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Real-time Assessment and Visual Feedback for Patient Rehabilitation Using Inertial Sensors

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REAL-TIME ASSESSMENT AND VISUAL FEEDBACK FOR PATIENT REHABILITATION USING INERTIAL SENSORS

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DEDICATION

This research work is dedicated to my Professor Wenbing Zhao without whose patience, guidance and help I would not have been able to do this. I would also like to thank my committee members Professor Lili Dong and Professor Yongjian Fu for all their time and consideration. Last but not the least I would like to thank Cleveland State University Career Services and all who have been a part of it since 2016, my family, friends and the God almighty.

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ABSTRACT

Rehabilitation exercises needs have been continuously increasing and have been projected to increase in future as well based on its demand for aging population, recovering from surgery, injury and illness and the living and working lifestyle of the people. This research aims to tackle one of the most critical issues faced by the exercise administers- Adherence or Non-Adherence to Home Exercise problems especially has been a significant issue resulting in extensive research on the psychological analysis of people involved. In this research, a solution is provided to increase the adherence of such programs through an automated real-time assessment with constant visual feedback providing a game like an environment and recording the same for analysis purposes. Inertial sensors like Accelerometer and Gyroscope has been used to implement a rule-based framework for human activity recognition for measuring the ankle joint angle. This system is also secure as it contains only the recordings of the data and the avatar that could be live fed or recorded for the treatment analysis purposes which could save time and cost. The results obtained after testing on four healthy human subjects shows that with proper implementation of rule parameters, good quality and quantity of the exercises can be assessed in real time.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

Figure Page

ABBREVIATIONS

API – Application Programming Interface

TCP – Transfer Control Protocol

HEP – Home Exercise Programs

MS -- Microsoft

USB – Universal Serial Bus

SD -- Secure Digital

IMU – Inertial Measurement Unit

CHAPTER I

INTRODUCTION

Rehabilitation is assisting a person in restoring normalcy/ regular activity through guidance, and therapeutic means after a physical impairment or disability caused due to factors like injury, illness, surgery and more. It helps in the improvement of the physical condition. Rehabilitation dates back to the early 20th century, the period noted for wars and violence [54]. In fact, the practice is believed to have originated in the United States of America. Since then, due to an increased number of patients and the research done in the particular field, the process of rehabilitation has been improved and innovated a lot. The medical and health climate combined with the lifestyle practices has increased the risk of humans acquiring injury or illness due to various reasons. The rehabilitation which arose out of the necessity for recovery has almost become the necessity for daily and healthy life [1], [6], [52], [53], [45]. The increasing world population requires an increased need for rehabilitation specialists especially in the fields of occupational and physical therapy. The projected job growth for these specialists is 28 percent from 2016 to 2026 as per the job outlook handbook [55]. This has in return increased the demand for innovation and the overlapping of multiple fields for health monitoring purposes like Fitbit and similar wearable tech with sensors. The rehabilitation considered in this research mainly pertains to therapists and doctors dealing with physical ailments.

A. Aim

This research was aimed to develop a real-time assessment and visual feedback for the patient rehabilitation using inertial sensors- accelerometer and gyroscope. We are utilizing Shimmer sensor, which is a compact, wireless sensor which comes with the inertial sensors as a part of a much more health-related monitoring sensor.

B. Motivation

The primary motivation for this research was derived from the Kinect research project for the Rehabilitation exercise monitoring and guidance system [50]. It employs an exercise guidance system used for the tracking the exercise motion of a full body part like limbs, necks, and back. These exercises are tended towards the later part of recovery.

The Kinect is not small enough to be employed for joint exercise like Anklejoints, where due to the small body part and its skeleton system to monitor that part is not accurate. If a physical exercise has to be implemented for the ankle joint after an injury or surgery, it has to be fine-tuned and monitored very carefully in the initial stages. As these exercises not only help with the whole gait and balance of the body but also the amount of stress, one puts on the other ankle to balance the body weight. This action creates considerable pressure on the other foot and the strain on its muscles so much that light stretch exercises are advised for the other leg as well. Due to the cost and economic factors, and not all patients can complete the usual six to ten-week period of healing (major ankle injuries) at the hospital before one even starts to exercise. This research project aims to help patients even when they are not meeting with therapists for their rehabilitation to perform exercises.

Such exercises, which are done by patients on their own without a physical therapist nearby are called Home Exercise Programs, which is one of the most researched topics in the field of therapists, especially the concept of "compliance" and "adherence."

C. Literature Review

The major components of this research can be subcategorized into rehabilitation exercises, sensors, real-time assessment and visual feedback. Various researches such have been concentrated on the accurate measurement of an angle in the past. The population has increased, and the so has the injury and in turn the demand for rehabilitation specialists, but the methodologies used for measuring the angle has not. In the current time of Internet of technologies and Artificial Intelligence, most of the physical therapists are still using Goniometer to measure the angle of the patients. Though Goniometer requires no special classes, it still needs another human help for measuring the angle after every repetition of the activity. This still traditional, boring method has only discouraged the patients even more [1], [6], [8], [9], [45]. Without the constant monitoring and help after the initial injury period, the patients are influenced by various personal, economic and social factors that cause a barrier which stops them from recovering earlier.

Accurate angle measurement uses spans more than healthcare applications, but it is needed the most for it. Regarding the angle measurement in this research, the application of this biomechanical measurement could be used for drop foot correction, foot rotation monitoring and various other preventive and corrective lower leg activities. Gait analysis research have used kinematic sensors for study and monitored upper extremity and mobility in [16], [58], [59], [60], [61], [62], [14], [51], [50].

There has been a vast concentration of research on both sides of the issue, technical and psychological to make the rehabilitation a qualitative over time. Regarding technical is where are the various techniques have evolved from dual orthogonal fluoroscopic and magnetic resonance imaging to sensors both wired and wireless [12]. The angle calculation techniques used could not only be derived from the inclination angle or tilt angle measurement of an object to prevent from toppling as in case of a robot or drone but also from the angle measurements from the game objects in terms of their movements in animated avatars and virtual realities. This idea of angle measurement in games derived could be used along with the gamification of the rehabilitation process thereby resulting in better quality rehabilitation both technical and psychological aspect.

The recent developments that are being experimented are discussed widely in Chapter IV, but before the advent, in fact, a large portion of the rehabilitation population still use archaic methods such as printed sheets and papers with exercise manuals and to-do lists. It is not only a tedious job in the current world filled with distraction but also a painful job. Hence there is an inherent need to make the exercise more engaging and self-automated. Research has shown that gamification has helped engage and improve people's physical exercises [19], [20]. They have had various additions to them such as scoring, repetition counts and has increased the engaging level in detection of static axes in a few [21], [22]. Advancement of this has been the real-time feedback as discussed in [50].

With the advent of the games and virtual reality, a lot of effort is going into creating expensive health monitors and hence in this research we use basic inertial sensors from an IMU unit to measure the angle of ankle joint which proved to be very tricky while was trying to be obtained using Microsoft Kinect.

D. Thesis and Organization

This thesis modifies and builds upon the idea of using a visual system, real-time assessment and avatars with a game like setting [50] along with wireless sensors for transmitting the measured joint angle and storing it in a Microsoft Excel for analysis. The various methods of each section had advanced to its current part in the research would be discussed in the further chapters.

The existing system and proposed system are analyzed along with the system requirements. The three essential connection modules for the working of this system is discussed as the last part of this thesis.

This research has heavily used the Shimmer Sensor's calibrated inertial sensors value along the triaxial for the calculations.

CHAPTER II

SYSTEM REQUIREMENTS

The two main hardware components used are

- Personal Computer with Bluetooth
- One Shimmer3 sensor along with a shimmer dock (for charging), charging connector and a belt for sensor positioning

A. *Shimmer Sensor*

The sensor used in this project is Shimmer3 manufactured by Shimmer Sensing, a Dublin based wearable technology company [46]. This sensor can be used for monitoring health and biophysical responses and also has a range of sensors that are used for athletic performance as well. The Shimmer3 is a compact sensor with a small and slim frame measuring 51mm x 34mm x 14mm with enclosures for snapping its belt. It uses 9DoF inertial sensing via accel, gyro, mag to provide useful data quality. It connects via Bluetooth and offers local storage through microSD card. It is powered using a Li-ion battery management system. This wireless sensor is charged using a dock explicitly manufactured for the purpose. It can be charged using a USB cable connected through a mini USB socket. Further specifications can be found in the Shimmer Sensing website [46]. It utilizes a 24MHz MSP430 CPU for its control.

Figure 1: Shimmer Sensor with Dock

1) *Motivation for Choosing Shimmer:* The Shimmer sensor IMU unit was chosen due to the varied background research conducted chiefly in the field of biomechanics for the measurement of angle [46]. Its small form could be easily strapped on any part of the body, and its robust make stands good wear and tear. The other market competitors being Polhemus G4[48], Xsens[47], and ReFlex [49] but the number of projects being done on Shimmer[14], [51], [53], the quality of data and the range of data that can be obtained (raw and calibrated.) and finally the support for the development is vast as compared to other competitors. Plus, the ability to purchase extra health monitoring sensors for the same price [46] and the total amount is just for one whole unit of a sensor and not for its support software makes it an ideal choice for inexpensive projects for all.

2) *Parts of the Shimmer Sensor used*: The Shimmer sensor is charged using the sensor dock and the two LED lights with the capacity to pattern five colored sequences

help in notifying the status of the device [46]. We use of the Calibrated Low Noise Accelerometer and Calibrated Low Noise Gyroscope to obtain the data in the computer through Bluetooth connection from the sensor. The data generated while performing the "plantar flexion" and "dorsiflexion" actions are taken as the readings.

