Department of Information Science and Technology

Augmented Reality System with Application in Physical Rehabilitation

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Master in Telecommunications and Computer Engineering

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Resumo

O envelhecimento causa um aumento das necessidades dos serviços de fisioterapia, com aumento dos custos associados a longos períodos de reabilitação. Os métodos tradicionais de reabilitação dependem da avaliação subjetiva de fisioterapeutas sem registo automatizado de dados de treino. Com o principal objetivo de superar os problemas do método tradicional e melhorar a eficiência da reabilitação, é utilizada a RA (Realidade Aumentada), que representa uma tecnologia promissora, que fornece uma interação imersiva com objetos reais e virtuais. Os dispositivos de RA são capazes de garantir uma postura correta do corpo de capturar e verificar o ambiente real, o que levou a um número crescente de aplicações de RA focados na reabilitação física. Neste projeto, é apresentada uma plataforma de RA, utilizada para materializar um plano de reabilitação física para pacientes que sofreram AVC.

O treino de marcha é uma parte significativa da reabilitação física para pacientes com AVC. A RA apresenta-se como uma solução promissora para a avaliação do treino, fornecendo informações aos pacientes e aos profissionais de fisioterapia sobre os exercícios a serem realizados e os resultados alcançados. Como parte deste projeto, uma aplicação iOS foi desenvolvida na plataforma Unity 3D. Esta aplicação fornece aos pacientes um ambiente imersivo que combina objetos reais e virtuais. A interface de RA é materializada por um iPhone montado num suporte de cabeça do utilizador, assim como um conjunto de sensores sem fios para medição de parâmetros fisiológicos e de movimento. A posição e a velocidade do paciente são registadas por um tapete inteligente que inclui sensores capacitivos conectados a uma unidade de computação, caracterizada por comunicação via Wi-Fi. O cenário de treino em RA e os resultados experimentais correspondentes fazem parte desta dissertação.

Palavras-chave: Realidade Aumentada, Reabilitação Física, Parâmetros Físicos, Sensores de Movimento, Sensores de Localização

Abstract

The aging phenomenon causes increased physiotherapy services requirements, with increased costs associated with long rehabilitation periods. Traditional rehabilitation methods rely on the subjective assessment of physiotherapists without supported training data. To overcome the shortcoming of traditional rehabilitation method and improve the efficiency of rehabilitation, AR (Augmented Reality) which represents a promissory technology that provides an immersive interaction with real and virtual objects is used. The AR devices may assure the capture body posture and scan the real environment that conducted to a growing number of AR applications focused on physical rehabilitation. In this MSc thesis, an AR platform used to materialize a physical rehabilitation plan for stroke patients is presented.

Gait training is a significant part of physical rehabilitation for stroke patients. AR represents a promissory solution for training assessment providing information to the patients and physiotherapists about exercises to be done and the reached results. As part of MSc work an iOS application was developed in unity 3D platform. This application immersing patients in a mixed environment that combine real-world and virtual objects. The human computer interface is materialized by an iPhone as head-mounted 3D display and a set of wireless sensors for physiological and motion parameters measurement. The position and velocity of the patient are recorded by a smart carpet that includes capacitive sensors connected to a computation unit characterized by Wi-Fi communication capabilities. AR training scenario and the corresponding experimental results are part of the thesis.

Keywords: Augmented Reality, Physical Rehabilitation, Physical Parameters, Motion Sensors, Localization Sensors

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Content

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List of Acronyms

AR	Augmented Reality
WHO	World Health Organization
VR	Virtual Reality
MR	Mixed Reality
NED	Near-Eye Display
CPU	Central Processing Unit
HPU	Holographic Processor
GPS	Global Positioning System
BPO	Body-Powered Orthosis
IR	Infrared Radiation
DB	Database
NoSQL	Not Only Structured Query Language
BaaS	Backend as a Service
API	Applications Programming Interfaces
SDK	Software Development Kits
IoT	Internet of Things
ECMO	Extracorporeal Membrane Oxygenation
UI	User Interface
WSN	Wireless Sensor Network
IR	Infrared
SLS	Structure Light System
3D	Three Dimensions
CMOS	Complementary Metal Oxide Semiconductor
VGA	Video Graphics Array
GUI	Graphical User Interface
HDMI	High Definition Multimedia Interface
TCP	Transmission Control Protocol
VPN	Virtual Private Network
WLAN	Wireless Local Area Networks
ECG	Electrocardiography
EMG	Electromyography
GSR	Galvanic Skin Response
EOG	Electrooculography
HR	Heart Rate
EDR	Electrodermal Resistance
EDA	Electrodermal Activity
PPG	Photoplethysmography
IMU	Inertial Measurement Unit

Chapter 1 – Introduction

1.1 Motivation

Stroke is a sudden cerebrovascular disease with a high rate of death and disability. Based on the data from The World Health Organization (WHO), over 6 million people are suffer stroke, placing a burden on family and society. Survivors may suffer loss of vision and/or speech, paralysis and confusion. The risk of further episodes is significantly increased for people having experienced a previous stroke. In recent years, the number of strokes continues to increase because of the aging population [1].

Common symptoms of patients after stroke include the inability to move a one-sided limb or can't feel a side of the body, upper limb and lower limb impairment, and problem in daily life [2]. Acute stroke patients are often suffered varying degrees of neurological deficits, mental dysfunction, and limited daily living ability. Since the 1950s, physiotherapist began to give therapeutic prescriptions to stroke patients and achieved positive results. In Twitchell's [15] study, 121 post stroke patients are observed. The possibility of restoring hand motion capability within 4 weeks is 70%, almost patients will recovery their hand motion activity in 3 months and a few of them will restore in six months. Rehabilitation medicine shown good efficiency on restoration. Rehabilitation medicine provides targeted treatment to patients and plays an important role in our lives. Modern Rehabilitation medicine is a technology that studies the dysfunction of the body caused by disability, and carries out rehabilitation assessment, rehabilitation training, and rehabilitation to achieve the purpose of improving or reconstructing the body, mind, and social function of the patient.

In purpose to improve the efficient of physical rehabilitation, the new concepts [13] of rehabilitation and functional training are:

• It should be patient-centered and consider the needs of patients for functional rehabilitation;

• Functional training should be linked to the patient's daily life, work activities, focusing only on the training of functional activities;

• Patients should be encouraged to perform functional activities as often as they can, instead of being limited to 5% of the daytime daily, under the guidance of the therapist; it is best to keep the patient in a skill learning environment;

• Only by multi-disciplinary participation, and with the cooperation of the patient's family, can we truly meet the specific needs of each patient in functional rehabilitation.

In the study [14], 312 stroke survivors (average age in 63, 57% female, 70% white) participate in the survey, only 31% performed the exercise associated with their recommended rehabilitation plan, insufficient rehabilitation exercise will bring worse health status to stroke patients and some repetitive exercise with designated place will bring tired emotion to patients. In terms of economic, the rehabilitation plan is limited time period, the extension of the rehabilitation period is expensive, the usage of specific equipment magnetotherapy and massage are also expensive [16], the above demonstrated the shortcoming of traditional rehabilitation method:

• heavy physiotherapy assessment equipment;

• high costs associated with long therapy periods and the need of fulltime physiotherapists;

• lack of objective evaluation of rehabilitation processes,

• less or no feedback to the patients, no data record and no data analysis.

To solve this problem, utilization of new technologies and improve patients' personal intervention, such as motivation are helpful.

Smart rehabilitation technologies can provide parameters that can be used as part of feedback elements on treatment [17]. Therapy application with the AR system was widely used in body rehabilitation and physical exercise in recent years. A training system for hand rehabilitation which proposed in [18] enables patients to simultaneously interact with real or virtual environments. A serious game based on Augmented Reality in [19] also has good result in the upper-limb rehabilitation. Users of AR rehabilitation systems get rid of heavy medical equipment, get more relax in the training process. Due to the diversity and flexibility of therapy application, function and metrics could extend according to the requirement of rehabilitation, which demonstrates the efficiency and convenience of the AR system.

The research that integrate AR scenes and biomedical sensors are rarely in recent years. In order to enrich study and help the stroke patients recover in a shorter duration, the method in this thesis is proposed. This rehabilitation system can measure and record all training data which could provide a basis of diagnosis for physiotherapist, and location-free environment also save costs for the rehabilitation.

1.2 Objectives

The main objectives of the project are development of a serious games framework that integrates the information provided by 3D sensors with additional information provided by the wearable and environment distributed sensors to allow reality-virtual reality interactions and augmented reality. The used sensors are associated with motor rehabilitation activity of the upper and lower limbs. Thus, acquired kinematic and dynamic information can be later used to provide feedback to the user as part of the rehabilitation process. An additional objective will be the development of software module for data analysis and visualization module that will allow to extract information about patterns associated with rehabilitation and to develop models associated with the rehabilitation process. These methods will be used to perform the optimization of the motor rehabilitation process for stroke or cerebral palsy patients.

1.3 Research Method

This research method is based on an iOS application centered, assisted by biomedical sensors and Firebase database. At first, a Unity-based iOS application was developed, several AR scenarios were built, Google VR tools to localize patients during the motion rehabilitation exercises. Then integrate biomedical sensors, patients' health status was measured in real time and upload to Firebase, corresponding indoor localization and velocity info being provided by a smart carpet. Depth sensor collect the data of actual environment and generate model which could be used in Unity project. At last, several volunteers participate in the research and provide test data.

1.4 Structure of the dissertation

Chapter 2 includes a literature review on AR devices and software tools that are used in physical rehabilitation. Several smart sensors, wearable and non-wearable, that are used in physical therapy are described. Chapter 3 presents the whole gait training system, including all devices used of this system, such as 3D scanning sensor, Sense Floor and the Shimmer sensor.

The iOS application for physical rehabilitation is presented in Chapter 4. Chapter 5. The implementation of an information system for data storage based on Firebase real-time database technology is also described. Chapter 6 considers the experimental results and discussion. Chapter 7 is concerned with conclusions and future work. Lastly, a user manual on system applications and a technical manual explaining the main functions of the applications was developed.

Chapter 2 – State of the art

This chapter focus on researches in augmented reality, physical therapy applications and patient assistant sensors. It presents some medical applications on the market and remote data storage solutions.

2.1 Augmented Reality

Augmented Reality (AR) Technology is an emerging technology based on virtual reality technology. It uses computer vision technology, sensor technology and visualization technology, interactive technology, etc. to organically superimpose computer-generated virtual images or other information into real-world scenes that users see, including visual, auditory, olfactory, tactile information, etc. This technology has broad and far-reaching application prospects in medical research, precision instrument manufacturing and maintenance, military and entertainment.

Augmented Reality (AR) is the extension of Virtual Reality (VR). Different from VR, AR creates an environment including both real-world and virtual objects [20]. In AR scenarios, users could perform actions with the assessment devices. Thus, the user could see an augmented scene characterized by information of real world and additional virtual information at the same time, a very known example, being Pokemon Go [21]. The upper limbs training for stroke patients in [22] presents a virtual cup on the table and lets patients do corresponding actions, is a good template on integrating AR and physical rehabilitation. The principle of AR is traditional pattern recognition technology: some real information is marked in the necessary objects, through computer and other technologies, followed by the simulation and superimposition, the virtual information is applied to the real world, perceived by human senses [23]. AR bring user a sensory experience, the real environment and virtual objects are superimposed in real time on the same picture or space, becoming augmented effects that we see.

