flexion and extension take place, the shoulder gyroscope Z axis readings will change accordingly

Wrist Gyroscope/Accelerometer x,y and z readings

Starting from the anatomical position, the wrist gyroscope/accelerometer X, Y and Z axes move along the following anatomical axes and cardinal planes:

-***X*** axis: The X axis represents movements in the transverse plane about the vertical axis. When movements of internal and external rotation take place, the wrist gyroscope and accelerometer X axis readings will change accordingly.

-***Y*** axis: The Y axis represents movements in the sagittal plane about the frontal axis. When movements of flexion and extension take place, the wrist gyroscope and accelerometer Y axis readings will change accordingly

-***Z*** axis: The Z axis represents movements in the frontal plane about the sagittal axis. When movements of Abduction and Adduction take place, the wrist gyroscope and accelerometer Z axis readings will change accordingly

Matlab readings visualization and interpretation

To test and visualize the mapped shoulder and accelerometer axes readings, the following movements were performed and graphed in Matlab: Full arm flexion and extension, full arm abduction and adduction, full body rotation, lower arm flexion and extension, lower arm abduction and adduction and arm internal and external rotation. The following are the results:

Full arm flexion and extension

The movement was performed as followed:

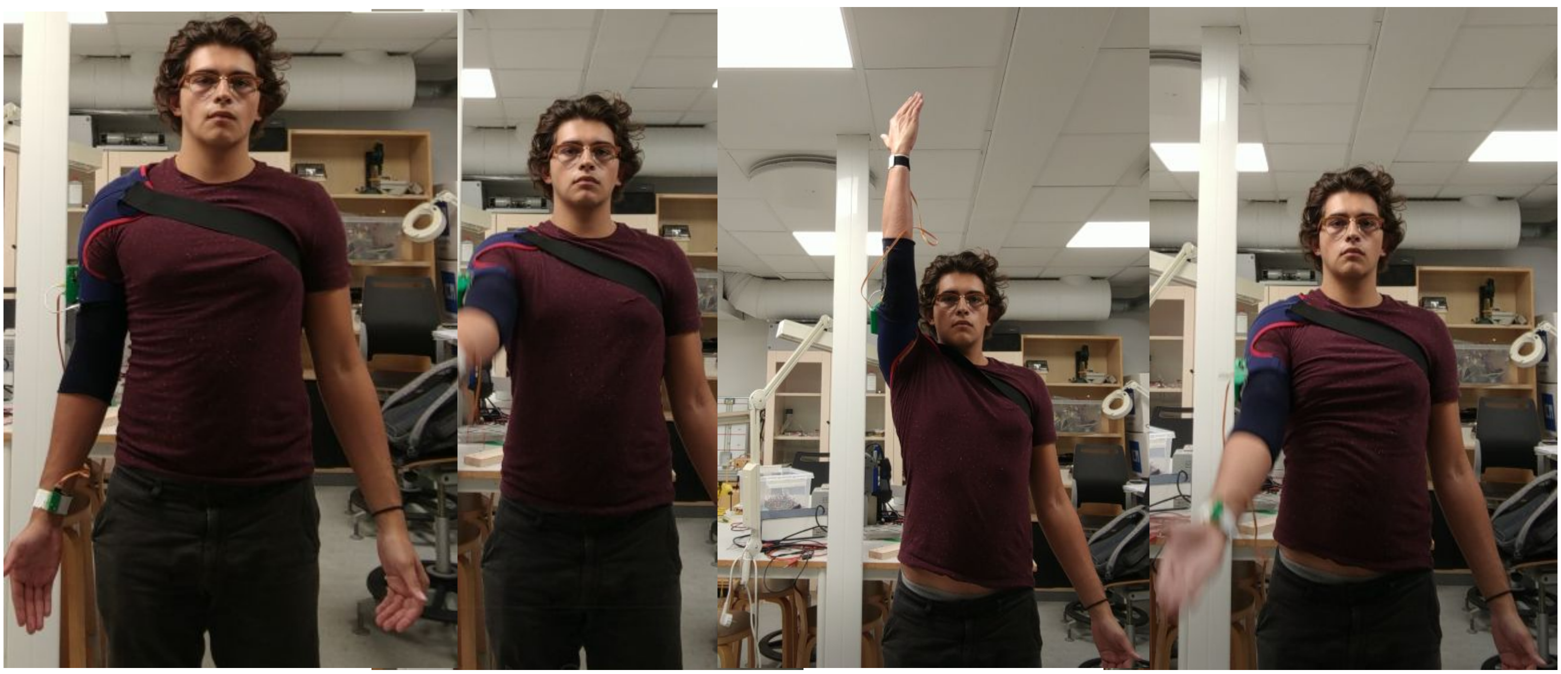

Figure 10: Flexion (Arm going up) and Extension (Arm going down) demonstration

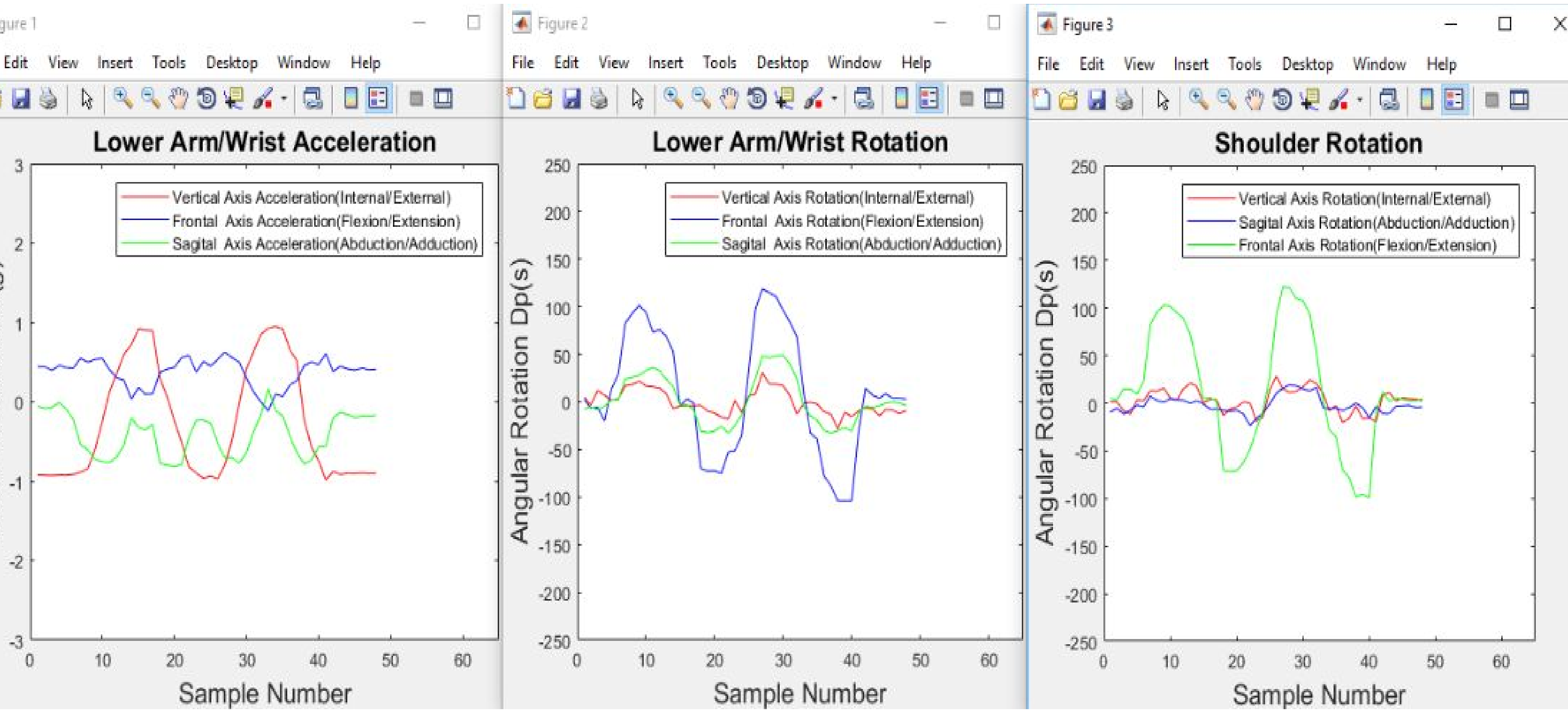

Figure 11: Matlab readings for full arm flexion and extension

Important note: To fully understand the readings of the accelerometer, one must not think in terms of rotation, **but linear acceleration due to gravity**, meaning the following: As mentioned before, when one performs a movement of flexion and extension, **the movement is taking place in the sagittal plane** and **we see a rotation around or perpendicular to the frontal axis**. But when we perform this movements, **we are accelerating up and down about the longitudinal (vertical) axis. Meaning the force of gravity is pulling us down in the vertical axis.**

Full arm abduction and adduction

The movement was performed as followed:

Figure 12: Abduction(Arm goes away from body) and Adduction (Arm goes towards body) demo