B. *Software*

- Language used: C#
- Technologies used: Bluetooth, TCP
- Tools used: Microsoft visual studio 2015-Shimmer Capture, Unity editor 5.5, Microsoft Excel version 2013 or later

Any Bluetooth enabled host running Windows 7 operating system or later with Microsoft .NET Framework 4 and which can host the tools and technologies mentioned can be used while in this research project Windows 10 operating system was utilized.

1) Reason for Choice of Software: Since Unity has been researched much in relation to Kinect and other gaming sensors for producing avatars [50] and also offers better C# support in the online community utilizing the ShimmerCapture/Shimmer C# API seemed to be the best option for the research project. The other support provided by the Shimmer Sensing are Shimmer 9DoF Calibration, Shimmer LabVIEW Instrument Driver, Shimmer MATLAB Instrument Driver, Shimmer Java/Android API, and Shimmer LabVIEW Development Library [46]. The ConsensysPRO Software and the ShimmerCapture for Android are the applications developed by the company. It is to be noted that most of the researches done have utilized all the other drivers and application support available as compared to the ShimmerCapture/Shimmer C# API like the fall analysis for old people [44].

Programming with the ShimmerCapture/Shimmer C# API and building the Unity

Application for the interactive avatar was feasible and achieved through this research project. The data collected is recorded in an excel sheet for further analysis. Bluetooth was used to communicate the data between the sensor the Microsoft Visual studio-ShimmerCapture module and the data transfer occurs between Unity and Microsoft Visual studio-ShimmerCapture application via TCP.

CHAPTER III

SYSTEM ANALYSIS

As this is a newly proposed idea combining visual feedback and real-time data assessment using inertial sensors, in this section a case by case analysis of the whole component of this system works better than the individual projects that exist outside.

A. Existing Systems

The existing system that is implemented which currently does the whole project is not available as this is a novel idea implemented. Parts of the systems are currently implemented using different methodologies are available [54], [35], [16], but there is no data available on the quantity or quality of the Home Exercise programs in those cases, as they have implemented fairly recent [52], [56].

1) *Goniometer:* A goniometer is an instrument used for the precise measurement of angles. It is still used in the measurement of angles between the faces of the crystals. It is using this instruments that Physical therapists, Occupational therapists, doctors and athletic trainers obtain the range of motion around the joint of a body. It is available in various sizes for helping measure the range of motion on a joint as small as the fingers to the knees and shoulder. Digital goniometers are also available, but a good quality one is very expensive.

These goniometers have in fact been developed into mobile phone applications, which then uses the mobile phone's accelerometer and gyroscope to determine the range of motion by strapping the cellphone to the joints.

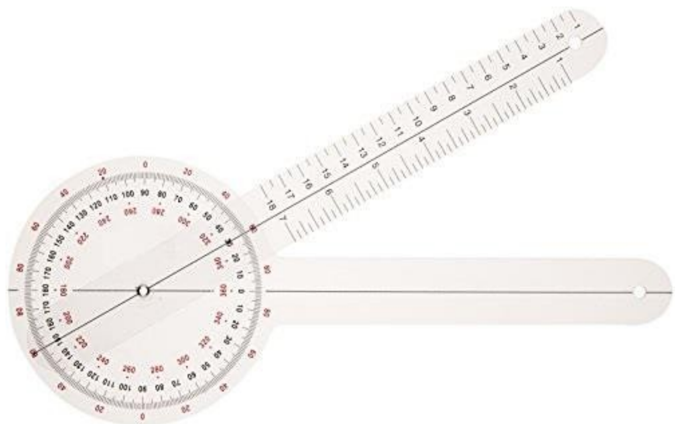


Figure 2: Goniometer

2) *Software:* There is also various software available in the market such as HEP2GO [52], Medbridge [56]and Formulift [53] (to name a few) which helps the therapists and exercise administer to implement and keep track of the Home Exercise programs for their client's and patients. There is also various software used that are associated with either clinics or hospitals which provides such customizes services. The advancement in these exercises have gone far to the extent of live video or recording the video while performing the exercise and sending it over to the doctors, therapists, and trainers for analysis.

3) *Disadvantages:* Every system has both advantageous and disadvantageous sides, and it's weighing these options which makes one decide if the particular methodology would suit them. Regarding the current software of either looking at and keeping track of the exercise is another automated way of maintaining records online for the patient and the clinical use. There have been instances where the live video or video recording have proved

to be distracting for the patients as they are more concerned about their appearance.

B. Proposed System Advantages

There are numerous researches conducted currently, and quite many papers have been published using the Shimmer sensor in the field of healthcare, and there is good evidence for the accuracy of its sensors as compared to the others in the market [51], [46], [15].

The visual feedback system in this project uses Avatars along with a rule-based framework for repetition counts. This not only limits distraction as only the body part involved is in motion but also provides a secure way of using and transmitting the recording, as no private information of the patient is bound to be misused. It can provide an interactive alternative for the patients exercising at home.

The shimmer sensor is also compact and does not need the help of another person as in case of using a regular goniometer which is used by the therapists during patient visits to the hospitals and is less expensive as compared to digital goniometer that can provide good quality accuracy by strapping to the body.

CHAPTER IV
RESEARCH OVERVIEW

In the Research overview section, we discuss in detail the keywords of this research project connected with the past researches briefly mentioned in the Literature Review section and the current system developed from the ideas.

A. Rehabilitation

The two major approaches used for human activity recognition are

- Learning-based
- Rule-based

1) Learning-based Approach: Learning based approach utilizes training data for a particular activity. There is no necessity to describe it completely provided there are sufficient training datasets are available because this approach works on obtaining the sufficient data first and it is from these a defined model is developed for new activity [23]-[29]. This is the major advantage of the Learning based system over the rule-based system as it saves time and cost in prescribing a set of conditions an activity should adhere to. At the same time, this becomes its major disadvantage as well in terms of its usage for this particular type of research where the humans or the patients always need guidance for the therapeutic exercises in order to recover from the wrong posture due to injury or illness.

Obtaining sufficient training data is also quite difficult in these cases as these activities or exercises are mostly tailored and customized according to the various conditions including but not limited to age, physical conditions and more.

2) Rule-based Approach: In the rule-based approach, all the parameters or the conditions for the activity or the exercise to be performed are sufficiently provided as the benchmarks [40]. In the case of monitoring and guiding a therapeutic exercise, these rules defined are primarily for determining the quality of the exercise performed rather than trying to discover the type of exercise that is being performed. Since in most of these cases, the activities or the exercises are predefined, and the patient who does is made knowledgeable on how to perform a certain exercise to obtain optimal functioning of the body part. So, the rules required are very small in number and are not expected to be a completely detailed form of an exercise. These rules are mostly defined by the joint angles of the body part involved. Few examples of the past research done with such joint angles as rules can be found as gait training rules: trunk flexion angle and lean angle, and the distance a set of joints for postural control traverse in[32], [33], Knee angle for Knee rehabilitation exercises in[35] while minimum hip angle is used to determine the sit-stand exercise in [34], [36].

The rules in our research project framework are based on the influence given in [40] where the angle between the two fingers is taken as the parameter which increases or decreases while performing a hand gesture. Therapeutic exercises for rehabilitation are usually analyzed as the following three in [40], [37], [38],

- Rules for Dynamic poses (Dynamic rules)

A moving body segment's successive key position sequence for each activity recurrence

- Rules for Static poses (Static rule)

A key body segment's position and/or orientation that must remain the same during each repetition

- Rules for movement invariance (Invariance rules)

The moving body segment must meet this condition during every repetition

These rules may never be the same for every exercise or activity as they are dependent on the context and can be given as one or more reference configurations [50]. A few cases of examples it could be are the joint angle such as the hip angle between two nearby body parts like the thorax and the lower limbs, also could be one between the movable arm and the upper thorax region. It could also be one of the planes like frontal or maybe even the distance between joints or relative position of joints.

In our case of establishing the joint part in the research project, we take the ankle joint and its movement up and down with respect to the standing body position or front and back with legs stretched out, commonly known as Planar Flexion, and Dorsiflexion is the exercise activity we measure for therapeutic purpose. On an average, the Plantar Flexion or "toes down" position is considered to be in the range of 0 to 45 degrees angle and the Dorsiflexion or "toes-up" is considered to be between 0 and 20 degrees angle with the 0-degree angle being the stationary rest position of the foot and the ankle joint.

B. Inertial Sensor

Two types of inertial sensors are used for measuring the joint angle. They are

- Accelerometer
- Gyroscope

The Accelerometer used in the Shimmer3 sensor is Kionix KXRB5-2042 and the Gyroscope is Invensense MPU9150. Both accelerometer and gyroscope are used for determining the angular position of a body. A good amount of research has explored using inertial sensors for angle measurement [13], [14], [34].