AR is also a technology with great potential and can be quickly integrated into people's lives. AR-based rehabilitation applications can be downloaded by patients or the physical therapist's on their mobile device. Thus there is no time and place restrictions for AR based physical rehabilitation patient's rehabilitation outcomes.

2.1.1 Augmented Reality Technology

AR technology is to enhance the user experience in the real world through certain sensing devices. When the user wears the AR device, he is in the real world but can feel the superimposed contents from the AR device and the real world, in this case, the real world and the illusory image are combined perfectly. Users will not have a feeling of separation because of the real-time combination and many amazing scenes will show in front of the user.

AR is a novel technology that bring user immersive feeling of real world [24]. VR is a closely related technology with AR, but they are different fundamentally. The AR makes some changings in the reality, strengthen an extreme experience based on the reality, use some kinds of equipment to obtain "real" images, scenes are transmitted to user through information processing technology, superimposed some information such as text, sound and virtual images. The VR build completely virtual environment which get rid of the real world. VR technology make people unable to distinguish the localization in real environment, such as VR game player will suddenly fall or scream while he is in a peace reality. Make user get unprecedented experience. Table 2.1 indicate the comparation between AR technology and VR technology [3].

	VR	AR
Display devices	Head-attached devices, smart glasses	Head-attached devices, hand-held devices, spatial devices
Source of scenes	Virtual scenes from computer	Synthetic scenes combine real world and computer
Environment	Virtual	Virtual and Reality
Perspective	Virtual objects will change their position and size based on the user's perspective in the virtual world.	The behavior of virtual objects is based on the user's perspective in the real world.
Feeling of the real world	Feeling being transported to other places, no feeling of the real world.	Feeling still in the real world, but superimposed with new elements and objects
Awareness of the real world	A perfectly rendered virtual world cannot be distinguished from the real world.	Based on their nature and behavior, virtual information can be identified, such as text or virtual objects floating around the user.

Table 2.1 Comparison between Augmented Reality and Virtual Reality

Mixed Reality (MR) refers to the creation of new environments and visualizations that combine real and virtual worlds. Physical entities and digital objects coexist and interact in real time to simulate real objects. It is a mix of reality, augmented reality, enhanced virtual and virtual reality technologies. Fig 2.1 shows the relationship between AR, VR and MR [44].

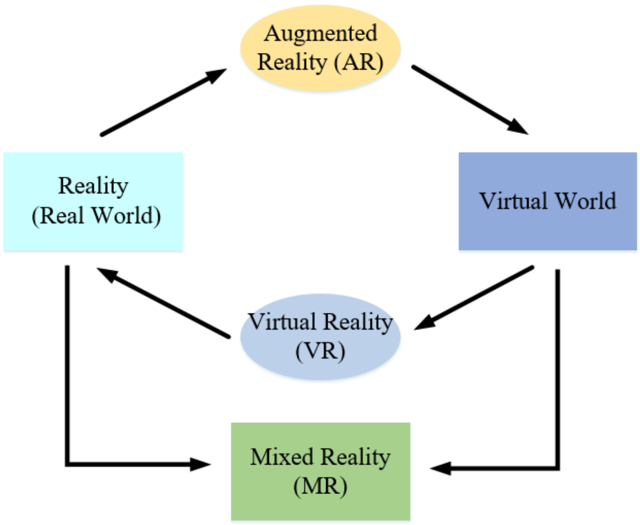


Figure 2.1 Relationship between AR, VR and MR

VR and AR have differences in the technology principle and display devices. Considering construction of 3D scenes, VR tends to be illusory and emotional. It is easy to apply to entertainment, while AR is more realistic and rational, and suitable for more serious directions, such as work and training. VR and AR have not yet reached the limit, but there are signs of convergence, this is the MR. MR is based on the hybrid technology developed by VR and AR, which has the common characteristics of both.

2.1.2 Augmented Reality Display Technology

The goal of augmented reality technology is to present a world combining virtual and reality. Therefore, display technology is an important part of augmented reality systems. Currently, commonly used display devices include head-mounted display devices, computer screen display devices, handheld mobile display devices, and projection display devices.

a) Head-attached display devices

Head-attached display devices are also called Near-Eye Display (NED), belong to wearable display devices. The display fixed on the head of the user, and the virtual image can be superimposed and displayed on the real object observed by the user’s eyes through the corresponding optical components, in this case the AR effect is achieved. The main function of this type of device is to fuse the real information in the user's environment with the computer-generated virtual information, which can be divided into a video perspective helmet display and an optical see-through helmet display according to the real environment.

Microsoft's Hololens (Fig 2.2(a)) augmented reality glasses use holographic technology, combined with multiple sensors, to project virtual content into holographic images to achieve virtual and real fusion [25]. The lens integrates to enable real-world interaction without the need to interface with any other device. Meta's Meta2 (Fig 2.2(b)) is also a highly immersive augmented reality lens with a larger field of view than Hololens, but the tracking fidelity still needs to be optimized, and the computer needs to be connected for calculation during use [26].

According to the principle of reflection of light, the optical see-through head-mounted display creates a picture in which a virtual object and a real scene are merged by a combination of a plurality of optical lenses. Compared with the video perspective helmet display, the optical perspective does not need to undergo the process of image fusion when displaying the enhanced image, and the image seen by the user is the superposition of the current real scene and the virtual information. Google Glass (Fig 2.2(c)), launched by Google, is an optical see-through head-mounted display that is optically magnified to display data to the user through a prism. Google Glass can control photos, video calls, global positioning system (GPS) positioning, word processing, email and more.

Head-mounted display devices are limited by factors such as size, cost and related technologies.

a) Microsoft Hololens AR glass

b) Meta2 AR glass

c) Google Glass

Figure 2.2 Head-attached display devices of AR technology

b) Computer screen display device

Computer screen display devices generally have higher resolution and are larger in size as conventional output devices. In augmented reality applications, such devices are better suited for rendering and superimposing fine virtual objects indoors or in a wide range of scenes. Due to the weak immersion of these devices, but the price is low, it is generally suitable for low-end or multi-user augmented reality systems.

c) Hand-held display device

Hand-held mobile display devices are a type of display device that allows a user to hold a hand. In recent years, smart mobile terminals have developed rapidly. Most of the existing smart handheld devices are equipped with cameras, global positioning systems (GPS) and gyroscopes, accelerometers and other sensors, and have high-resolution large display screens. Augmented reality provides a good development platform. Compared with helmet-type display devices, handheld mobile display devices are generally smaller, lighter, and easy to carry, but have a weak immersion, and the computing performance of different devices is uneven due to hardware limitations. At present, with the release of AR Kit (see Fig 2.3(a)) under the iOS system and the augmented reality platform AR Core (see Fig 2.3(b)) under the Android system, most of the new intelligent mobile terminals support augmented reality technology. Following pictures shows a template application using AR Kit and AR Core [27][28].

a) AR Kit supported by iOS b) AR Core supported by Android OS

Figure 2.3 AR Kit template and AR Core template

d) Spatial display device

The spatial display device allows users to directly participate in AR interactions in three-dimensional space through a variety of techniques, including screen-based video penetration display, spatial optical penetration display, and projection-based spatial display. Due to its large size, the space display device can only be used in the fixed display field, lacking an immersive experience, but has outstanding advantages for applications such as demonstrating three-dimensional models.

Based on the above four display modes, the hand-held display mode is widely used. Bridge headset is composed of iPhone and structure sensor, it has same principle as hand-held display devices, but fixed at the head. It makes the AR scenes more stable and in terms of limbs rehabilitation, this way of wearing has no burden on patients' upper limb.

2.2 Physical Therapy Applications and Sensors

Physical therapy applications refer to some applications with various purpose that have the function of monitoring patients' health status, improve patients' motion ability, or promote research, health, etc.

Impairment of limbs function is prevalent among stroke survivors, motivating the search for effective rehabilitation therapy [4] for reduce time. Augmented Reality features bring benefits to people with physical disabilities. Funny and unburdened therapy system could achieve high efficiency of physiotherapy sessions that presents higher acceptance from the patient side. Limbs motion therapy is an indispensable part of the treatment to improve muscle strength and dexterity [5].

2.2.1 Physical Therapy Applications

A training environment based on augmented reality and assistive device for post-stroke hand rehabilitation, proposed by Xun Luo in 2005 [4], utilizes head-mounted display (shown in Fig 2.4 (1)), virtual objects (see Fig 2.4 (2)) for reach-and-grasp task training and a body-powered orthosis (BPO) in the gloves (see Fig 2.4 (3)). Patients are required to grasp a virtual fish tank in this training. Two functions on therapist-side are monitoring and control. During training sessions, the user's hand movement is supervised by the therapist. This can be done by either the therapist staying on-site with the user, watching through a camera link. Grasping is a highlight in this research, which adds more fun in the physical therapy. What is also notable is the improvement of customer satisfaction.

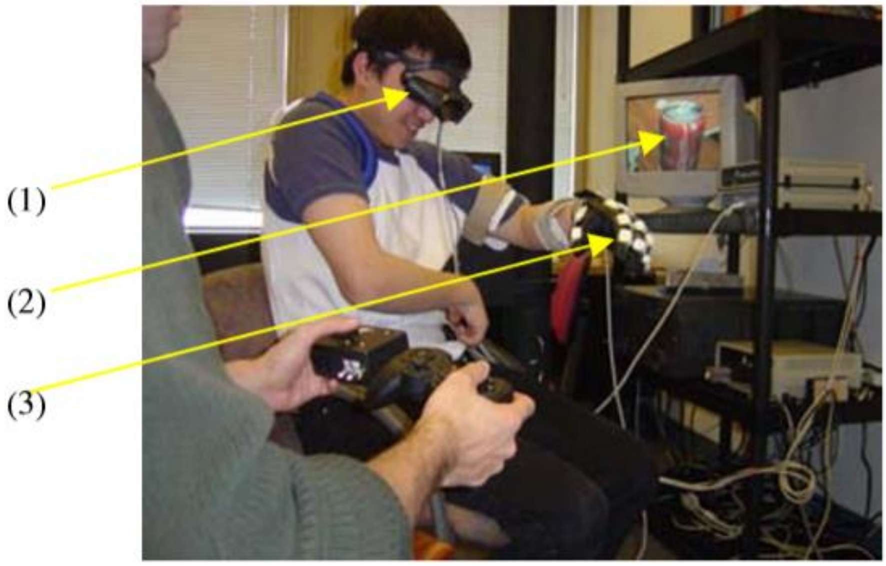
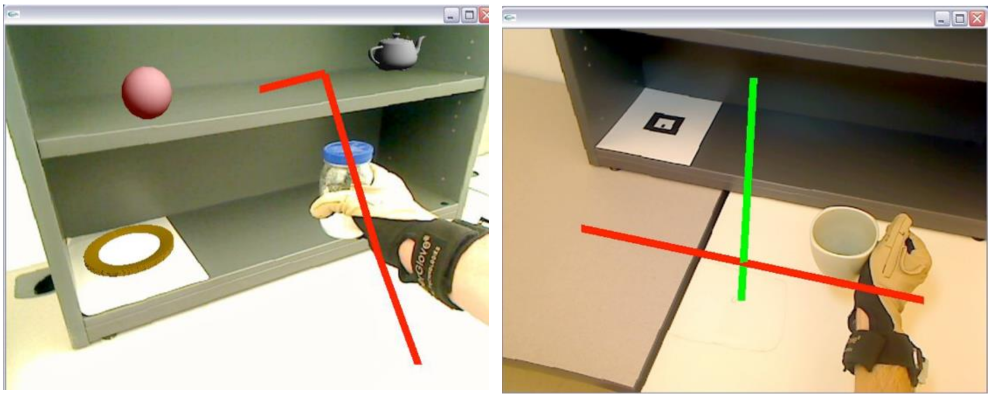