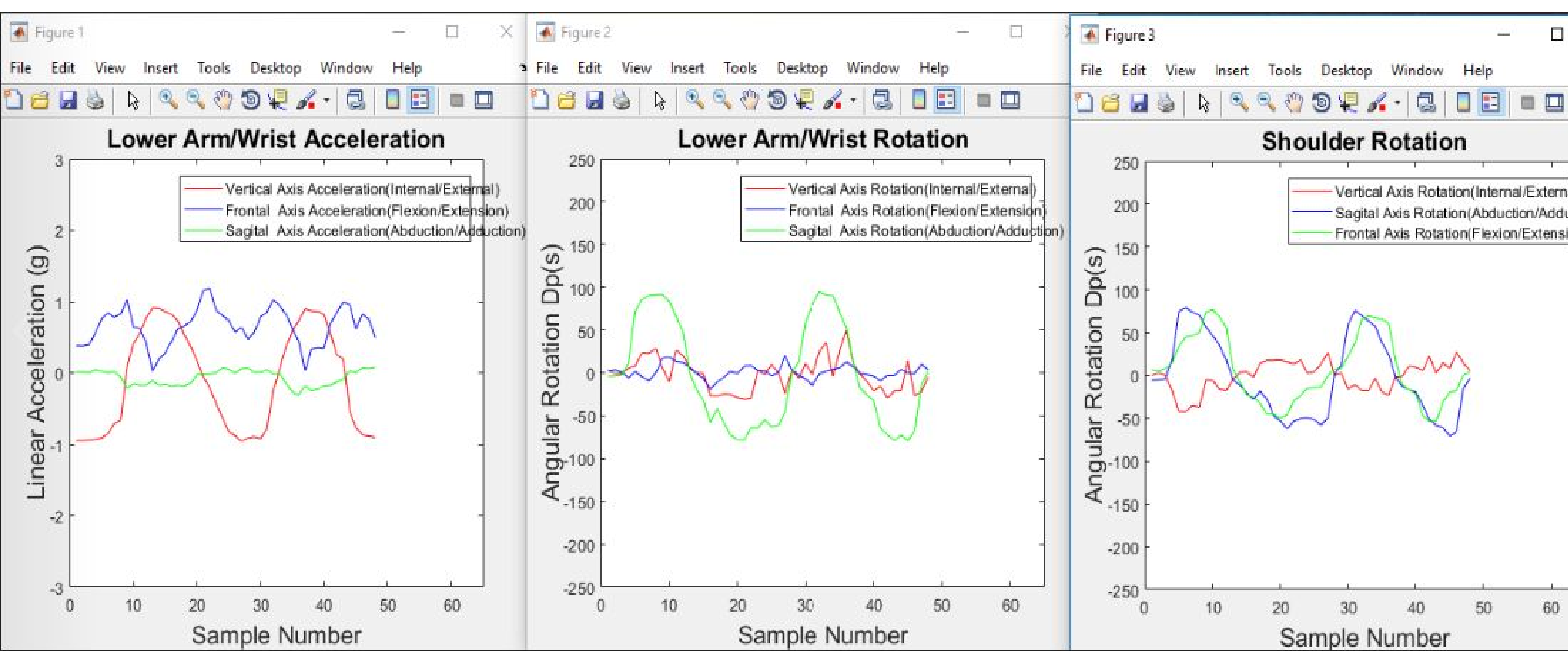

Figure 13:Matlab readings for full arm abduction and adduction

Full body rotation

The movement was performed as followed:

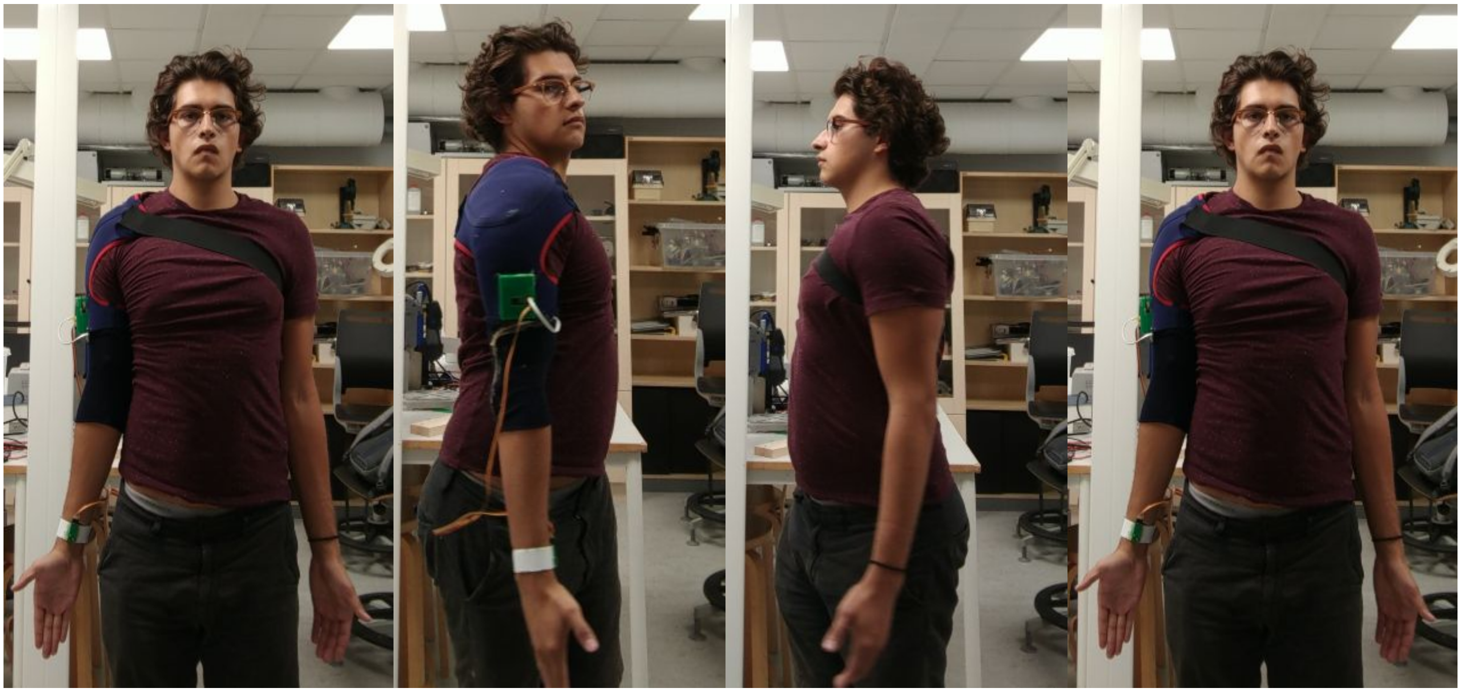

Figure 15: Full body internal and external rotation movement demonstration

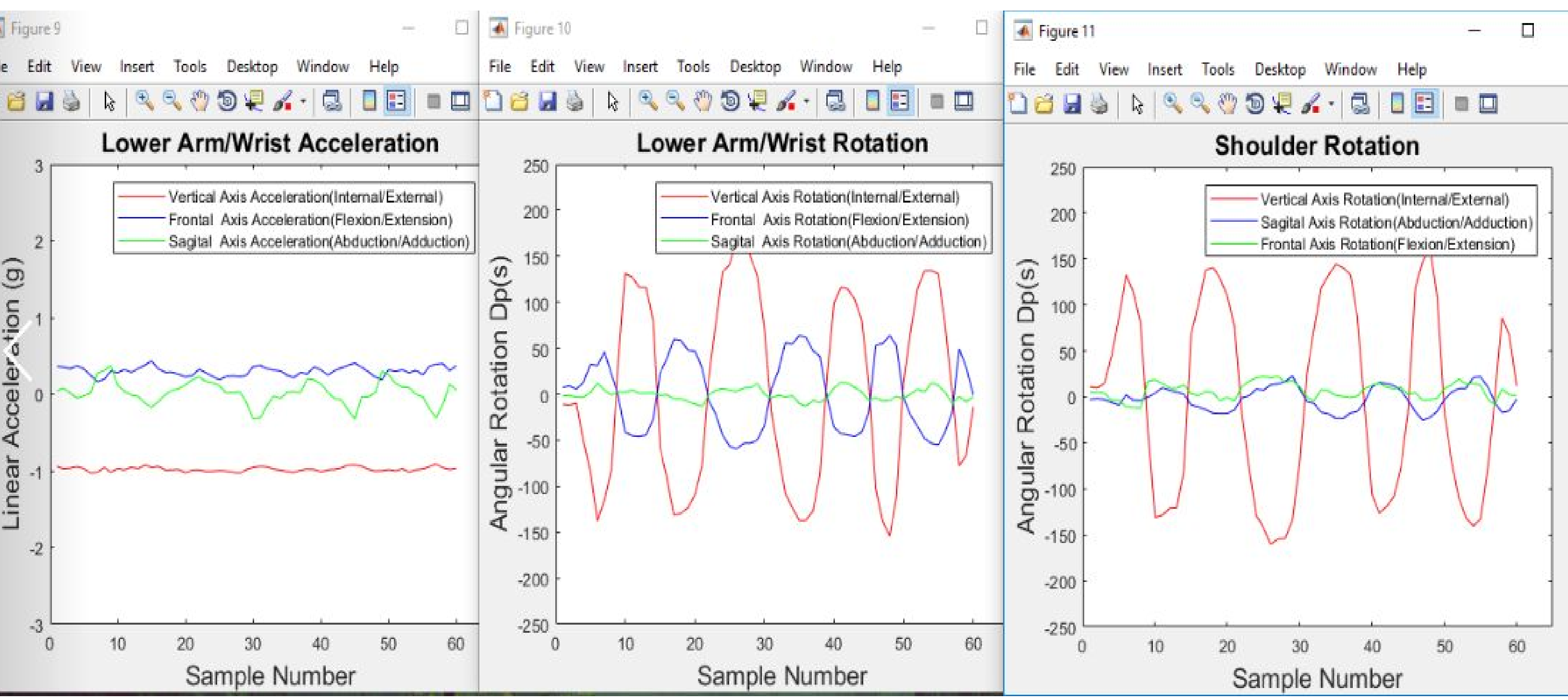

Figure 16: Matlab readings for full body rotation movement

Lower arm flexion and extension

The movement was performed as followed:

Figure 17: Lower arm flexion and extension demonstration

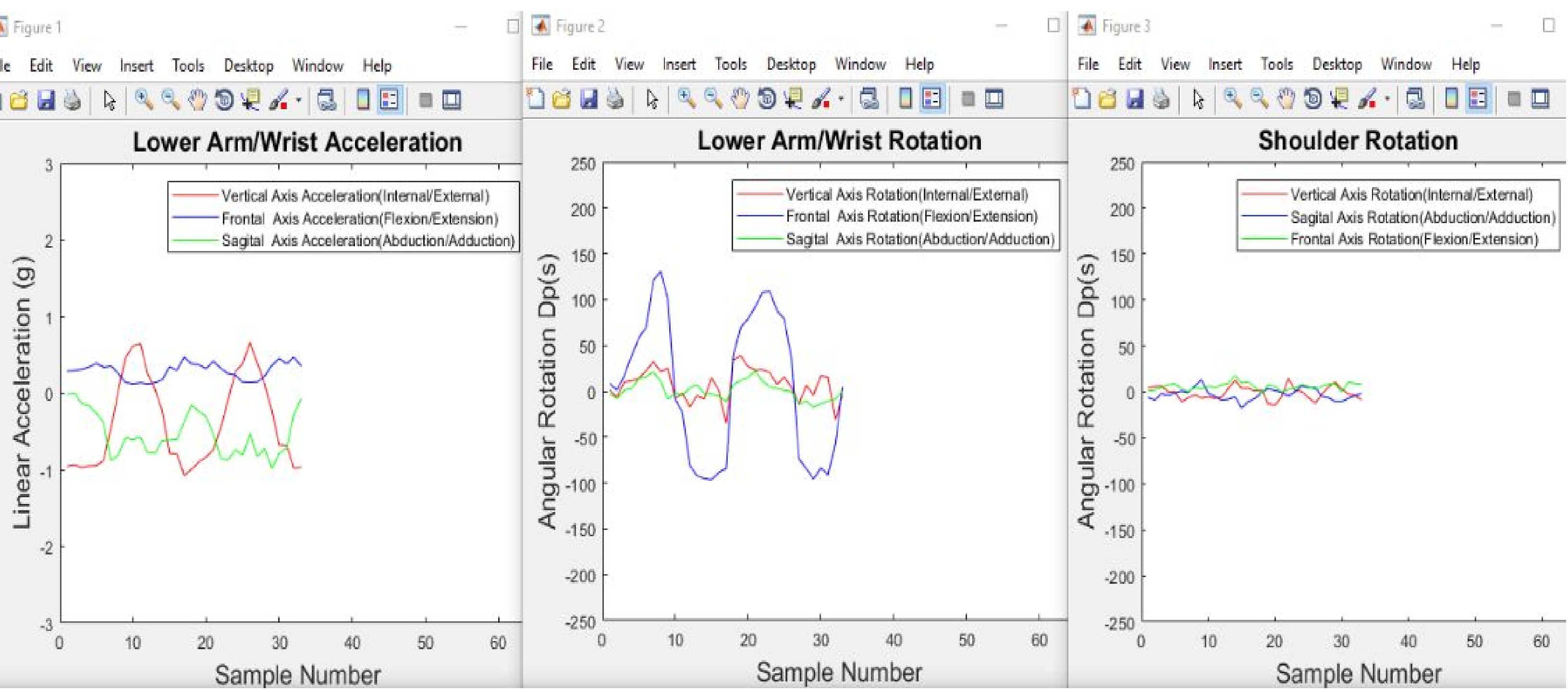

Figure 18: Matlab readings for lower arm flexion and extension

Lower abduction and adduction

The movement was performed as followed:

Figure 19: Lower arm abduction and adduction demonstration

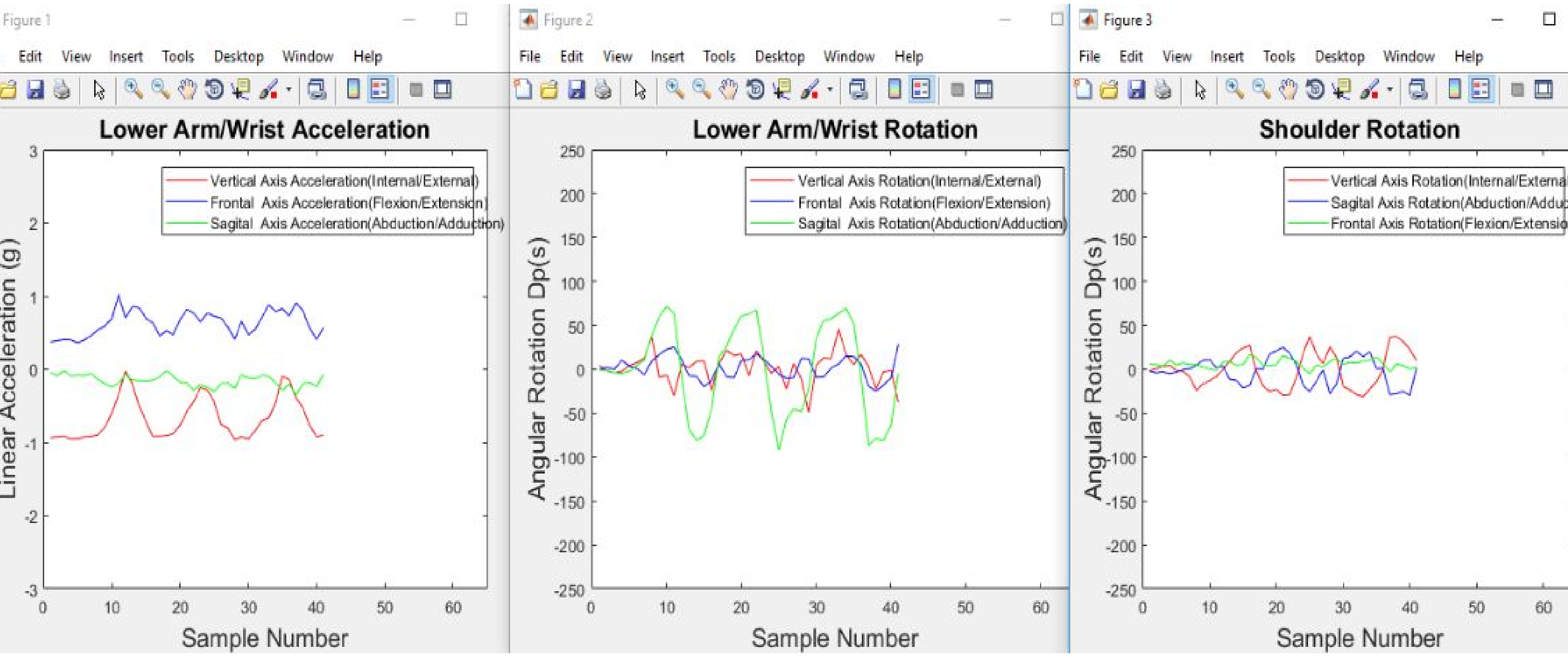

Figure 20: Matlab readings for lower arm abduction and adduction

Arm internal and external rotation

The movement was performed as followed:

Figure 21: Arm internal and external rotation demonstration

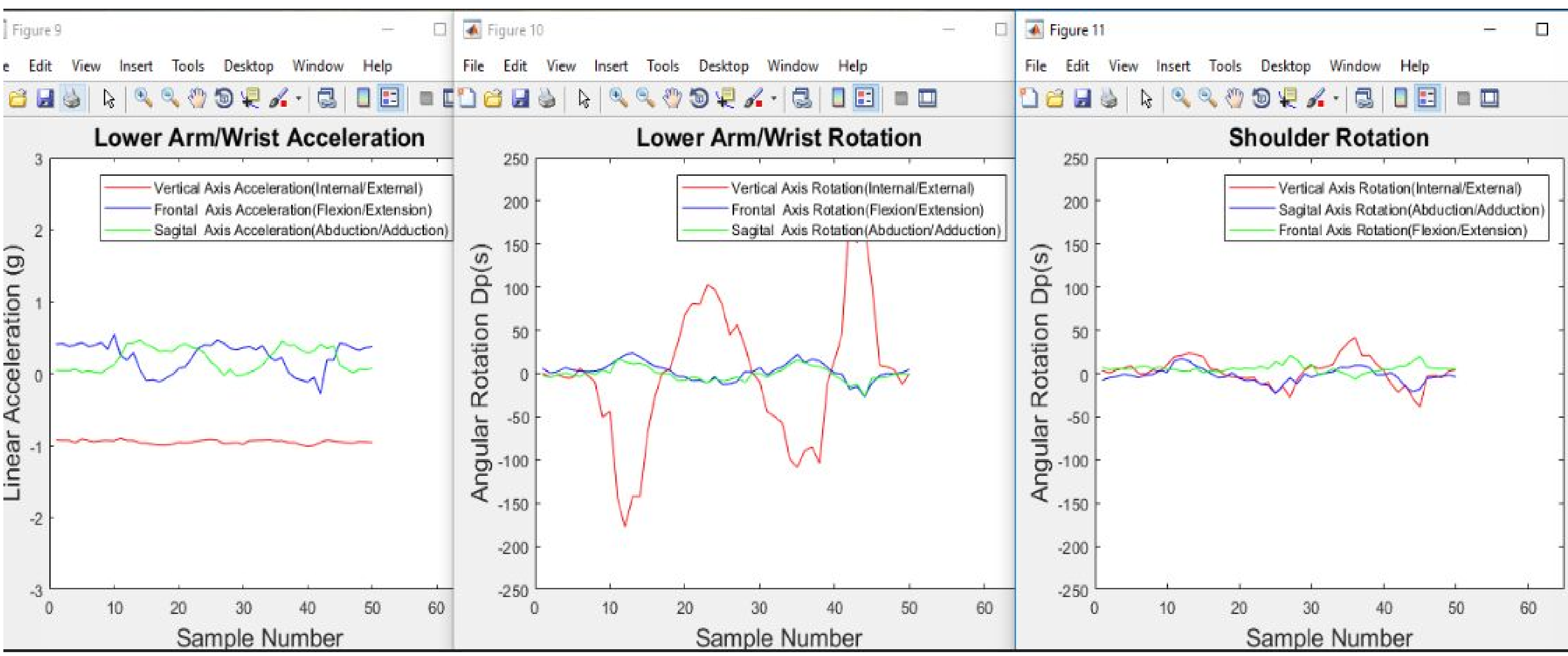

Figure 22: Matlab results for arm internal and external rotation

Flex readings interpretation

The flex sensor, is a variable resistor whose resistance changes as the sensor is being bent. This sensor can be connected in series with a constant resistor, to create a voltage divider. The output from this voltage division acts as the input for the ADC reader in our BLE smart module. The schematics for the sensor can be seen below:

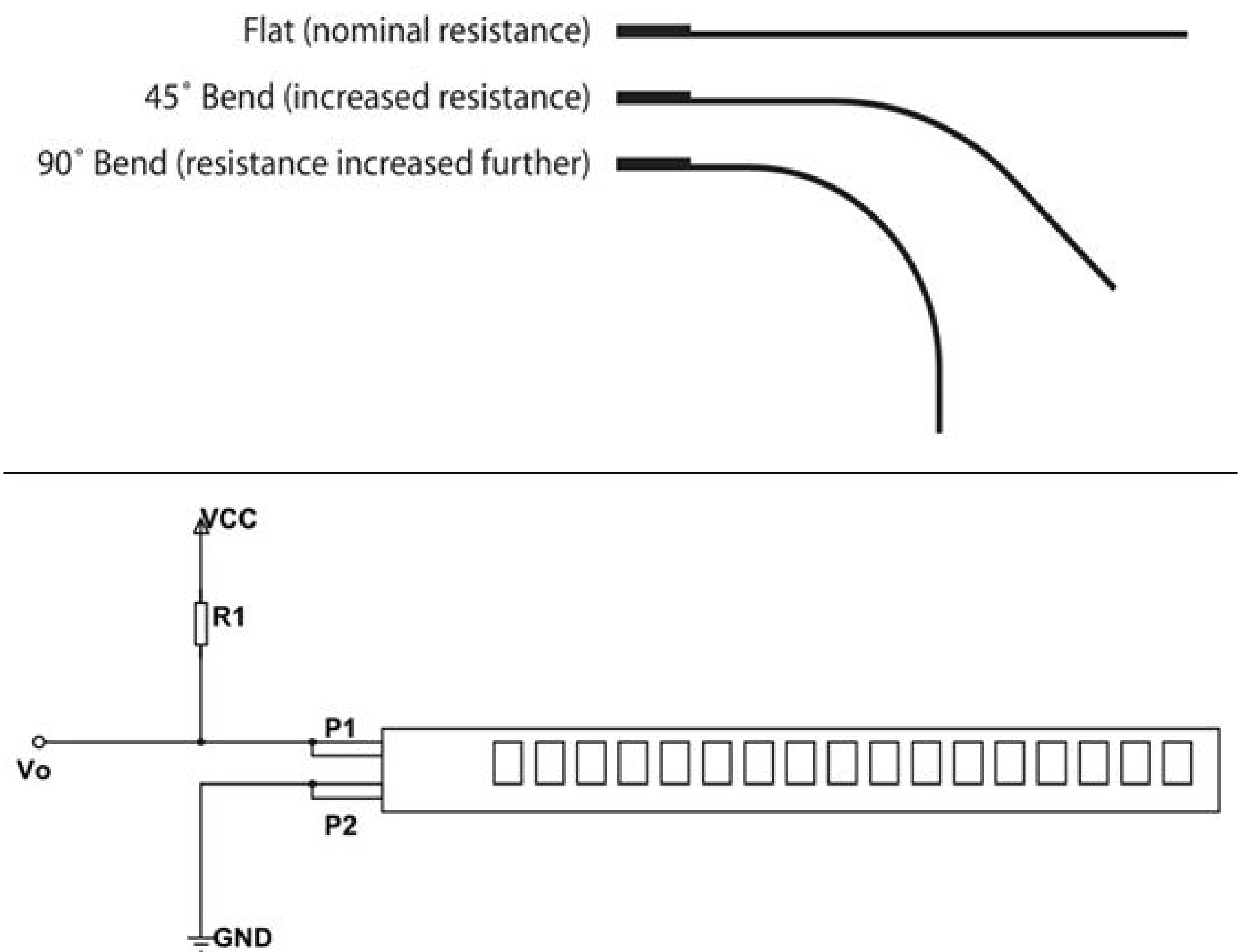

FIGURE 22:. The functionality and schematic of the Flex Sensor.

NOTE: In our device, R1 is equal to 26K ohm. The value for R1 needs to be calculated for each sensor, depending on the maximum 90 degree nominal resistance of the flex sensor. A value in between the flat resistance and max resistance value was chosen.

The following schematic will output a value to our ADC reader in our BLE Module, with the output being $Vo = (P1/P1 + R1) * Vin$. Where P1 is the variable resistance of the flex sensor. The flex sensor resistance goes from approximately 3.8k Ohms when is flat, to around 30k Ohms when is bent fully. Meaning that when the resistor is flat, we should obtain a voltage output of approximately 0.42V -> 0.42 = (3.8KΩ/3.8KΩ+26KΩ)*3.3V and around 1.75V when the sensor if fully bent -> 1.75= (30KΩ/30KΩ+26KΩ)*3.3V. The BLE uses a 12 bit ADC converter whose output MSB is right shifted >> 4 bits, to reduce the value to an 8 bit resolution.

Note: The BLE can obtain values from it's ADC registers in 7 bit, 9 bit, 10 bit and 12 bit formats respectively. For this project, we tried different options and reading values from the 12 bit ADC and right shifting the MSB 4 bits resulted in the most stable results.

As mentioned above, when we obtain values from the ADC register, we right shift our result 4 bits and send the remaining 8MSB bits to our matlab program. From this we can see the readings that we obtain, and use them to map our input values to an approximate bend angle of the arm!. Using this readings we obtain we can use the following formula to check the expected voltage that our ADC is reading ->
$Vin = ADC\ value * VRE/4096\ (VRE = Reference\ voltage = 3.3V,\ 4096 = 12\ bit\ resolution)$

When the arm is flat, we get a reading of approximately 30 in decimal notation. If this value is left shifted 4 bits, we obtain the number 480 -> Vin = (480*3.3)/4096 = 0.38V. When the arm is bent completely, we obtain a value of approximately 130-> 130 << 4 = 2080.
Vin = (2080*3.3)/4096 = 1.68V.

With this information a mapping and constrain function was created to map the ADC inputs to an appropriated angle. To do this we can look at the average values we obtain when the arm is flat, bent 90 degrees and fully bent. This values are then put into a mapping and constrain function to map our input to a bending angle and obtain more stable results. This process should be done for every user, before a recording session starts, to ensure one can get usable results. The mapping and constraint functions can be seen below:

```
function map = myMap(x, in_min,in_max,out_min,out_max)%Function used to map our raw flex reading to an angle

    map = (x - in_min) * (out_max - out_min) / (in_max - in_min) + out_min;
end

function y = constrain(rawFlex,x,min,max) %Used after we have mapped our raw value to an angle
if (rawFlex > max)%If our raw value is greater than our max angle, set angle to max angle
    y = max;
elseif (x < min) %If our mapped input is less than the minimun angle, set angle to min angle
    y = min;
elseif (max < x) %If our mapped input is greater than our max angle, set angle to max
    y = max;
else             %Keep the mapped input as it is
    y = x;
end

end
```

Figure 23: Matlab map and constrain functions, in the mapping function, x is our input (Flex reading), in_min is our minimum value obtained from the ADC when the arm is flat, in_max is the maximum value obtained when the armed is fully flexed and out_min/max, represent the angles we want to map the inputs into (0 to 100 degrees, or whatever the user chooses)

When the user obtains the average values obtained when the arm is flat, bent 90 degrees and fully bent, he can then map the original raw value to an angle, as seen below:

```
Flex = extractBetween(data,'FLEX: (',')');%Flex reading
Flex = str2double(Flex);%Getting result as double
rawFlex = Flex; %Saving raw value
Flex = myMap(Flex,32,112,0,100); %Mapping Flex reading to an angle
Flex = constrain(rawFlex,Flex,0,100); %Constraining our reading
```