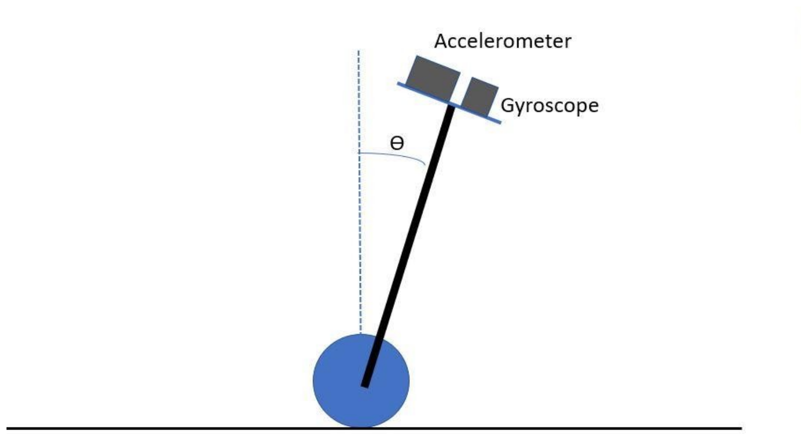


Figure 3: Inertial Sensors for Angle Measurement

1) Accelerometer: An accelerometer is used for measurement of acceleration. The forces acting on a body is not just the gravity vector, but there are acceleration components' forces influencing the body, resulting in the measurement not being accurate. The force of gravity which acts on a body has a constant acceleration and is always pointed to the center of the earth. While the title angle can be measured using the formula

θ = sin-1 (Acceleration Measured / Acceleration due to the force of gravity).

As the value of acceleration measured becomes 0G when the accelerometer in perpendicular to the gravity and 1G when it is parallel. So, to obtain the angular position, we can use the Arctan function to determine the position of the gravity (which is visible on the accelerometer). As mentioned earlier there is not just the acceleration due to gravity that acts on a body as it happens when the body is stationary, but more forces act on the body due to its movement and result in producing the measured value to be inaccurate, resulting in incorrect angles.

These other components act on the body due to its movement acts on it only for a small period as opposed to the force of gravity which is present always. Hence, we use the Low Pass Filter to reduce the noise by filtering out the excess acceleration components. This results in just the acceleration due to the force of gravity on the body using which we can determine the tilt angle. This low pass filter even though it filters the high-frequency components it increases the latency. This results in a slow response time. Hence the Gyroscope is used.

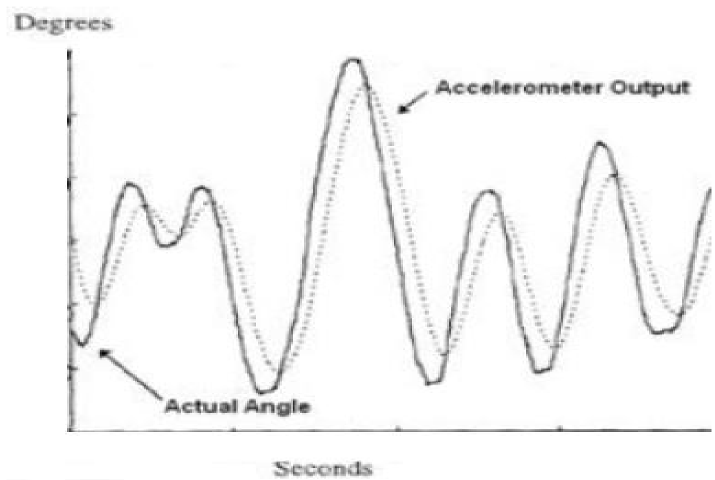


Figure 4: Accelerometer Data with Drift

2) *Gyroscope:* The gyroscope measures a body's angular velocity. It typically gives us the “the rate of change of the angular position over time (angular velocity).” Integration of this angular velocity gives us the angular position of the body. This integration used to obtain the value for the change over a long period of time it will involve approximations. These approximations introduce errors. Also, the noise produced also gets integrated. This is especially troublesome when the data changes faster than the sampling frequency. This error produced increases over time. It is called as drift. This is the error which will cause the gyroscope pointer to not to return to 0 at the rest/static position. This is particularly sensitive when the temperature changes as we integrate, a small offset due to drift can drive the values to infinity. Hence the gyroscope data is reliable only for a short period of time. This is where pairing with the accelerometer helps.

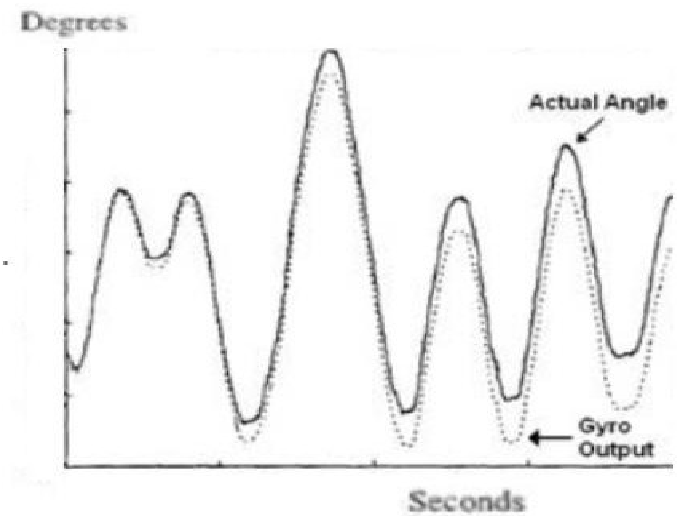


Figure 5: Gyroscope Data with Error

3) *Sensor Fusion:* Thus, the accelerometers weakness results in the calculated tilt angle have slow response time resulting in it being good and useful only over a long period of time while the gyroscope's weakness results in the integrated tilt angle drifting over a long period of time and hence is good only for only short time periods.

The fusing of these two sensor values could result in producing near typical values of the measured tilt angle. Various types of filters are used to fuse these values, the commonly used filters are

- Kalman Filter
- Complementary Filter

In this research project, a Complementary filter is used for sensor fusion. It is usually given by

Angle = HPF * (angle + gyroscope data* dt) + LPF * (accelerometer data)

(HPF +LPF =1; For this research project HPF = 0.98, LPF = 0.02)

The low pass accelerometer data processed with the Atan function is then combined with the gyroscope data integrated every time with the current angle which corrects drift in the long period of time. Thus, the strengths and weaknesses of both the sensors are balanced with each other resulting in fast responding, drift-free tilt angle.

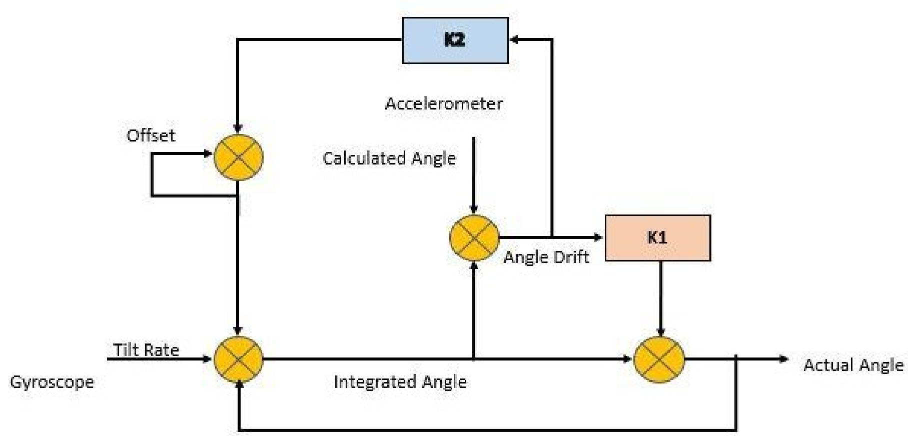


Figure 6: Complementary Filter

C. Real-time Assessment

Measuring the joint angle helps not only for rehabilitation purposes but also in prevention. The real-time monitoring of the values would only help in determining the extent to which the exercise is being performed properly, that is quality of the activity can be known instantaneously which will help in immediate correction [51]. It also helps keep tabs on the improvement done by one while practicing the Home Exercise Programs. Patient adherence to Home Exercise Programs has always been an uphill challenge forthe therapists as discussed under the Introduction and in [1], [6], [8], [9], [45]. While this being the majority of the case, there are few for whom over adherence has been an issue because of the thought that doing more is going to make them heal quicker. These pitfalls can be avoided as these real-time assessment values are generated and stored in the PC. These values could then be assessed by the therapists remotely located, as it is being done or obtaining the data from the patient after the activity was done in order to determine the quality and improvement of the patient's exercise.

For real-time assessment, we obtain the values generated by the Shimmer3 sensor by pairing it with the PC using the Bluetooth module. The Bluetooth in the PC is paired with the Shimmer3 sensor's Bluetooth. The data is obtained and then stored in an excel sheet in PC which is later used for validating the right angles at the therapists' end.

There is a Log and Stream module available in the Shimmer3 sensor module. The module is not used in this project as this research aims at obtaining real-time values easily for the patient or the therapist to be able to view or share immediately after the completion of the activity. The Log and Stream module in the API stores the values in the microSD card that can be inserted into the Shimmer3 sensor to capture the required values. This microSD card has to be then extracted, and the values have to obtained from connecting it to a reader to the PC. We are bypassing this hardware requirement and as well the non-valued added step and saving time in our proposed research project.

The ShimmerCapture module also gives a live graph feed of the calibrated low noise accelerometer values along the three axes and the calibrated gyroscope values along the three axes. There are two places in this project to view the live feed of data, one being the output pane in the Microsoft Visual studio-ShimmerCapture while the other being the live angle displayed in the Unity side of the application. When these two data are cross verified with the data stored in excel, they all match perfectly thereby achieving the real-time assessment of data obtained from the Shimmer3 and also stored in an Excel sheet at a defined location in the PC.

Obtaining the data in PC directly from the system is possible. It requires the usage of the ConsensysPRO application which can be downloaded for a price from the Shimmer Sensing website. The proposed research project provides a free solution for obtaining the data in the PC limiting the cost of the whole project to just the Shimmer3 sensor unit and other software licenses if required.