Figure 2.4 Example of the upper limb training rehabilitation

A hand rehabilitation augmented reality system named AR-REHAB (see Fig 2.5) is proposed in [29]. Combing the fields of augmented reality and haptic, this system enhances patient involvement in the rehabilitation exercise, and it also measures the patient's performance without the direct supervision of a therapist. The AR-REHAB system composed of a webcam, a head-mounted display, a data glove, and the decision support engine. The webcam captures the real-world scene whereas the Head Mounted Display renders the augmented scene back to the subject. The data glove reads the subject's hand spatial characteristics while the patient performs the task. In the shelf exercise (Figure 2.5 (a)), the user is asked to move a real kitchen object (a mug) back and forth numerous times to a shelf along a guided path presented in front of him. The cup exercise involves handling a real cylindrical cup across the real space, lifting it in a straight motion along a prescribed path, and repeating the exercise for a specified number of times (Figure 2.5(b)). In addition, the system is empowered with an intelligent decision support engine to assess the patients' progress to help therapists fine-tune the exercises based on the patient's progress.



a) Template of shelf exercise b) template of cup exercise

Figure 2.5 An Augmented Reality Template of hand rehabilitation for stroke patients

In [6], the authors design a interesting game to exercise the upper limb muacle of stroke patients, the scenario of this application as shown in Fig 2.6, 4 circles (representing holes) are placed in the formation of a square on the screen. The camera's capture stream is presented semi-transparently on the screen, a rabbit runs between the four holes. In order to score a point, the patient must touch the rabbit when as it peers out of each hole, the game detects where the marker is, and if it is at the same hole as the rabbit, the player scores a point. This game allows the patient to find a suitable level with which they are comfortable and gradually increase the level as they progress. Different patients have different physical status, purposeful and efficient are demonstrated by providing a suitable options, approach the function of physical rehabilitation.

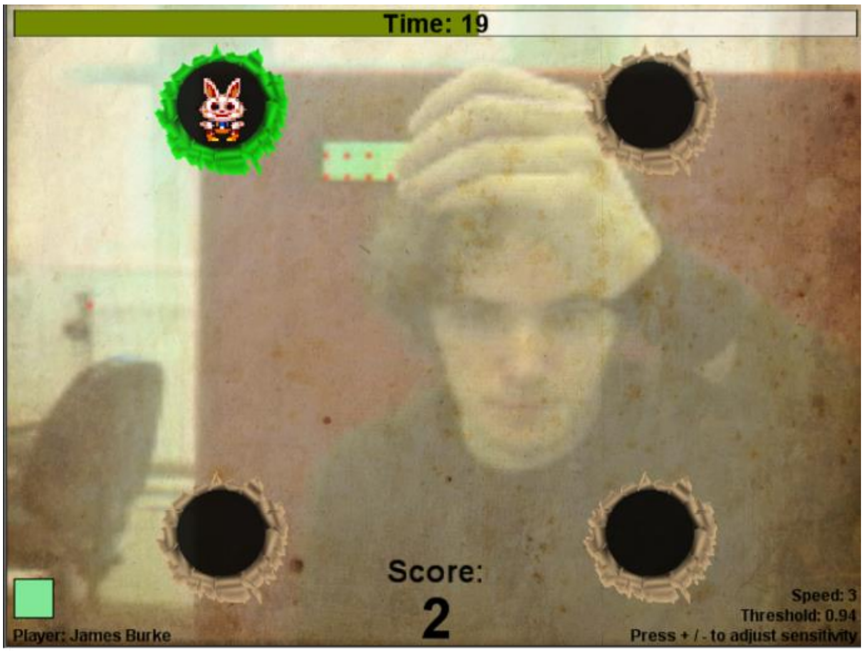


Figure 2.6 The Rabbit Chase System for upper limb rehabilitation

NeuroR [8] is a system for motor rehabilitation after stroke, similar with [7][6], it combines AR with psychological exercises. Patients can visualize themselves and their surroundings with NeuroR, just like standing in front of a mirror. The virtual upper limb is superimposed on its true upper limb and the true upper limb is removed from the virtual image to avoid phantom upper limb visualization. A series of exercises were developed, including low-complexity exercises such as shoulder flexion, shoulder abduction, shoulder adduction and wrist extension, as well as high-complexity exercises such as stretching and grasping the target, dragging it to the desired position and releasing it. NeuroR can be used to check the effectiveness of visual stimulation and motor imaging training in hemiplegia rehabilitation. But in terms of information feedback, NeuroR can't provide real-time data in measured physical characteristics and accuracy of actions while this IOS application can. NeuroR training patients by repeating mechanical actions while patients have more options in this gait training.

Ana Grasielle Dionísio Corrêa [9] uses an AR tool applied to an upper limb rehabilitation program in Occupational Therapy sessions which could see in Fig 2.7. For this study, they selected Duchenne Muscular Dystrophy patients with physical and functional limited abilities. let the patients carry out actual experiments and analyzed the results of the experiment. The results are presented in the form of a table. Following picture shows the patients experience with GenVirtual.

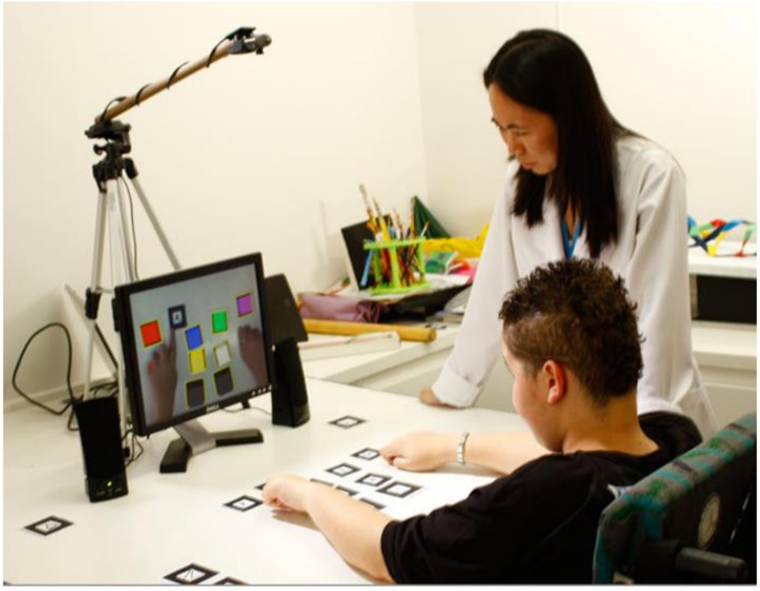


Figure 2.7 The Template of AR physical therapy application

In terms of the limbs motion rehabilitation, an application named YouMove [10] designed by University of Alberta. YouMove allows users to record and learn physical movement sequences. The recording system is designed to be simple, allowing anyone to create and share training content. In Fig 2.8, a large-scale augmented reality mirror is used in this training system. YouMove system trains the user through a series of stages that gradually reduce the user's reliance on guidance and feedback. Motor rehabilitation is a traditional way to help patients rid away disorder. Mirror-based augmented reality offers unique opportunities for interaction. The user's reflection can be used to directly activate on-screen components, allowing for direct manipulation of a 2D interface from 3D free space. Patients could do this training by themselves, activated button by dwelling the hand over the button, given some time to adjust their posture.

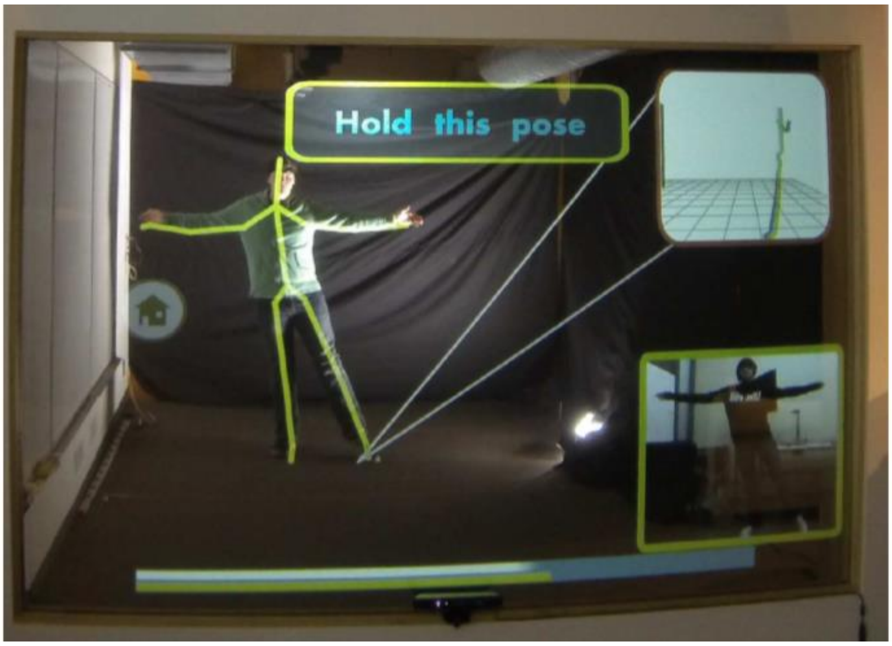


Figure 2.8 The Template of YouMove

The 3D sensor used in YouMove application have been identified as an effective and efficient solution for the rehabilitation area because of its potential on patient motion monitoring.

2.2.2 Patient Health Status Assistant Sensors

Patients' health status assessment sensors in physical rehabilitation can be divided into two categories.

Wearable – Sensors that need to be connected to some part of the human body.

Non-wearable – Sensors that don't need to be attached to any part of the body, being placed somewhere near the patient so that it's possible to identify patient-related movements and collect data.

In [30], a smart sensor system (see Fig2.9) is used for monitoring an elderly person activity. It includes several accelerometers distributed at the joints, Electromyography (EMG) sensor, Electrocardiography (ECG) sensor all of them being used to follow the user's physical status.

Advanced mobile technologies will play significant rules for the physical rehabilitation. Moreover, the digital trend of health care has become an essential element in providing high-quality medical services. In particular, the new revolution in sensor technology has enabled more intelligent sensors, such as air pressure sensors, gyroscopes, pressure sensors to enter various medical and health care equipment, greatly promoted the process of medical digitization. Experts in the scientific and technological circles said that there are currently two methods for the use of technology. One is to fill the utility of existing needs, and the other is to provide the creativity of high-level ideal service. These two methods have been particularly evident in the promotion and transformation of sensors in the healthcare service industry in recent years.