Figure 24: Mapping the raw flex sensors to an angle

Example of raw flex sensor readings :

```
WA: (0 0 0),WG: (0 0 0),SG: (688 199 1650),FLEX: (41)

WA: (0 0 0),WG: (0 0 0),SG: (1169 1351 2246),FLEX: (41)

WA: (0 0 0),WG: (0 0 0),SG: (840 1129 3053),FLEX: (63)

WA: (0 0 0),WG: (0 0 0),SG: (872 351 1169),FLEX: (86)

WA: (0 0 0),WG: (0 0 0),SG: (153 425 109),FLEX: (106)

WA: (0 0 0),WG: (0 0 0),SG: (64992 129 798),FLEX: (125)
```

```
WA: (0 0 0),WG: (0 0 0),SG: (64992 129 798),FLEX: (125)

WA: (0 0 0),WG: (0 0 0),SG: (571 64031 65311),FLEX: (122)

WA: (0 0 0),WG: (0 0 0),SG: (881 63946 5),FLEX: (96)

WA: (0 0 0),WG: (0 0 0),SG: (13 63962 345),FLEX: (83)

WA: (0 0 0),WG: (0 0 0),SG: (64354 65117 65500),FLEX: (52)

WA: (0 0 0),WG: (0 0 0),SG: (65312 65119 600),FLEX: (39)

WA: (0 0 0),WG: (0 0 0),SG: (908 440 1898),FLEX: (48)

WA: (0 0 0),WG: (0 0 0),SG: (812 550 1479),FLEX: (74)

WA: (0 0 0),WG: (0 0 0),SG: (29 312 941),FLEX: (97)
```

Figure 23: Raw Flex sensor readings

As seen above, when the arm is being bent, the values increase and when the arm is turning into a flat position the values decrease. Once the user has obtained the average values for the different bent positions and plugged them into the mapping function, he can expect similar results, as seen below:

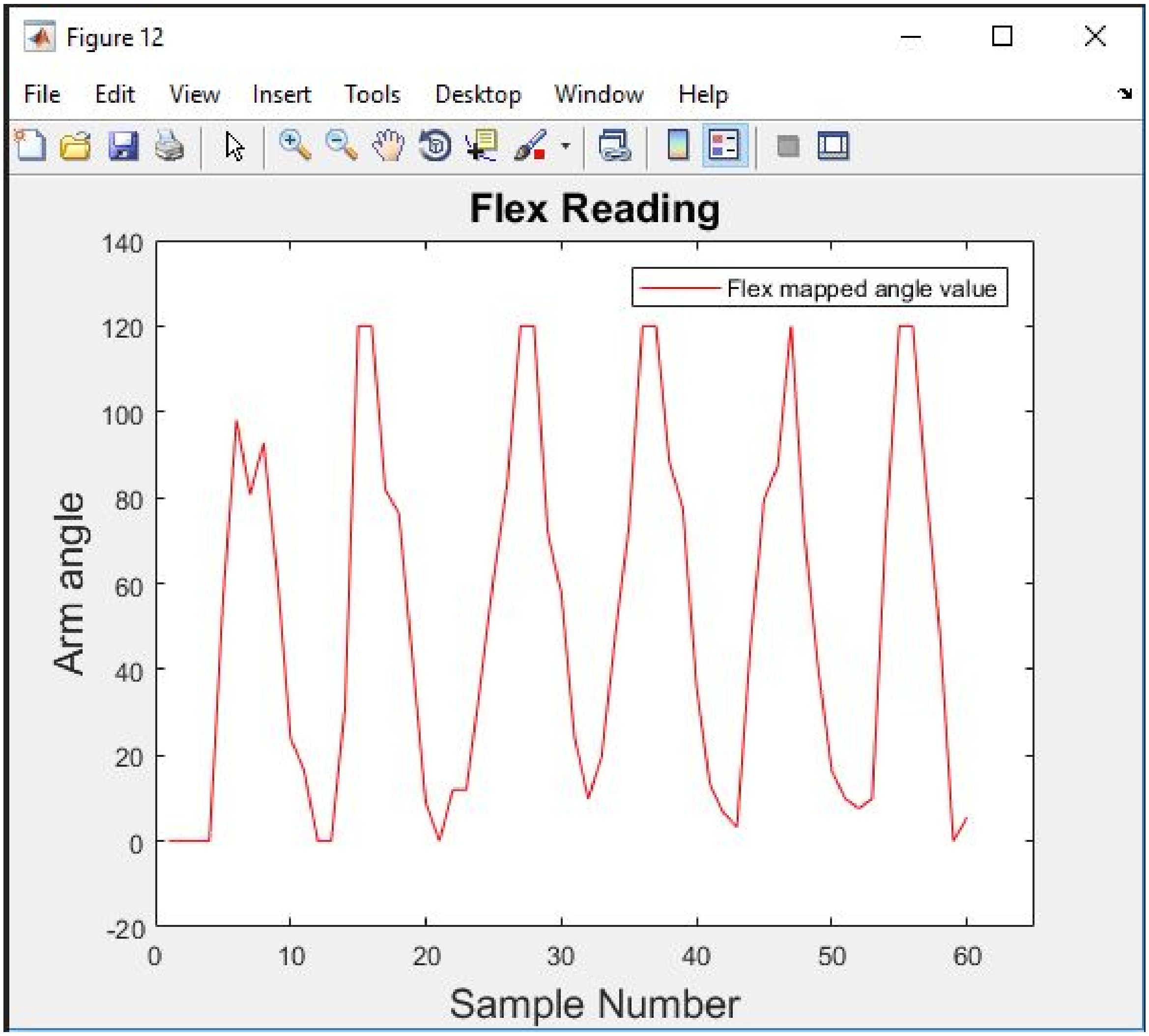

Figure 24: Matlab flex sensor output graph

References

[1]-Cardinal Planes and Axes of movement. Website physio-pedia.com
Link:https://www.physio-pedia.com/Cardinal_Planes_and_Axes_of_Movement
[2]-Anatomical Planes and Axes explained. Youtube channel: Physiotutors
Link: https://www.youtube.com/watch?v=yq8cE-EDtuE