D. Visual Feedback

The Shimmer3 sensor ankle joint angle measurement is what sets apart this research project from the paper it is based on in which Kinect is utilized. The visual feedback of the joint angle measurement using Unity is what sets this research project apart from all the other Shimmer3 sensor projects available, with both real-time and recorded assessment of data. The Unity editor v 5.05 is used where a basic scene is constructed using an avatar in a seated position with legs stretched out in front. This particular posture is obtained to simulate a scene very near to the reality where after a patient gets ankle injury, the patient after the healing will be requested to do exercises seated on a chair with their leg stretched in front of them supported by cushion and stool.

This particular stance is used by the therapists to avoid straining the non-hurt leg, foot, and ankle joint while exercising. People usually tend to put more stress on the other non-injured leg while doing everyday tasks. Especially during the rehabilitation when the initial days are considered to be a little painful, it tends even to hurt the other leg at times, as due to the prolonged non-use of the injured leg, it develops as a habit to lean on the non-injured leg more. This posture eases the strain while performing the therapeutic activity. The avatar is made simple so as to view the clarity at which the foot is being exercised. The avatars can also be changed as per the need of the patients or the therapists. A gaming environment like this makes the activity much more enjoyable one and interactive as well. These avatars as compared to the real-time video monitoring or recording are much better because it not only offers privacy and but also helps in the security of the patient and the data obtained. The disadvantage that one may usually tell like sending the same file over again is bypassed by recording the time stamp as well. Also, with sufficient training, the therapists will be able to identify fake values easily when a patient tries to not adhere to the Home Exercise Programs.

Collecting these data will provide us the option of analyzing them further to obtain further insights as to the physiology and psychology of the patients with the activity performed which is still considered as part of the problem that therapists face in making patient adhere to the HEP. This visual feedback along with the value when viewed by the therapists before meeting with the respective patient, will help them be prepared more and save time in terms of trying to figure out if the patient has adhered to the HEP or not.

CHAPTER V

SYSTEM DESIGN AND IMPLEMENTATION

In this section, the system is discussed by splitting into the three steps of the design connection while briefly explaining the technology used in these connections and how they have been implemented as a part of the code to obtain the real-time assessment, visual feedback and automated data collected from the assessment.

- Connecting the Shimmer Sensor to the ShimmerCapture C# application
- Connecting the ShimmerCapture C# application to the Unity application
- Connecting the Unity application to Excel application

A brief discussion of how each application is built is also discussed under each section. All the research work was conducted using the software and hardware specifications given in Chapter II.

A. Shimmer Sensor to ShimmerCapture

ShimmerCapture C# application is an application built using the basic framework of the Shimmer3 sensor "Shimmer-C-API-REV0_7" available on the Shimmer Sensing website [46]. The revision used for the research is Revision 7. Using the main function "control.cs", the ShimmerCapture C# application is edited according to the need of the user. Using the main framework and including the various other scripts needed specifically like the Graddes3DOrientation.cs, ShimmerBluetooth.cs and enabling those in the main program works the connection between the Shimmer Sensor and the Unity application.

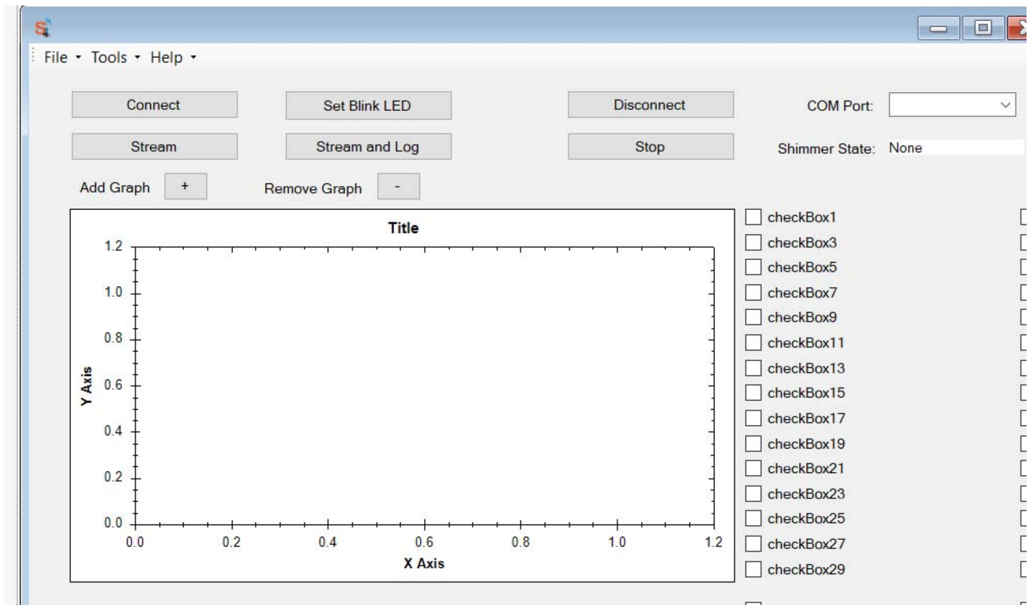


Figure 7: ShimmerCapture Application

The basic set up provided in the Shimmer sensing website does not always work. The Shimmer sensor after charged to full can be connected to a laptop or a personal computer which has a Bluetooth module available. The Bluetooth has to be enabled in the computer device, and after turning on the Shimmer sensor, it can be recognized by either going to control panel and clicking the Add device module and recognizing the device or by enabling the recognize the Bluetooth devices under the Bluetooth settings and giving the required password for the device. The Shimmer sensor will start blinking its two LEDs in a sequence of lights as shown in the Shimmer sensor user manual to show that it is paired with the computer device.

The ShimmerCapture application is enabled, and it can be edited through the "control.cs" C# script. Starting the application, in the resulting window the right COM port has to be chosen as the first step. To obtain the information of the COM port, the properties of the added Shimmer device in the control panel needs to be analyzed. Under the Services tab of the resulting Properties window after right-clicking on the device, we can find the COM port through which the Shimmer3 sensor communicates with the ShimmerCapture application. The COM port for this experiment is COM5.

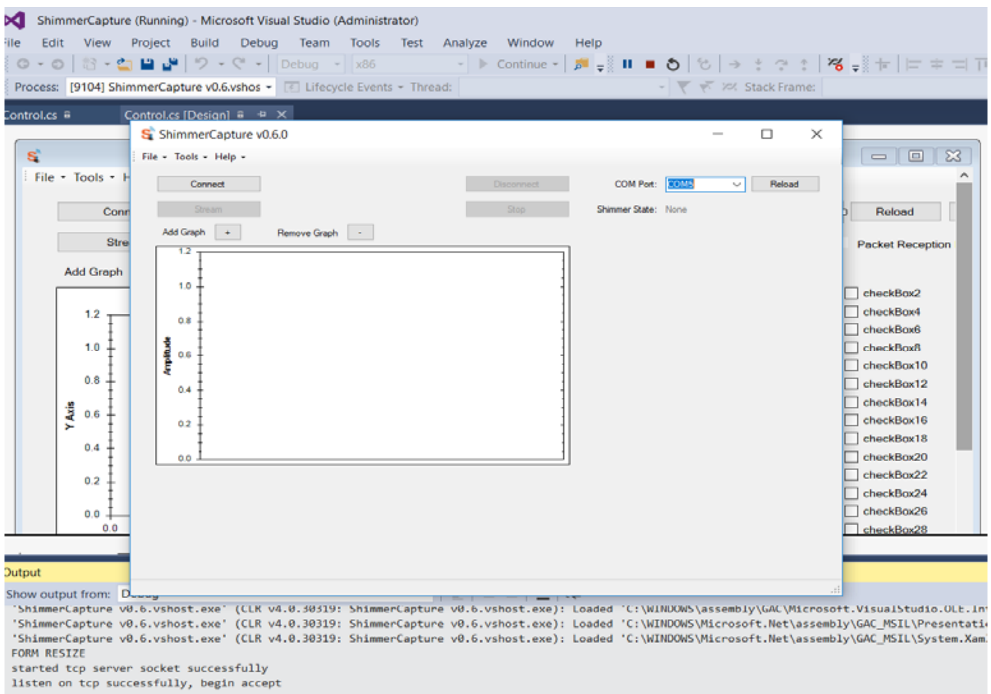


Figure 8: ShimmerCapture- After COM Port

Clicking on the “Connect” button enables the other buttons on the application screen. This will also generate a series of outputs in the “Output screen” in the Microsoft Visual Studio, showing the communication between the Shimmer3 sensor and the ShimmerCapture.