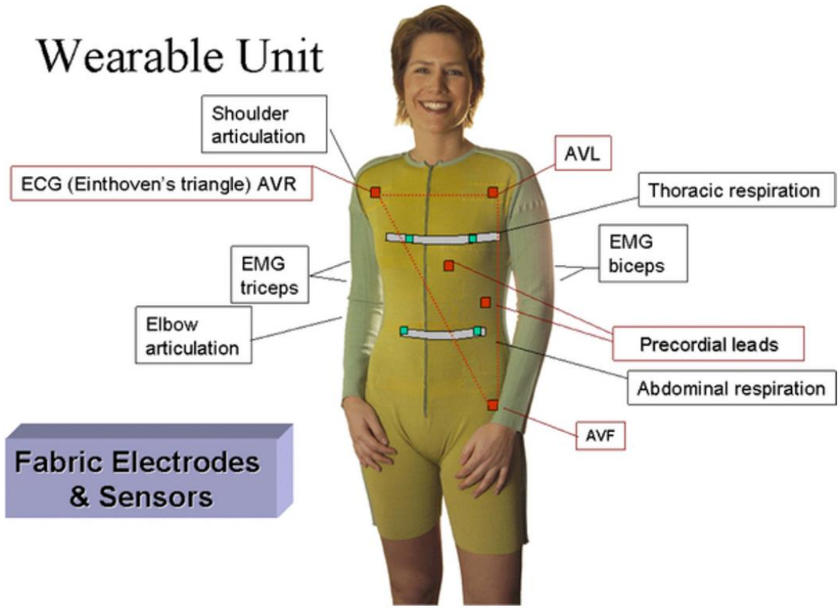
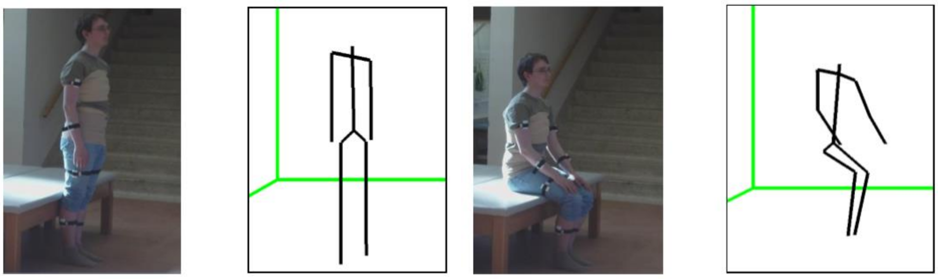


Figure 2.9 Example of e-textile system for the remote, continuous monitoring of physiological and movement data

To develop the correct patient walking gait pattern the gait rehabilitation is required. For this reason, the therapist must accompany patients to monitor and guide them do gait training with some assistant devices [31]. A gait detector, a processor and lithium battery, a laser pointer, a brace composed to the gait monitoring system. Gait is an important parameter that can illustrate a patient's physical characteristics, such as speed, step frequency, step length, and the body balance during walking. Patients could do this training at their own home, not limited by the place and time, improve the efficiency of physical rehabilitation for stroke patients.

Shimmer sensor - is another wearable sensor that could monitor the user' physical characteristics.

In [32], ten shimmer sensors and one host formed a wireless inertial motion capture system which shows in Fig 2.10. Shimmers are attached to separate locations of a human body to reach both angular and acceleration data with which body movements can be captured by applying Euler-angle based algorithms, specifically, single rotation order algorithm and the optimal rotation order algorithm.



a) standing up posture b) sitting down posture

Figure 2.10 User position identification based on Shimmer sensor

Motion capture system provides patients' real-time motion to therapists, demonstrate the possibility of remote monitoring. Shimmer as a wireless wearable physical monitoring sensor, easy to monitor the physical characteristics during motion access, easy to fix on the patients' limb or joint. Many categories are designed according to the functionality, ECG, EMG, GSR, etc.

Kinect (show in Fig 2.11) for Windows V2 is a depth sensor developed by Microsoft. The Kinect Sensor is a motion sensing device for the Xbox game console and Windows PCs [33]. Kinect V2 for Windows was introduced in 2014 and comes with higher specifications than the first version. It can see better, clearer and see more than its earlier version. Kinect V2 can capture full HD quality images up to resolutions of 1920 x 1080 pixels. This data can then be used in applications to create virtual mirrors, or to take screenshots to be sent for printing or shared on social media sites. The infrared depth camera can see in one more dimension. It can sense high fidelity depth information using infrared sensors and recreate a 3-Dimensional view of what the Kinect sees. It is also able to perform body tracking from the depth data that it captures. The Kinect can track up to 6 persons with 25 joints associated with each person.

Kinect captures the player's movements all over the body and uses the body to play the game, as an assistant device used in physical rehabilitation. Hand-gesture recognition, human-activity recognition and body biometrics estimation could implement with Kinect.

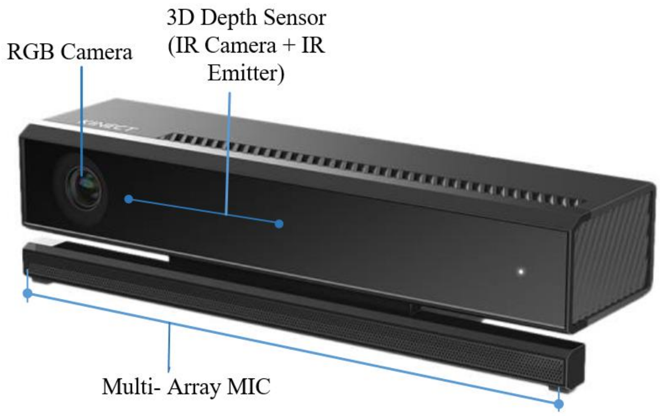


Figure 2.11 Microsoft Kinect V2

Structure sensor (show in Fig 2.12) is a depth sensor which could scan the real environment and it is manufactured by Occipital. It includes two infrared (IR) LED, an infrared structure light projector and an infrared camera. The Structure projects a unique infrared pattern of dots out in front of it, and the infrared camera captures the projected pattern as it is reflected off objects. Apparent variations in the position of the captured dots are interpreted by software to determine the relative position of a captured image. Some applications developed by Occipital used for indoor scanning and Mixed Reality (MR). Structure sensor has the scanning range from 40cm to 350cm which demonstrate it's a perfect tool for indoor scanning.

Figure 2.12 Structure sensor from Occipital

A Unity plugin file combine Structure Sensor's depth sensor generate a 3D scan of your real world, creating a digital physical space. The real world can occlude virtual objects, and virtual objects cast shadows and bounce off of your real world. Using this plugin allows the developer to create their own games. The Unity package contains the libraries and code needed to scan a large area and begin tracking in VR mode. In this project, this Unity plugin are used to scan indoor area and create AR scenarios.

2.3 Data Storage

The functional recovery process varies from patient to patient or from disease to disease. Therefore, in the process of performing rehabilitation treatment or training, the functional consequence assessment method can better reflect the rehabilitation effect. Because of the many factors that affect the outcome of rehabilitation, this means that a large-scale rehabilitation data system must be established to enable multi-factor, multi-level analysis.

For this work, measured data is stored in the Firebase Realtime Database. Firebase Database (DB) allows reading and writing of data easily, allows a certain amount of data to be collected and utilized based on the application.

Database is ubiquitous, behind the website, inside the application, in the stand-alone software, in the blockchain, and even in the web browser farthest from the database, it has gradually emerged its prototype: various state management frameworks and local storage. Database can simply be a hash of an in-memory hash disk, or it can be complex to be integrated by multiple data systems. A relational database is just a little part of a data system.

There are actual a variety of data system components:

- Database: Store data so you can find it again after yourself or other applications (PostgreSQL, MySQL, Oracle);
- Cache: Remember the result of expensive operations and speed up reading (Redis, Memcached);
- Search index: Allows users to search for data by keyword or filter data in various ways
- Stream processing: send messages to other processes for asynchronous processing (Kafka, Flink, Storm)
- Batch processing: Regular processing of accumulated bulk data (Hadoop)

Firebase is a real-time back-end database that helps developers quickly write Web-side and mobile-side applications, users can use Google's cloud services while using Firebase more easily since Google acquired Firebase in October 2014. This means it can help mobile and web application developers easily build apps. It's easy to develop an app with a framework behind the Firebase, without the need for a server and infrastructure. Build an app quickly without managing the infrastructure.

From the above information and characteristics, the main advantages of Firebase database are:

• Firebase encapsulates many easy-to-use APIs in a single SDK, saving time and the burden of managing application integration.

• High speed. Firebase encapsulates many easy-to-use APIs in a single SDK to help for quickly development of applications.

• Cross-platform work. Regardless of your target platform, Firebase provides support to help you deliver cross-platform mobile apps using Android, iOS, JavaScript, and the C++ SDK.

The structure of Firebase Realtime Database used in this dissertation is shown in the Fig 2.13, it consist of two non-relational nodes of measured data which comes from two smart sensor, and corresponding values in each branch of the node. It is clearly knows the relationship and source of data, this platform doesn’t require server-side code to access data and it is possible to add fields anytime without having to define them in the database model.

This system utilize Firebase Realtime DB as a data storage station, to connect smart sensor with unity project, data saved in a Json tree which made it easy to search and read, network API key demonstrates data privatization.

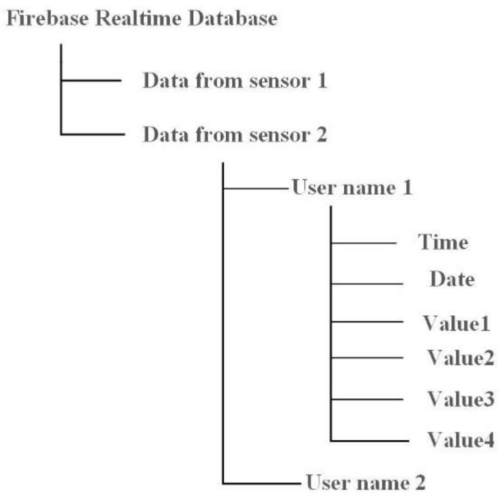


Figure 2.13 Firebase Database Structure

2.4 iOS mobile application

IOS is Apple's proprietary mobile operating system for mobile devices, providing an interface to many of its company's mobile devices, including iPhone, iPad and iPod touch. It is the second most popular mobile operating system in the world after Android, and its market share has risen to about 24.5% [34].

The iOS SDK is developed by Apple to allow developers to develop mobile apps for iOS.

Since the release of Xcode3.1, Xcode has become the development environment for the iOS software development kit. It is the same as the Mac OS X application, the iOS application uses the Objective-C language, and some applications can be written in C or C++. Apple Inc. usually publishes two iOS software development kits, including the main iOS X.0 (for example, iOS 10.0) and the secondary iOS X.X (for example, iOS 10.1). The official version will have several test versions before release, in order to test its compatibility and add new features.

The iOS Software Development Kit makes Mac PCs free to download [35]. The Software Development Kit contains features and services that allow developers to access iOS devices, such as hardware and software properties [36].

There are many iOS applications for physical rehabilitation that can download from App store, such as:

Pedometer makes the iPhone become a step counter, the principle is to use the gyroscope which inside the iPhone without any assistant device. This application let user easily keep track daily and weekly step counter, the Fig 2.14 presents the User Interface (UI) of a pedometer. The number of steps per day in a week is recorded and represented by a histogram [37].

Figure 2.14 Pedometer User Interface

ARC PT Patient App [38] is an application which could provides motion gudiance for disabled people, provides a corresponding exercise plan based on the patient's physical condition which shows in Fig 2.15. User could perform rehabilitation activities without time and place constraints. With this application, the effencify of therapy is improved. But shows disadvantage when user couldn't do the training with self-consciousness.

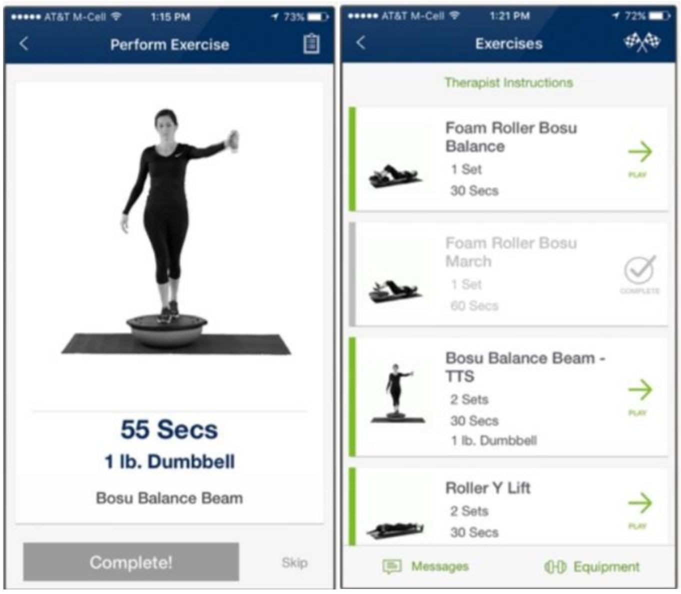


Figure 2.15 ARC PT Patient APP User Interface

Physioadvisor [39] is an app that all of the exercises have been selected based on the benefit they can provide to the general population and how frequently they're prescribed in clinical practice, it provides more than 500 exercises and 800 images, including detailed instructions on how to perform the exercises correctly. Patients could receive the physical rehabilitation plan from physiotherapist by this app, some helpful reminder feature makes sure patients never forgets to exercise. The joints associated with the current exercise are displayed on the screen (as shown in Fig 2.16) and the result of analysis also record based on this system.

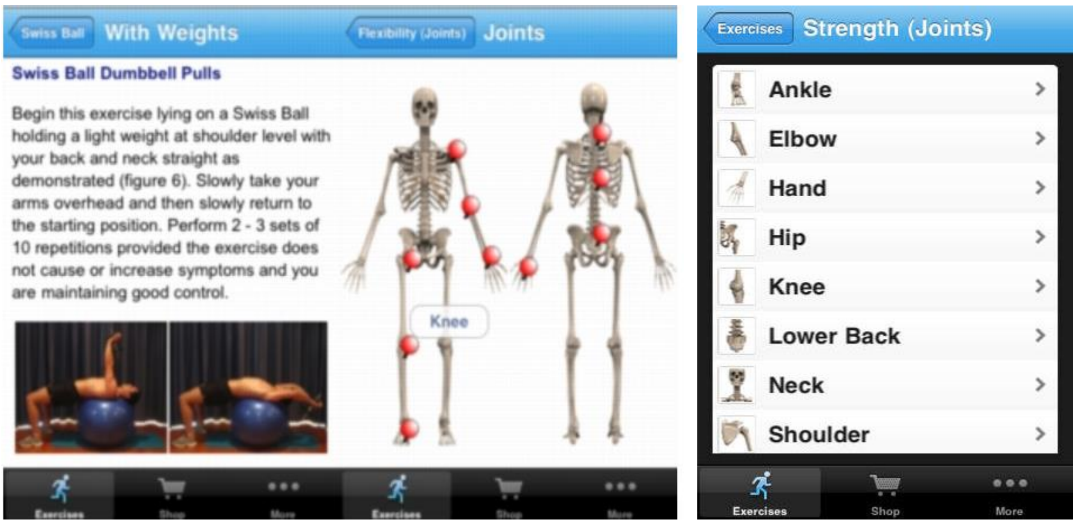


Figure 2.16 Physioadvisor User Interface

An IOS-based smart body rehabilitation application was proposed in [40] to improve patient engagement during physical rehabilitation by combining augmented reality serious games with a wearable sensor network. The system also provides a health status assessment that captures important data that clinical professionals need to analyze. This application could communicate with the WSN (Wireless Sensor Network) and processing measured data. Fig 2.17 is an augmented reality scenario of this application.

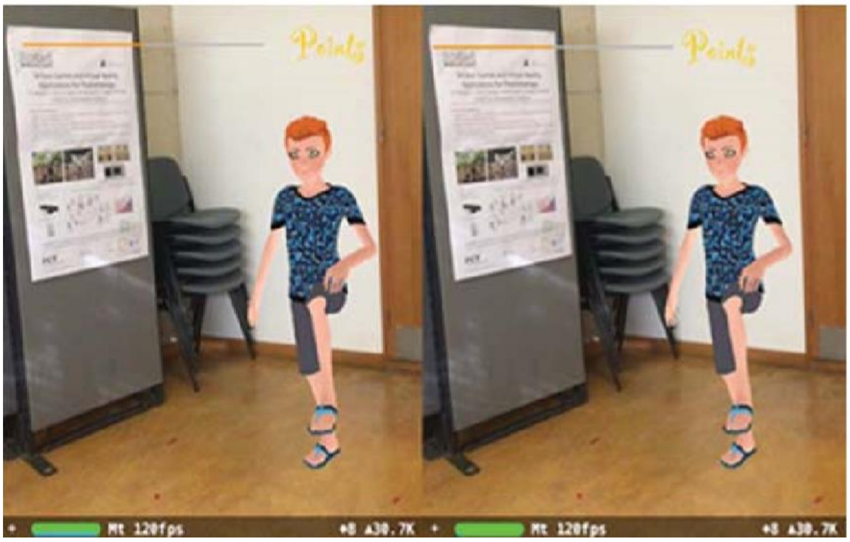


Figure 2.17 Augmented Reality Scenario for Physical Rehabilitation

Chapter 3 – System Description

This work intends to develop an IOS application aimed at training stroke patients, combining the AR technology and wireless sensor network (WSN). AR technology increase the performance of physical rehabilitation, WSN are used to provide more information from real world improving the AR scenario and the interaction. Figure 3.1 illustrates the system architecture which includes in three blocks.

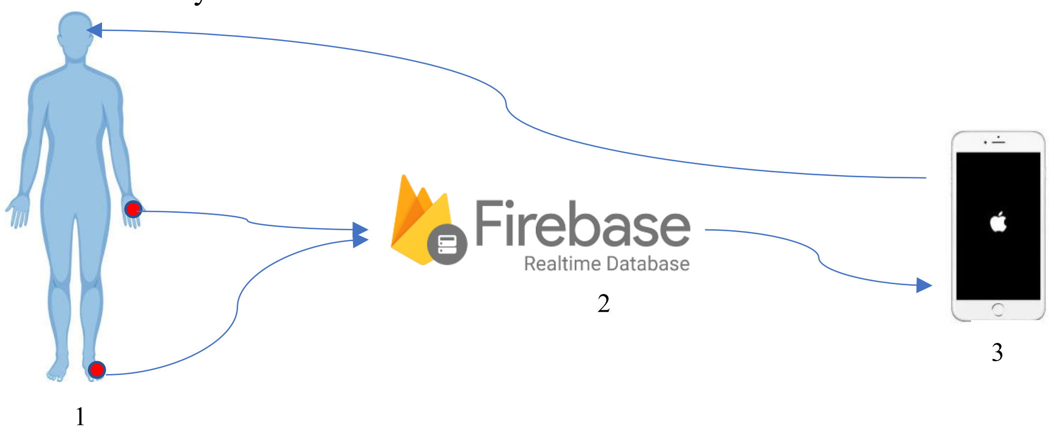


Figure 3.1 System Architecture, 1-sensing, 2-data storage, 3-AR scenario display

The first block (1) is dedicated to the training and patients, patients are wearing smart sensors which could measure physiological parameters, such as heart rate and galvanic skin response (GSR) during the training session. The second block (2) is mainly represented by the storage of the data collected by the sensors, the settings and application data. The technology used for data storage is Firebase, developed by Google. The Firebase proved to be a very flexible, scalable and easy-to-use NoSQL database tool. The last block (3) is dedicated to the IOS application associated with data analysis and data visualization.

3.1 Users and Applications

In this work, iPhone as a display device is used by patient using a mechanical structure denominated headset. In this case, this mobile application only has a type of user: patients. Physiotherapist can get their training information from web application.

Mobile Application: Developed for IOS that serves as a component of head-mounted AR display device. It provides instructions for *Patients* during training, A manually operated, a controller is used to perform the selection of the next action.

Web Application: Developed for physiotherapist which could monitor the training remotely, all training data of patients can be visualized on the web application. New physiotherapist could registered and join in this project by the web application.

Both applications require Internet connection to perform database communication, either for data storage in Firebase Realtime Database.

The main stakeholders in this system are:

- **Patients:** is the main user of this training system, and in this case, can be mentioned that the developed system mainly corresponds to the patient under physical rehabilitation needs. The patient represents a single user of the computer application and he is the only one who performs the training created by the user's physiotherapist;
- **Physiotherapists:** Supervise the patients training and impose the training plan. Using the web application, the physiotherapists insert the patient data and create the training plan and analyze the training results;

3.2 The Gait Training System

Figure 3.2 illustrates the implemented gait training system block diagram. The letter A-I represents each execution step.

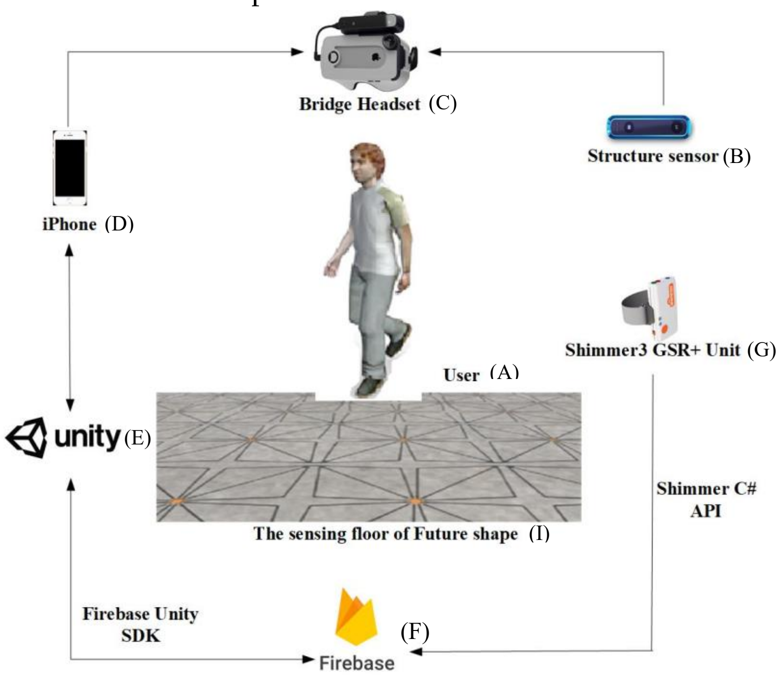


Figure 3.2 The block diagram of the gait training system based on AR and distributed smart sensors

The first step of the rehabilitation training is to let user (A) wear a wireless sensor (G) and bridge headset (C). The patient is walking in an AR scenario while the training which present by iPhone (D) and structure senor (B). Steps, speed and game score are recorded in real time using the IOS application developed by Unity 3D (E) and launched in iPhone. Patients' heart rate and GSR are measured by smart sensor, then uploads the data to Firebase project (F) with public rules by shimmer API. Finally, unity application reads the values of physical metrics associated with patient state.