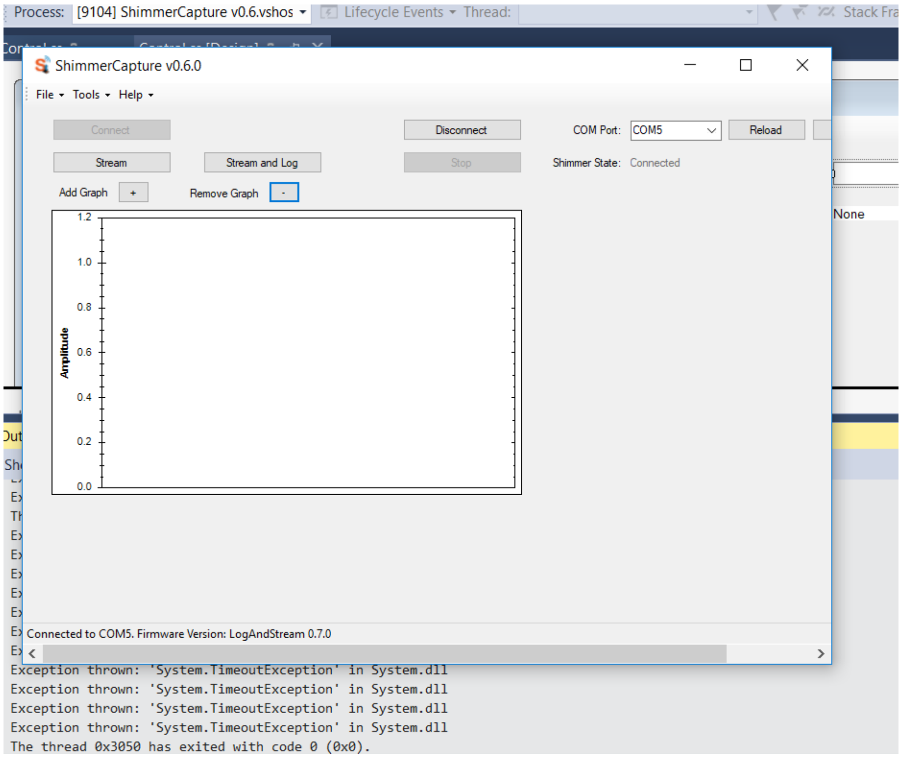


Figure 9: ShimmerCapture- After Connect

```
ExpID: default_exp
Config Time: 1475059451
Shimmer State = Connected
The thread 0x4dc4 has exited with code 0 (0x0).
Exception thrown: 'System.TimeoutException' in System.dll
Exception thrown: 'System.TimeoutException' in System.dll
```

Figure 10: Shimmer Status- Connected

In order to stream the data, clicking on the “Stream” button results in the enabling of the list of checkboxes. The Stream button when enabled triggers the two LEDs on the Shimmer3 sensor to be blinking in a set of colors and a particular sequence as given in its user manual in [46].

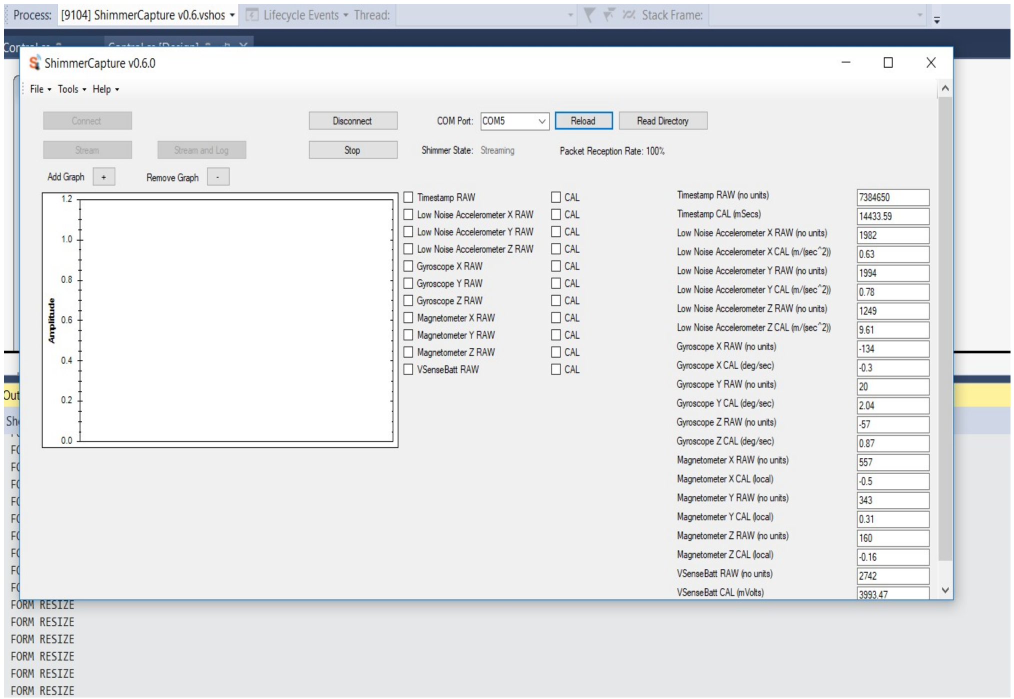


Figure 11: ShimmerCapture- Streaming

```
Shimmer State = Streaming
Exception thrown: 'System.TimeoutException' in System.dll
Timeout Streaming
```

Figure 12: Shimmer Status- Streaming

For this project we are using all the three axes of the Low Noise Accelerometer Calibrated values and the Calibrated Gyroscope values. Hence checking the "CAL" of the corresponding sensors' check boxes enables the sensors. The values are to be generated based on the position of the Shimmer3 sensor and can be seen as a live graph in the application.

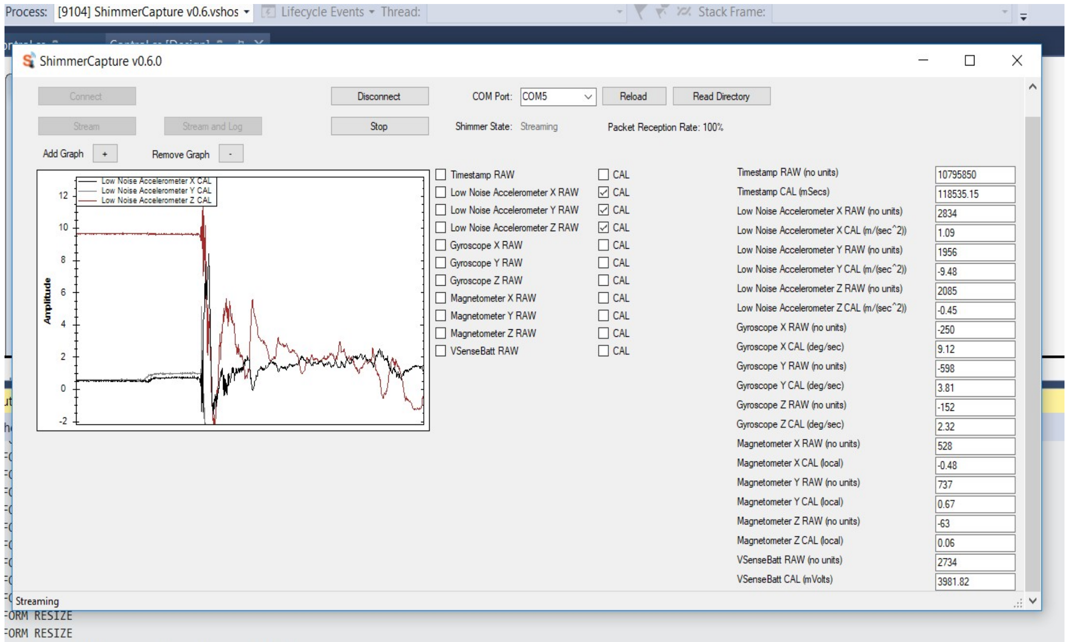


Figure 13: Calibrated Low Noise Accelerometer Values- Shimmer

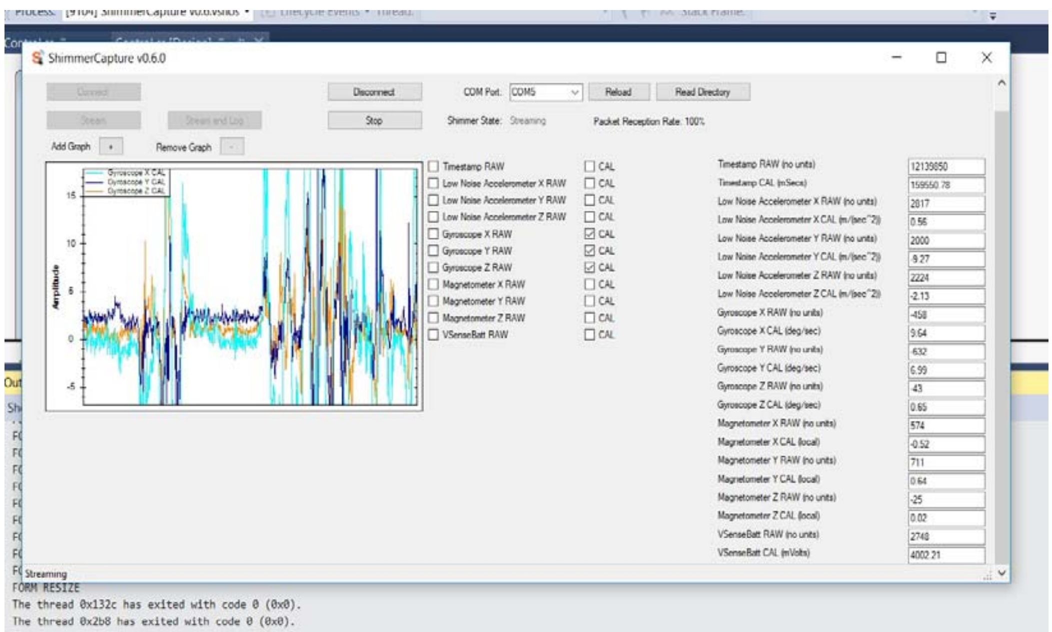


Figure 14: Calibrated Gyroscope Values- Shimmer

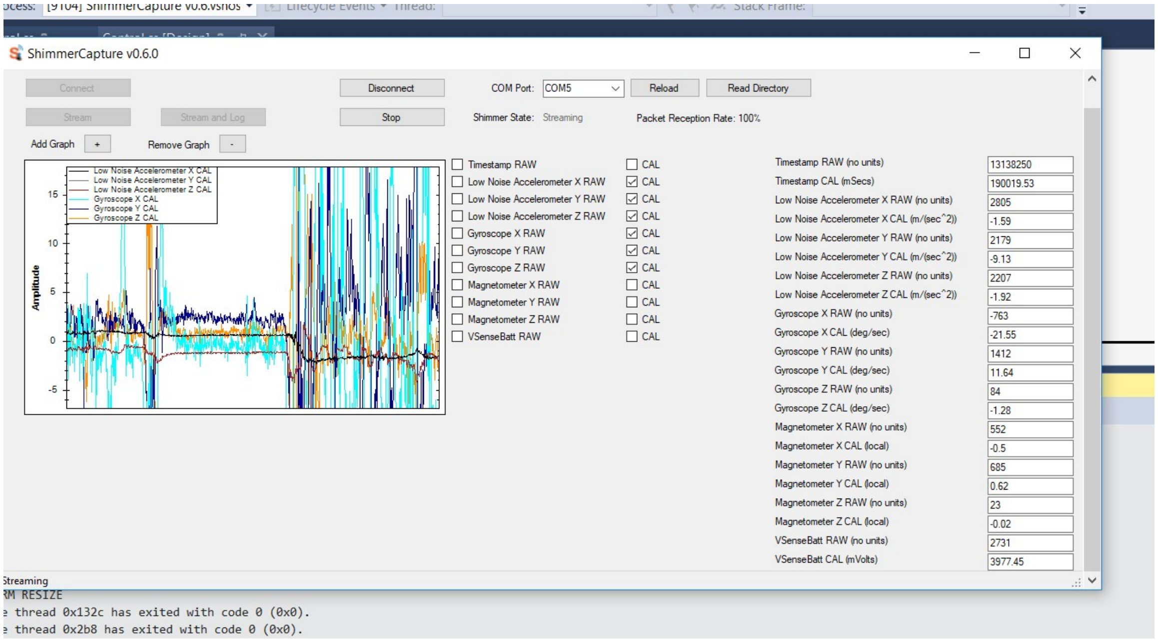


Figure 15: Both Gyroscope and Low Noise Accelerometer- Shimmer

To test the values being generated, the value of 'qx' which corresponds to Calibrated Gyroscope X axis is written on the Output screen from the program. Comparing the value generated to the graph peaks even under scale approximation shows the correctness of the value and also when cross verified with the data collected in "test.csv," it matches.

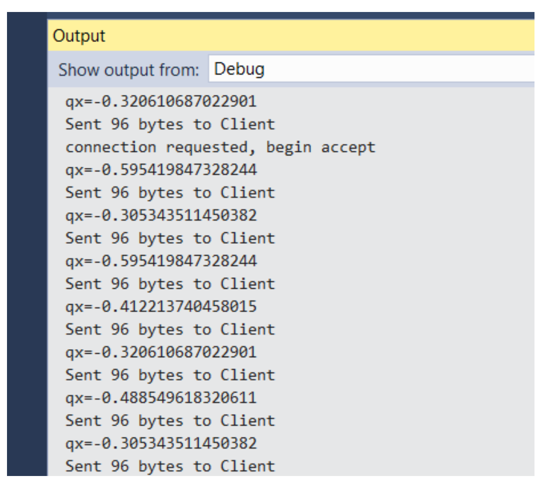


Figure 16: 'qx' Values and Bytes Sent to Unity

B. ShimmerCapture to Unity

The ShimmerCapture C# application is then connected to the Unity application using the TCP protocol. Using the libraries for networking in C# such as System. Net, the generated data from the sensor is put together as a packet and then transfers the same when requested by the Unity application.

Using a series of output lines that can be viewed in the console output we can determine from the sender side, the status of the bytes sent. The packet contains the following information,

- Time Stamp, Calibrated values
- Low Noise Accelerometer X axis, Calibrated values
- Low Noise Accelerometer X axis, Calibrated values
- Low Noise Accelerometer X axis, Calibrated values
- Gyroscope X axis, Calibrated values
- Gyroscope Y axis, Calibrated values
- Gyroscope Z axis, Calibrated values

The packet is then sent over to the Unity application. The Unity application is built with a basic seated avatar with the motion enabled only in the ankle part of the avatar. The seated application is built because usually when a person is hurt at the ankle, the first set of Home exercise programs are given for practice while seated on a chair with the injured leg over a cushioned stool for support. Then the exercises are initially made to be involuntary in the presence of the therapists with their help. Then they are taught the activities they would have to practice every day before coming for the next visit/appointment.

This avatar is built bearing in mind the closest possible posture for the exercise.

The actual connection of the built unity avatar with the Shimmer sensor occurs through the TCP connection with the ShimmerCapture application. Three essential C# are built into the Unity application and they are as follows

- Connection.cs- for establishing the connection between the ShimmerCapture application and the Unity application
- TCPconnection.cs- for communicating over the TCP protocol using sockets
- SensorController- for obtaining the packets of data sent from the ShimmerCapture application and connecting it to the Avatar. The analysis of the calibrated values obtained and storing the same in an MS Excel.

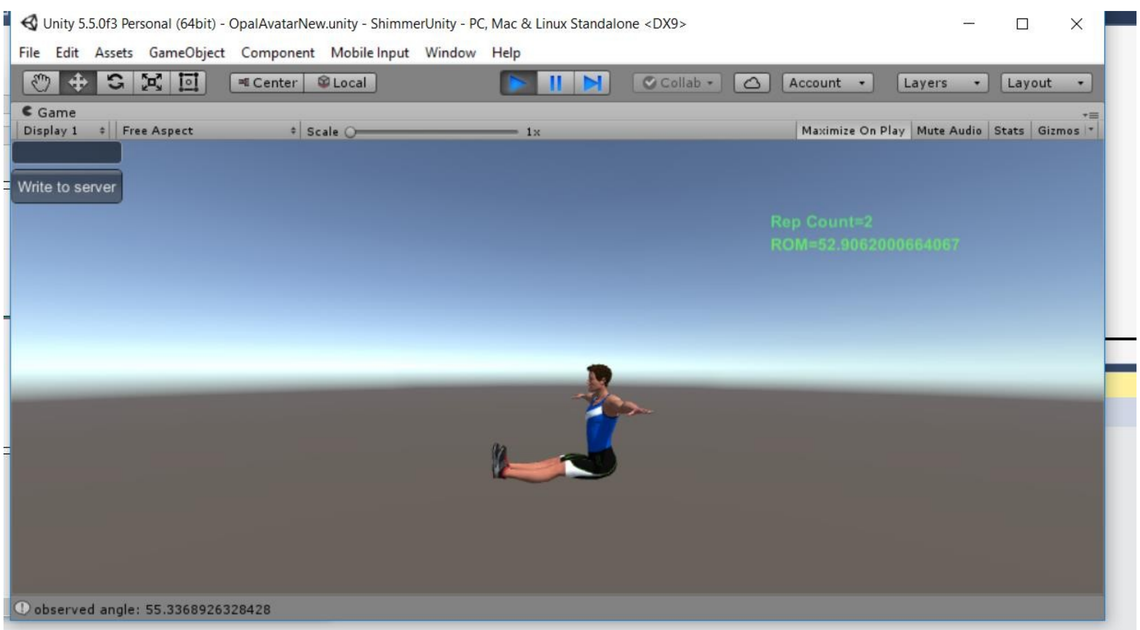


Figure 17: Unity Initial Setup

In the Connection section, the transport layer is initialized by connecting the sockets for sending requests to obtain the data. The rule for obtaining the information is given here as the update required once per frame for the connection checking. The commands are given for every network connection status and also the result and actions that need to occur based on the connection event are given in this program part.

In the TCPconnection section, after the connection is initialized in order to connect the right host and client, the sockets are set up from the unity section, and a connection is initiated. Any error in the socket connection is known here. The program for the connection that needs to be performed based on the socket connection and checking the connection per frame while streaming the data from the Shimmer3 sensor is provided here.

In the SensorController program, we obtain the packets by calling the TCP connection function and functions for receiving the packets while simultaneously requesting for it. The angle is obtained by calculating pitch angle and fused angle for calculating the observed angle which is recorded on a per frame basis in the MS Excel while the visual feedback utilizes Quaternion function for the calculation of foot vector position and the angle position on the GUI. In the Quaternion function, only the ‘w’ and ‘z’ values are given as the movement of the ankle only in one axis is needed, which is ‘z’ and the angle calculated is translated as the rotation of the ankle using the ‘w’ value. The result of completing the rule posed based on the observed angle increase or decrease determines the “rep count.” Based on comparing the observed angle with the last observed angle, the increase or decrease in the angle is determined to result in addition to the “rep count" accordingly.