Smart carpet (I) monitors parameters of patients' motion then transfer measured data to real-time database by execute a HTML file in an embedded Raspberry Pi.

The system directly collects information about:

- The galvanic skin response (GSR) value of patient
- The heart rate of patient
- Training duration
- Walking speed and steps
- Relative position on the smart carpet

When patient finished training, score and parameters of motion will show on the ending user interface.

3.3 Depth sensor

Structure sensor (shows in Fig 3.3) is a kind of depth sensor which could capture the real world by infrared (IR) camera and IR projector, size in 28mm x 119mm x 29mm and weights 95g, developed by Occipital Inc. in collaboration with Prime Sense in 2013. The chip of depth processing is PrimeSense1080 (PS1080) which is embedded on the main board and the block diagram is presents as Fig 3.4. The depth resolution of structure sensor is 640 x 480. The objects from 40cm to 350cm could be scanned and utilized as AR material. IR source consist of two infrared LEDs. Detailed parameters of structure sensor are shown in Table 3.1.

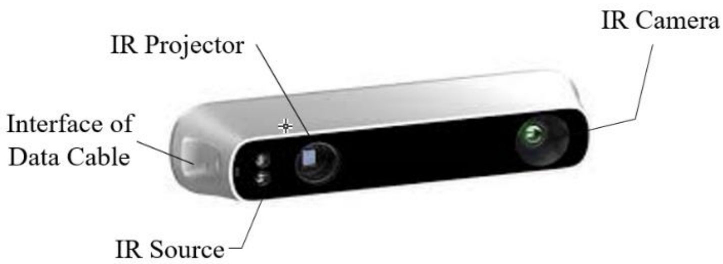


Figure 3.3 The composition of Structure Sensor

Length x Width x Height:	119.2mm x 27.9mm x 29mm
Weight:	99.2 grams
Minimum sensing distance:	40 centimeters
Maximum sensing distance:	3.5+ meters
Precision:	1% of measured distance (typical)
Resolution:	VGA (640 x 480) / QVGA (320 x 240)
Framerate:	30 / 60 frames per second
Battery Life:	3-4 hours of active sensing, 1000+ hours of standby
Streams:	Depth, Infrared
Illumination:	Infrared structured light projector, Uniform infrared LEDs
Field of View:	Horizontal: 58 degrees, Vertical: 45 degrees

Table 3.1 Technical specifications of Structure Sensor

Structure sensor could connect with iPhone, iPad and computer by a data cable and it performs as a mobile Structure Light System (SLS) when connected to a tablet, mobile phone, or a computer. This SLS consists of a laser-emitting diode, IR radiation range projector, IR sensor and the iPad's or iPhone's RGB sensor can send data to a system on a chip for processing [11]. In Fig 3.4, main circuit board inside the structure sensor present generation of three dimensions (3D) images. Structure sensor gives mobile device the ability to capture and understand the world in three dimensions. With the Structure Sensor attached to mobile device, user can walk around the world and instantly capture it in a digital form.

The PrimeSense SoC Carmine 3D sensor (see Fig 3.4 right) is the primary microcontroller that generates a three-dimensional scene. It controls a structured light sensor that sends out a regular pattern of infrared dots and locates them with a complementary metal oxide semiconductor (CMOS) sensor. The microcontroller creates a video graphics array (VGA) size depth image and sends the data through the USB interface [41].

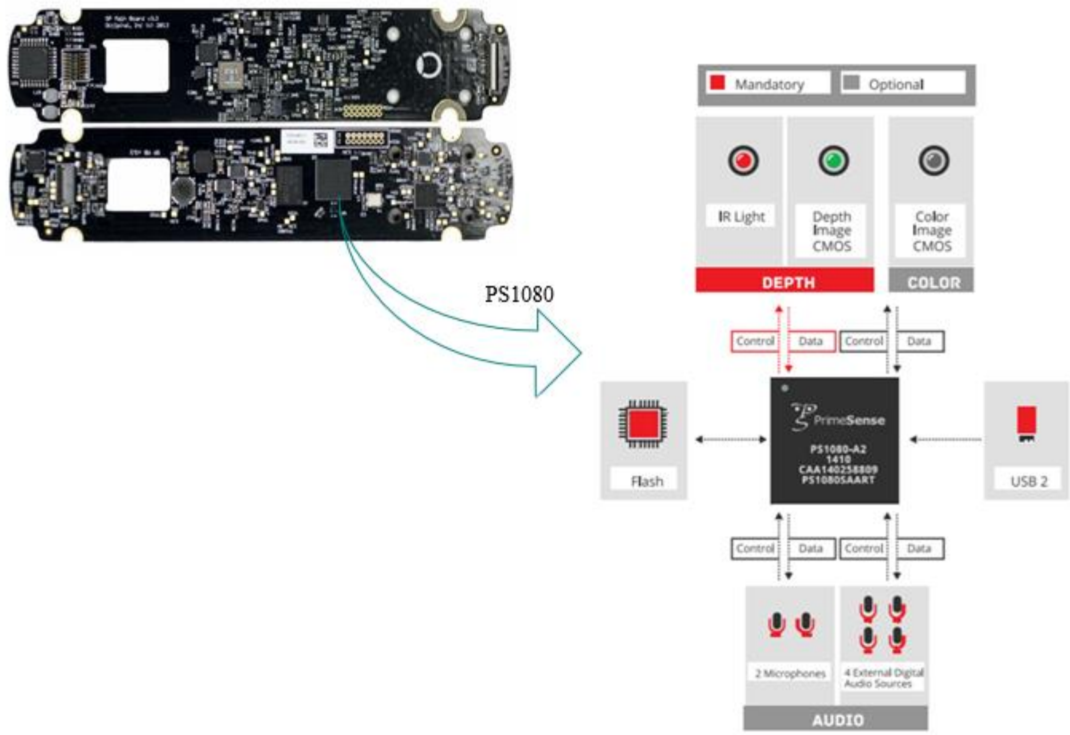


Figure 3.4 Main Circuit Board and Block Diagram of PS 1080

For an easier usage of the structure sensor, Occipital launched a headset in 2016. The headset "Bridge", that supports the structure sensor, iPhone and head-mounted frame. As shown in Fig 3.5 and Fig 3.6, Bridge relies on precise calibration between the iPhone's color camera and Structure Sensor to create mind-bending mixed reality. A glass lens doubles the iPhone's field of view to 120° in the bridge which create a wide view of the world. Bridge Engine fuses this with the depth data from Structure Sensor and presents a stereo view. Structure sensor and iPhone connected by a cable. Magnetic door latch help to fix iPhone in bridge. Volume of iPhone could be controlled by external buttons. Bridge headset combine iPhone and structure sensor flexibly and bring immersive experience to users.

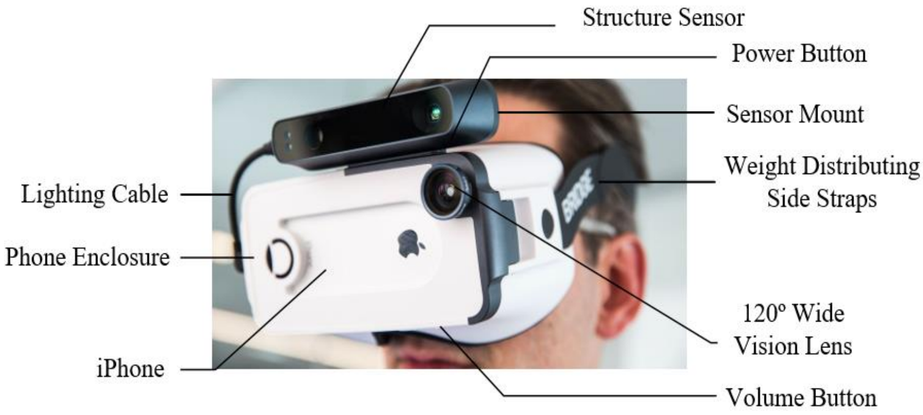


Figure 3.5 Front View of Bridge Headset

Figure 3.6 Reverse View of Bridge Headset

This technology holds great promise for the field of rehabilitation since it doesn't require the patient to wear additional equipment on their body, which makes it an important factor in the therapy of patients have body surgery. The device provides a new way of interacting between the user and the computer, the ability to bring the real world to the digital domain. The main advantages of this sensor compared to other motion sensors, also applied to rehabilitation are:

- Provides user interface in higher quality and no burden on the limbs;
- A SDK named *structure* is provided for the development of new applications;
- More interaction between patients and augmented reality system could be considered, it is benefit to improve the efficiency of rehabilitation.

3.4 SensFloor System

3.4.1 SensFloor general description

SensFloor system provides functionalities regarding the detection and tracking of people moving around in an area. These are functionalities made this system suitable for the requirements on gait monitoring during the gait training. Furthermore, the SensFloor system could distinguishes standing persons from a person lying on the floor in an intelligent way, which can effectively detect whether the patient falls during the training which makes training under a safeguard. In terms of the embedded sensors, the capacitive measurement principle allows for a unique advantage of the system compared to pressure sensors: as the sensors react from a certain distance without direct touch, there is no restriction on the floor covering. The SensFloor underlay is based on Smart Textiles with a thickness of 3 mm, and it could be installed under any type of floor. In this case, the availability of product is increased, gait training rehabilitation system even could achieve in the patients' home.

The main components of SensFloor are the capacitive proximity sensors. Capacitive proximity sensors are non-contact devices that can detect the presence of any object regardless of material. They utilize the variation of electrical field around capacitances as a metrics to detect objects on a certain position, proximity-sensitive sensor has unique advantages:

- Non-mechanical measurement system which has high long-term endurance
- Installable beneath any flooring except conductive flooring
- No special baseboard necessary, adaptable to any room geometry

A typical SensFloor unit (0.5m x 0.5m), has a sensor module with eight surrounding triangular sensor pads, resulting in 4 units and a spatial resolution of 32 sensor plates per square meter. Each square meter of the fabric features four radio modules and proximity sensors that can track the speed and direction of a person's movement. It can track the movement of several people at once, including those in wheelchairs. The information is then passed to a separate control unit where it can be analyzed in real-time.

Therefore, as soon as a person is moving or standing on the floor, the person's location is acquired very accurately based on the spatial resolution of the sensor grid. Choose a corner of Sensfloor as the coordinate origin, a simple plane rectangular coordinate system will be created which using x and y to represent position. The sensor signals are transmitted wirelessly at 868 MHz to the SensFloor transceiver (see the first step in Fig 3.7), using a proprietary protocol. Measured data that received from transceiver via Wi-Fi (see the second step in Fig 3.7) could presents in a web application clearly while execute script on embedded Raspberry Pi. By collecting and processing the sensor patterns over time it is possible to assign movement trajectories to the persons based on which several applications can be realized.