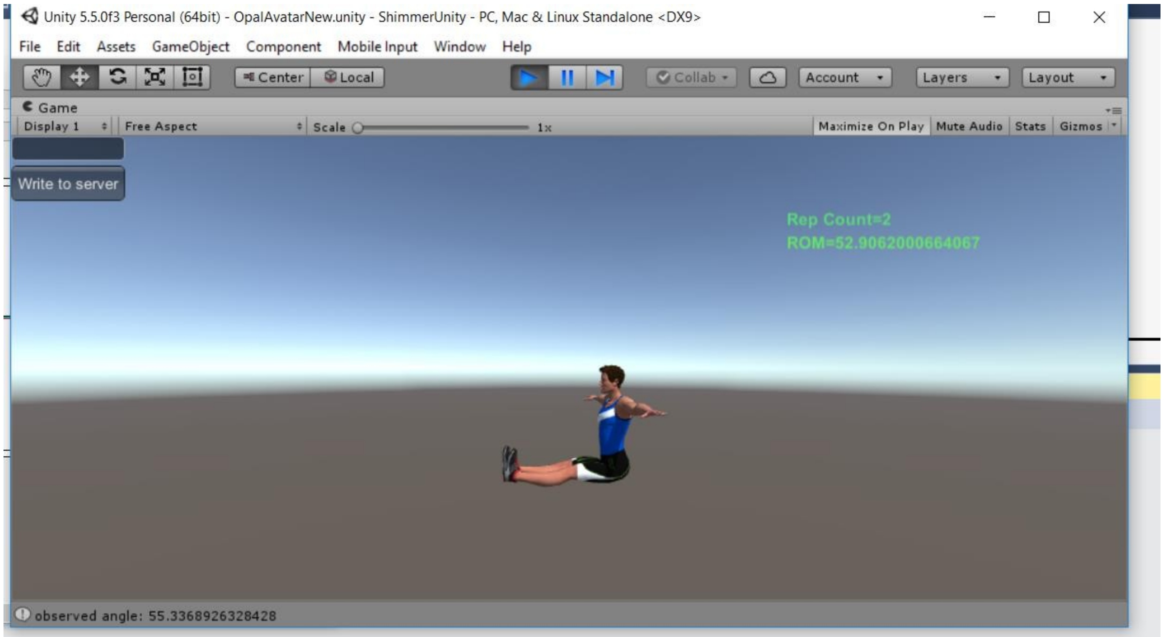


Figure 18: Unity with Visual Feedback

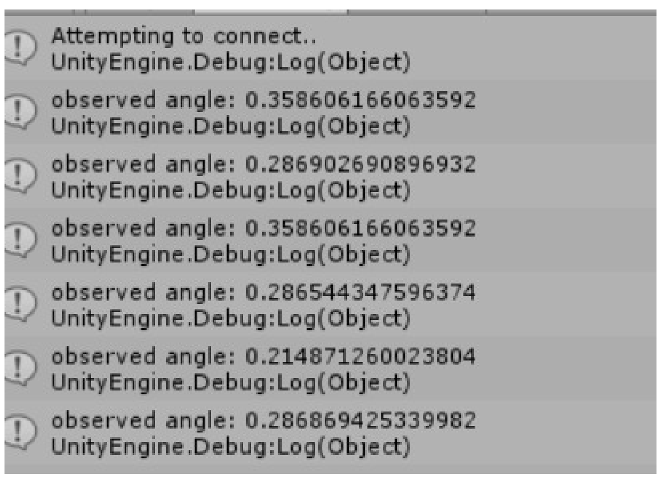


Figure 19: Observed Angle- Unity Console Window

C. Unity to Microsoft Excel

The following values are stored in the MS Excel application for further analysis of the angle.

- Time Stamp

- Observed angle
- Low Noise Accelerometer X axis
- Low Noise Accelerometer Y axis
- Low Noise Accelerometer Z axis
- Gyroscope X axis
- Gyroscope Y axis
- Gyroscope Z axis

The values that are generated can be cross verified with the values stored directly from the ShimmerCapture application. In the “control.cs” program, using the StreamWriter’s File.CreateText(), we create a “test.csv” file in which using the StreamWriter’s Write() we store the values of the Low Noise Accelerometer axes values. These values can be cross verified with the values stored in the “testUnity.csv” file created to store the values on the Unity application side.

Using the TextWriter and StreamWriter function of the unity we create a persistent data path for the application under the name “/testunity.csv.” Initially, if there is no file under the name in the established data path, then it creates a Microsoft Excel file under the same name in the data path else it just opens the file for editing as needed.

We use the File.AppendAllText() function to store all the values listed above as a comma separated values. This is done for frame by frame basis. After the completion of the necessary edition, the file is closed using the TextWriter’s Close() function.

These files can then be found in the system under the application files. The ShimmerCapture data file “test.csv” can be found under the bin folder of the application file while the “testunity.csv” file can be found under the Shimmer Unity application files section.

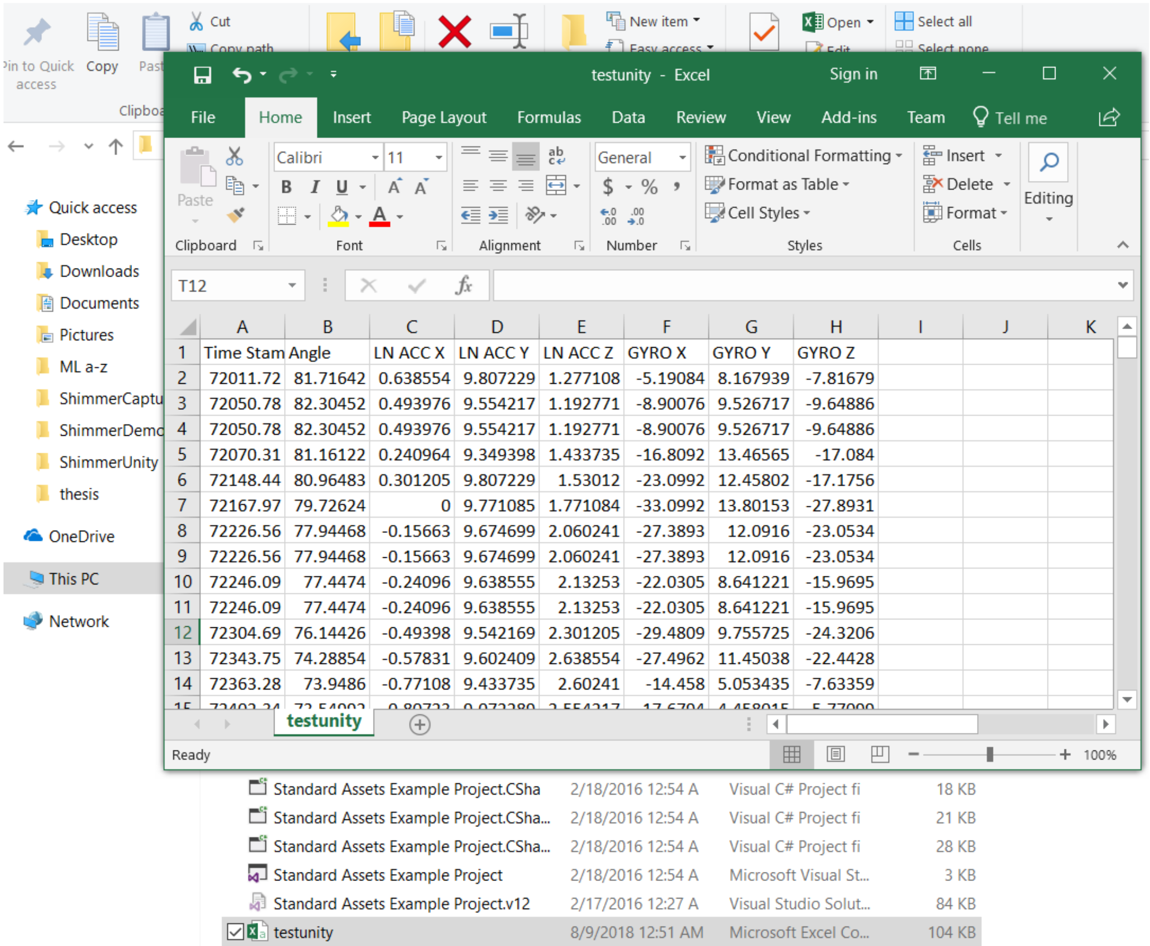


Figure 20: Sample Data Collected in MS Excel from Unity

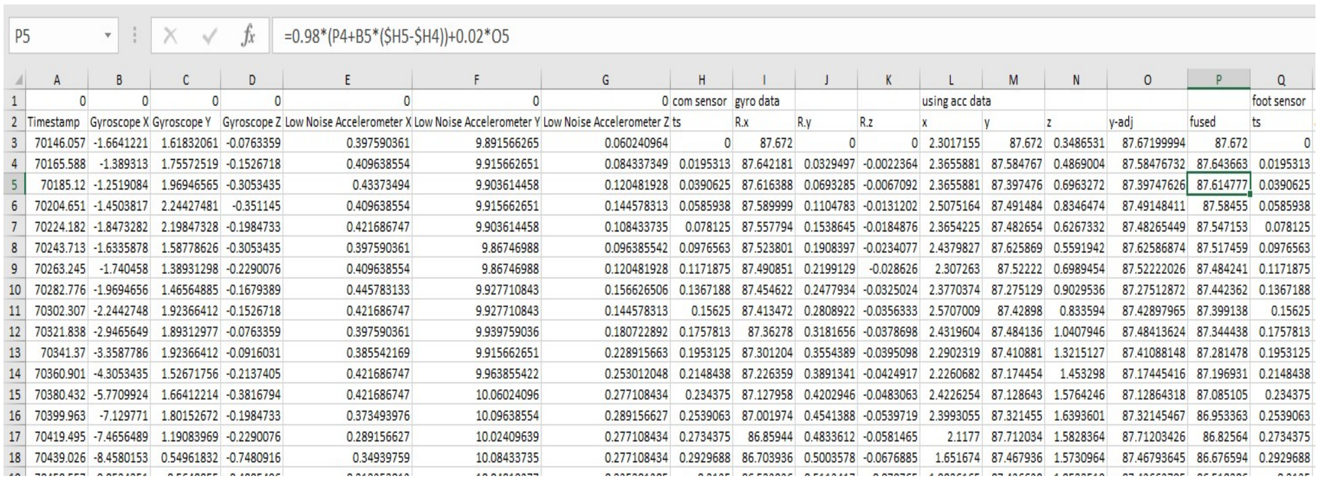
D. *Data Analysis*

From the data that is stored in the "testunity.csv," we can calculate the accelerometer angular position and the gyroscope angle using the timestamp value generated. Then using these two values the complementary filter equation given under the Chapter IV Sensor fusion is computed.

$$\text{Angle} = 0.98 * (\text{angle} + \text{gyroscope data} * dt) + 0.02 * (\text{accelerometer data})$$

(HPF +LPF =1; For this research project HPF = 0.98, LPF = 0.02)

Then this is plotted as graphically in the MS Excel resulting in smooth curves clearly depicting the action of the foot. The angle values generated are not the real-time values as mentioned in Chapter IV Rehabilitation section. This can be obtained by fine-tuning the filter and setting an appropriate rule and values for max observed angle and min observed angle in the SensorController Unity program.



P5 =0.98*(P4+B5*($H5-$H4))+0.02*O5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	0	0	0	0	0	0	0	com sensor	gyro data			using acc data					foot sensor
2	Timestamp	Gyroscope X	Gyroscope Y	Gyroscope Z	Low Noise Accelerometer X	Low Noise Accelerometer Y	Low Noise Accelerometer Z	ts	R.x	R.y	R.z	x	y	z	y-adj	fused	ts
3	70146.057	-1.6641221	1.61832061	-0.0763359	0.397590361	9.891566265	0.060240964	0	87.672	0	0	2.3017155	87.672	0.3486531	87.67199994	87.672	0
4	70165.588	-1.389313	1.75572519	-0.1526718	0.409638554	9.915662651	0.084337349	0.0195313	87.642181	0.0329497	-0.0022364	2.3655881	87.584767	0.4869004	87.58476732	87.643663	0.0195313
5	70185.12	-1.2519084	1.96946565	-0.3053435	0.43373494	9.903614458	0.120481928	0.0390625	87.616388	0.0693285	-0.0067092	2.3655881	87.397476	0.6963272	87.39747626	87.614777	0.0390625
6	70204.651	-1.4503817	2.24427481	-0.351145	0.409638554	9.915662651	0.144578313	0.0585938	87.589999	0.1104783	-0.0131202	2.5075164	87.491484	0.8346474	87.49148411	87.58455	0.0585938
7	70224.182	-1.8473282	2.19847328	-0.1984733	0.421686747	9.903614458	0.108433735	0.078125	87.557794	0.1538645	-0.0184876	2.3654225	87.482654	0.6267332	87.48265449	87.547153	0.078125
8	70243.713	-1.6335878	1.58778626	-0.3053435	0.397590361	9.86746988	0.096385542	0.0976563	87.523801	0.1908397	-0.0234077	2.4379827	87.625869	0.5591942	87.62586874	87.517459	0.0976563
9	70263.245	-1.740458	1.38931298	-0.2290076	0.409638554	9.86746988	0.120481928	0.1171875	87.490851	0.2199129	-0.028626	2.307263	87.52222	0.6989454	87.52222026	87.484241	0.1171875
10	70282.776	-1.9694656	1.46564885	-0.1679389	0.445783133	9.927710843	0.156626506	0.1367188	87.454622	0.2477934	-0.0325024	2.3770374	87.275129	0.9029536	87.27512872	87.442362	0.1367188
11	70302.307	-2.2442748	1.92366412	-0.1526718	0.421686747	9.927710843	0.144578313	0.15625	87.413472	0.2808922	-0.0356333	2.5707009	87.42898	0.833594	87.42897965	87.399138	0.15625
12	70321.838	-2.9465649	1.89312977	-0.0763359	0.397590361	9.939759036	0.180722892	0.1757813	87.36278	0.3181656	-0.0378698	2.4319604	87.484136	1.0407946	87.48413624	87.344438	0.1757813
13	70341.37	-3.3587786	1.92366412	-0.0916031	0.385542169	9.915662651	0.228915663	0.1953125	87.301204	0.3554389	-0.0395098	2.2902319	87.410881	1.3215127	87.41088148	87.281478	0.1953125
14	70360.901	-4.3053435	1.52671756	-0.2137405	0.421686747	9.963855422	0.253012048	0.2148438	87.226359	0.3891341	-0.0424917	2.2260682	87.174454	1.453298	87.17445416	87.196931	0.2148438
15	70380.432	-5.7709924	1.66412214	-0.3816794	0.421686747	10.06024096	0.277108434	0.234375	87.127958	0.4202946	-0.0483063	2.4226254	87.128643	1.5764246	87.12864318	87.085105	0.234375
16	70399.963	-7.129771	1.80152672	-0.1984733	0.373493976	10.09638554	0.289156627	0.2539063	87.001974	0.4541388	-0.0539719	2.3993055	87.321455	1.6393601	87.32145467	86.953363	0.2539063
17	70419.495	-7.4656489	1.19083969	-0.2290076	0.289156627	10.02409639	0.277108434	0.2734375	86.85944	0.4833612	-0.0581465	2.1177	87.712034	1.5828364	87.71203426	86.82564	0.2734375
18	70439.026	-8.4580153	0.54961832	-0.7480916	0.34939759	10.08433735	0.277108434	0.2929688	86.703936	0.5003578	-0.0676885	1.651674	87.467936	1.5730964	87.46793645	86.676594	0.2929688

Figure 21: Angle calculation Using Sensor fusion

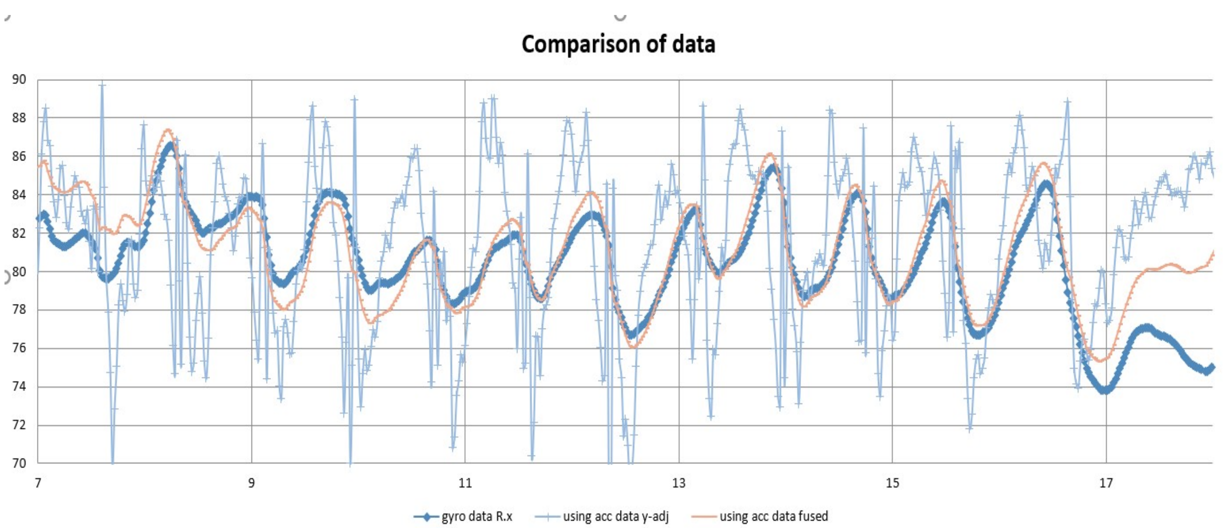


Figure 22: Fused Angle with Gyroscope and Accelerometer Data

CHAPTER VI
CONCLUSION

A rule-based framework for properly obtaining the ankle joint angle measurement was created. Shimmer sensor's accelerometer and gyroscope were used instead of the previously tested methods in order to use wireless sensor technologies and also to measure small angles that are not possible to be measured using Microsoft Kinect. The C# scripts to communicate between the Wireless sensor and the applications was implemented. An avatar-based application to provide visual feedback was created. The data generated using the sensor was successfully transmitted to the application. This was tested in many instances and at various places in different applications. The data generated was finally used to control the avatar's ankle while simultaneously the "rep count," implemented based on the rule-based framework, and the "Range of motion" of the ankle was displayed in real time as the activity was taking place. The generated data was stored in a Microsoft Excel file, and it was analyzed. A Complementary filter was used to fuse the inertial sensors-Accelerometer's and Gyroscope's angle data. A graph was plotted using these data, and a smooth curve depicting the ankle motion in the graph was obtained resulting in the success of the real-time assessment and visual feedback application using inertial sensors for patient rehabilitation.

CHAPTER VII
CHALLENGES AND FUTURE WORK

The Future Work on this whole research project can be subdivided into two categories of improvising the existing system and creating new systems based on the current application.

A. Challenges in Improvising the Existing System

- In terms of devising the existing system, the smoothing factor while the transformation of the ankle rotation during the live visual feedback can be improved to provide a smooth transition.
- A real live set up of the patient's position using chairs and cushions can be considered if available or can be developed in a cost-effective way
- Automated filter application in the MS Excel sheet to obtain the final values can be implemented using the Excel VBA language
- Implementing the Kalman filter to the program for more noise reduction and obtain clean data

B. Creating a New System Based on the Existing Application

- Providing a live graph on the Unity GUI for the observed value and ROM calculated

- Developing an Excel Macro for categorizing the rep counts and the data based on the date and time worked out for patient analysis as well
- Developing an Android application for the same and also including the graphing and charting abilities
- Increasing the Ankle range of motion to be more than Plantar Flexion and Dorsiflexion
- Implementing for other commonly injured parts of the body or joints such as Knee joint after the total knee replacement surgery and hip joints after the Hip surgery
- With HIPPA clearance this product once fully developed could be developed as a sole software or embedded part of an organization’s software and could potentially replace CPMs in the future, saving, cost and time by providing more quality and quantity

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