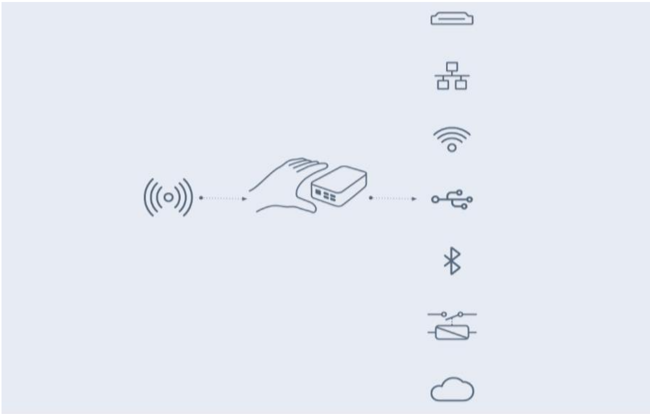


Figure 3.7 Data Transmission Method in SensFloor

Figure 3.8 shows the schematic of the SensFloor system with the transceiver SE10-H based on Raspberry PI. The basic functions of the transceiver are the detection of people, direction of movement, walking velocity, step counting, detection of a person lying on the floor, and self-tests.

Various interfaces support the developed applications:

• High Definition Multimedia Interface (HDMI) for depicting a Graphical User Interface (GUI) on an external monitor;

• Ethernet for accessing the internet, networks, web interfaces, and socket.io-API;

• Transmission Control Protocol (TCP) for configuration of the system, transmitting raw data, fall alert, activity monitoring;

• Virtual Private Network (VPN) login for remote maintenance.

A Wireless Local Area Networks (WLAN) provides a web interface for PC, tablet, and smartphone for configuration and visualization. Eight programmable potential-free relays provide binary electrical contacts for home automation systems.

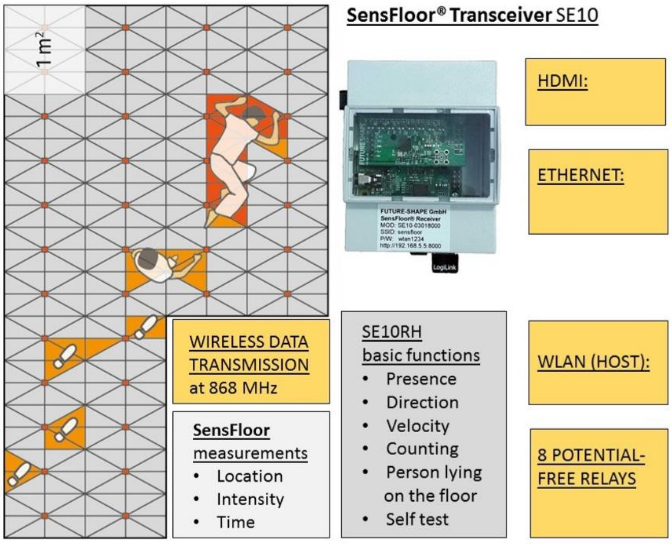


Figure 3.8 Schematic of the SensFloor system with transceiver SE10-H

In this study [42], a gait record system is presented. It provides useful data for health status assessments in Neurology, Geriatrics and Rehab. Users' walking speed, time, and pathway is recorded in the Fig 3.9. Using this gait training system, the expert could evaluate the effect of physical training and medication. Especially for patients with a higher risk of falling early diagnosis and treatment are essential. From their pathway, the ability of balance is clearly presented. Recorded pathway could evaluate training effectiveness by comparison with future pathway.

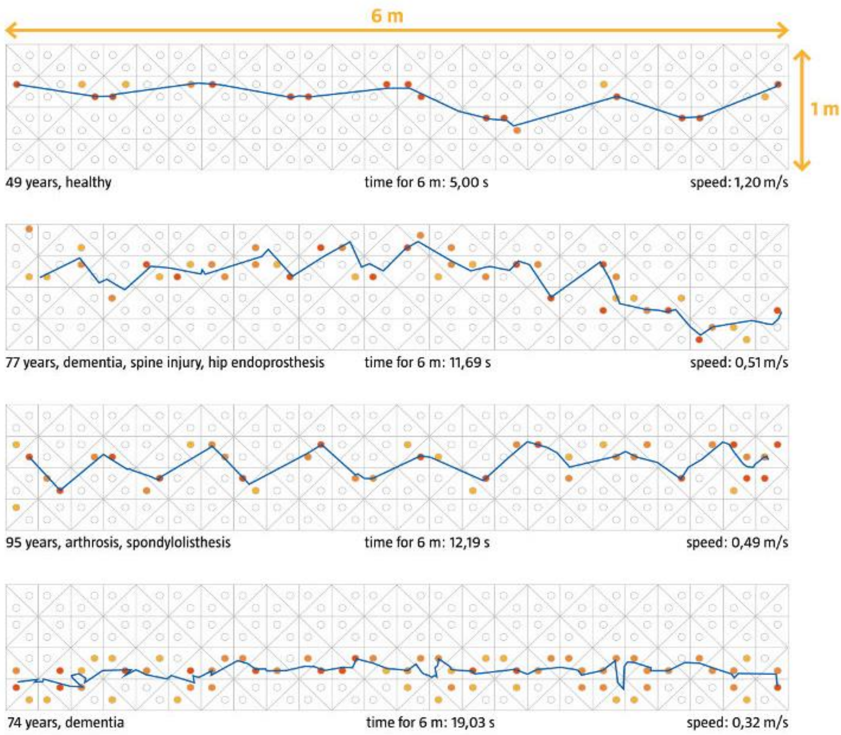


Figure 3.9 A Gait Record System

SensFloor could become a touch screen of detection users' steps, velocity and position. From the recording walking route, length of each step, whether body tilted to one side shows clearly. In the Fig 3.9, blue line presents the patients pathway in a six square meters smart carpet, points show each steps of the patient, the color of point means conductivity level of patient's gait, red means high conductivity while yellow higher. Compare with a healthy user, a 77-year-old user can't maintain straight walking with a constant speed because he has spine injury and hip endoprosthesis, his pathway tilt to right in the last two meters; a 74-year-old dementia user has the lowest speed; it seems that the 95-year-old user has more health status, he can maintain a straight walking route with a relatively stable speed.

3.4.2 SensFloor Web App

The SensFloor Web App (see Fig 3.10) could present real-time motion information of the people on the smart carpet, including user's position, speed, steps and time, fall detection etc. When there is a person walk on the carpet, the status of SensFloor is active, multiple rooms could be monitored simultaneously while connect the SensFloor transceiver SE_{10}. In Fig 3.11 (a), a square unit represent a smallest unit of carpet, size in 0.5m x 0.5m, the blue circle represents a person who walk on the carpet with the speed 2.1 km/h.

Activity is the option that directly shows the raw SensFloor data for your installation. When enabled, the application draws the current capacitance for each SensFloor patch sensor field (triangular shapes). The color changes from yellow (less capacitance) to red (more capacitance).

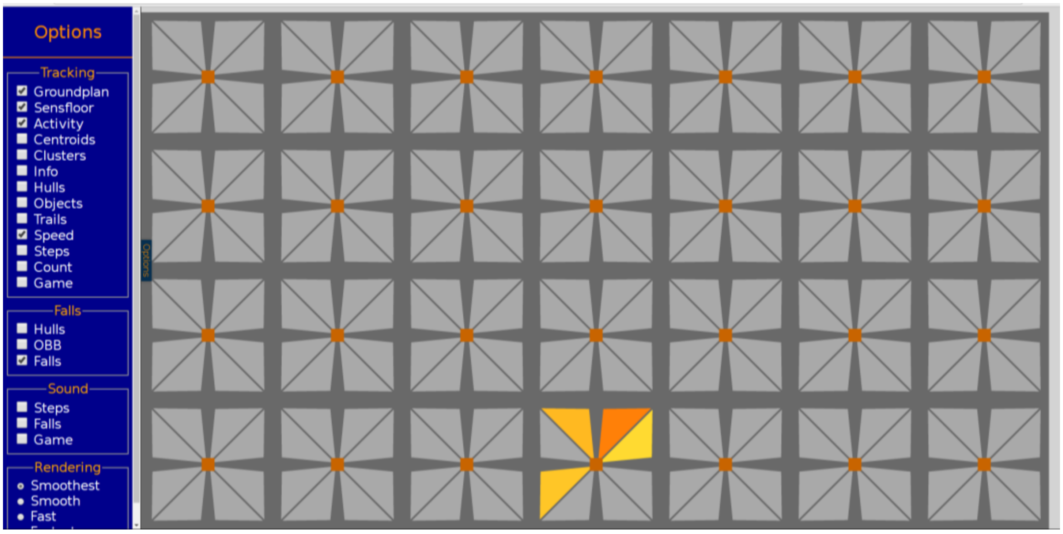


Figure 3.10 SensFloor activity displayed as colored sensor fields.

Steps option shows a short outwards-expanding and dissipating wave where a step was detected on the floor. Step detection performance varies depending on the floor resolution as well as the persons gait and speed.

The bar of selection provides different options, when enable the option of objects, trails, and speed, the point of objects and pathway shows with speed in the circle, and each object leaves behind a trail which represents trajectory in the last two seconds.

Info is enabled as the Fig 3.11 (b) shows, an information bar presents all characteristics:

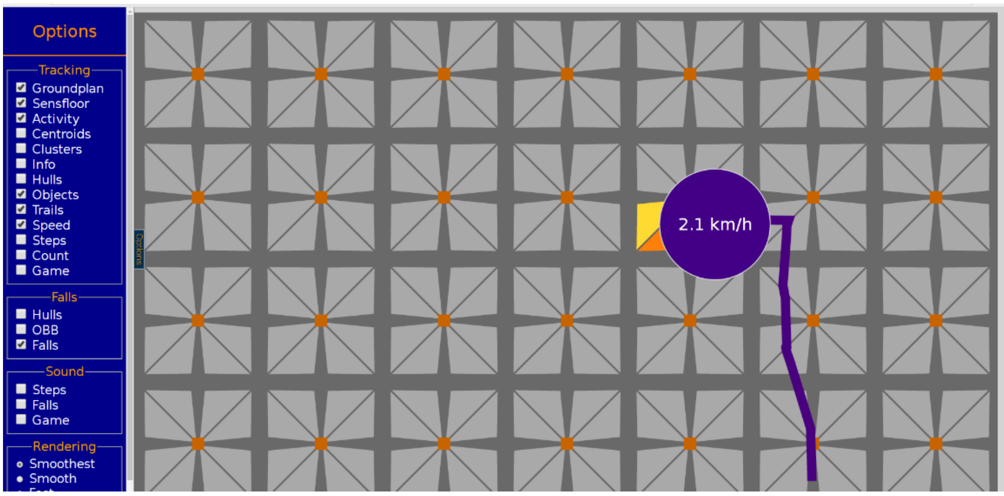
• age: lifetime of the cluster in seconds;

• size: number of centroids grouped;

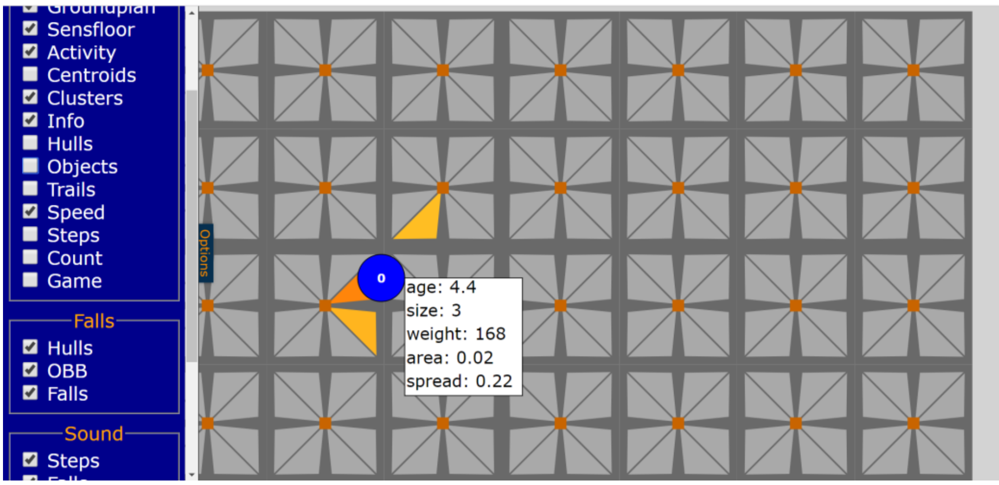
• weight: average capacitance of the centroids;

• area: size of the cluster in aquare meters;

• spread: standard deviation of the centroids.



(a) SensFloor Web Application with Object Selected



b) SensFloor Web Application with Info Selected

Figure 3.11 The SensFloor Web App

Fall Detection is a necessary part in physical rehabilitation. Walking obstacle is the most prominent symptom of stroke patients, they have very high possibility of fall due to the aging of the physiological structure and the decline of bodily functions. Falling can cause bruises, fractures and even life-threatening of the body tissues of the elderly, and psychologically stress and fear for the elderly. In fact, many casualties were not caused by accidental falls, but because the elderly did not receive timely treatment after the fall. Therefore, how to find out as soon as possible after the fall of the elderly, send a distress signal for timely treatment has become particularly important. In order to live a healthier life for the elderly, it is of great research value and practical significance to study and design an elderly fall detection and alarm system.

If a fall is detected, it will omit objects and clusters, and show a blinking red hull of where the fall is detected, as well as a red background (As shown in Fig 3.12).

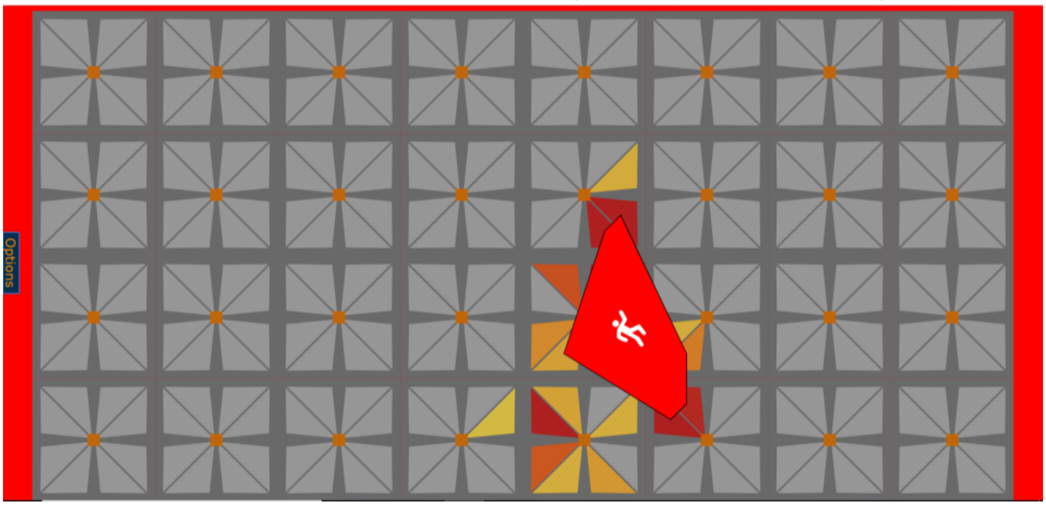


Figure 3.12 Fall detection

A falling mark will appear in the upper left corner of the SensFloor Station User Interface (UI) after a fall is checked (see Fig 3.13). The history of walking pathway and falling marks can be recorded as presented in Fig 3.14.

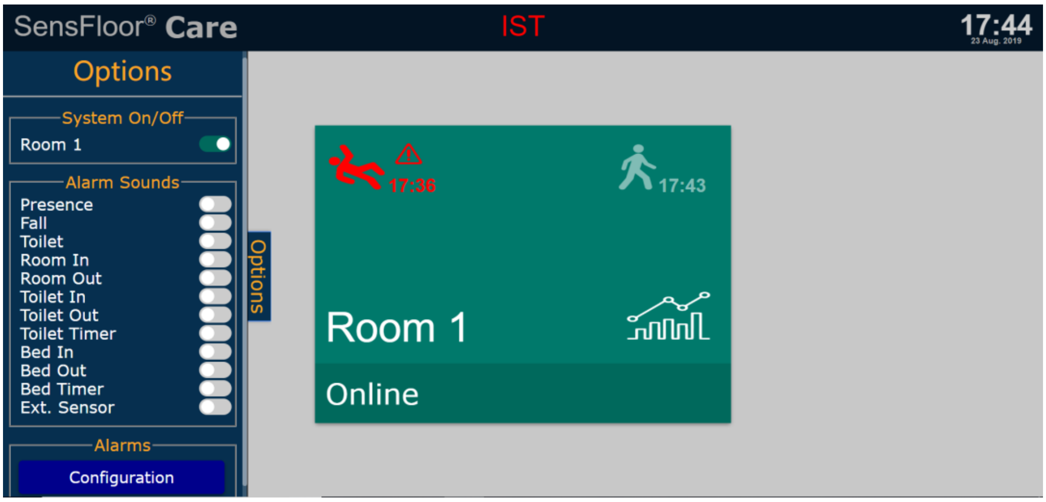


Figure 3.13 SensFloor Station User Interface

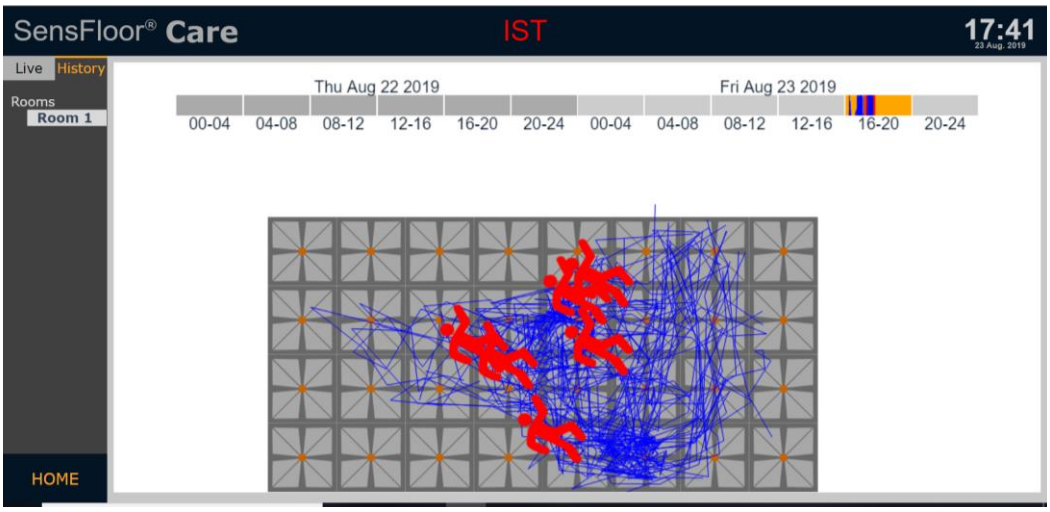


Figure 3.14 Fall Record in SensFloor Station

The web app can be opened on any device, including MacOS and iPhone device. The Receiver SE_{10} includes Raspberry Pi computer platform, that is connected to a Wi-Fi network and execute HTML file to transmit data to Firebase in real time. To obtain the data on the iPhone, the iPhone App software developed in Unity (C# script) is reading the data from database.

3.5 Smart Sensor for Physiological Measurements

Physiological measurement during training is not only the monitoring of patient's physical status, but also provides a basis for diagnosis for physical therapist, the recording data could prove the effectiveness of rehabilitation. There are many human physiological parameters in the field of rehabilitation, such as electrocardiography (ECG), electromyography (EMG), Galvanic Skin Response (GSR), electrooculography

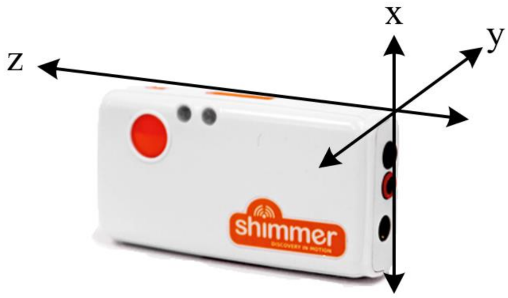
(EOG), heartrate (HR) etc. In this dissertation, two main physical parameters GSR and HR are considered to monitor patients' health status. In this context, the sensor of Shimmer 3 GSR+ unit is a great choose.

A smart sensors expressed by Shimmer 3 GSR+ Unit (see Fig 3.15) is wearable physiological parameters monitoring device based on MSP430 microcontroller (24MHz, MSP430 CPU), wireless communication transceiver and Bluetooth Radio – RN-42, the power supply is expressed by a 450mAh rechargeable Li-ion battery [21]. The core functionality of Shimmer is extended via a range of daughterboards which provide 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer and physiological information [22]. The Shimmer3 GSR+ Unit that is used in this application provides connections and preamplification for one channel of Galvanic Skin Response data acquisition Electrodermal Resistance (EDR) Measurement /Electrodermal Activity (EDA). The GSR+ Unit is suitable for measuring the electrical characteristics or conductance of your skin, as well as capturing a Photoplethysmography (PPG) signal and converting it to estimate heart rate (HR), using the Shimmer ear clip or optical pulse probe.

Figure 3.15 Shimmer 3 Sensor Specifications

The GSR evaluation is used for stress measurement on patients during the rehabilitation trainings. Connection between users' hand and Shimmer is presented in Fig 3.16a. The Shimmer GSR+ sensor monitors skin conductivity using two reusable electrodes attached to two fingers of one hand. The coordinate system shows in Fig 3.16b. Measured data of GSR, angular velocity and acceleration are stores and uploads to Firebase Real-time Database.

The Shimmer GSR+ unit is used for measuring the electrical characteristics or conductance of the skin, as well as capturing a PPG signal and converting to estimate heart rate (HR), using the Shimmer ear clip. This application can be applied to a variety of applications such as market research, emotional engagement, psychological arousal and stress detection.



a) b)

Figure 3.16 Shimmer Sensing (a. Connection between Shimmer and user b. Coordinate system of Shimmer)

Shimmer has an embedded gyroscope module SR47-2-0 which could monitor angular velocity and acceleration in each direction. Gyroscope indicates the motor state of patient's limb, the rotation of Shimmer presents patients' limb rotation and when it rotates along a specify axis, the corresponding curve will change dramatically.

In Fig 3.17, Shimmer is tied to a healthy user's ankle, the swing amplitude of user's wrist in X, Y, Z axis are presented, it could be seen that the user walks at a constant speed, and the stride of each step is almost similar. Gyroscope is an important parameter in evaluate motion ability. A comparison test between healthy people and patients in hand motion status will show in chapter 6.

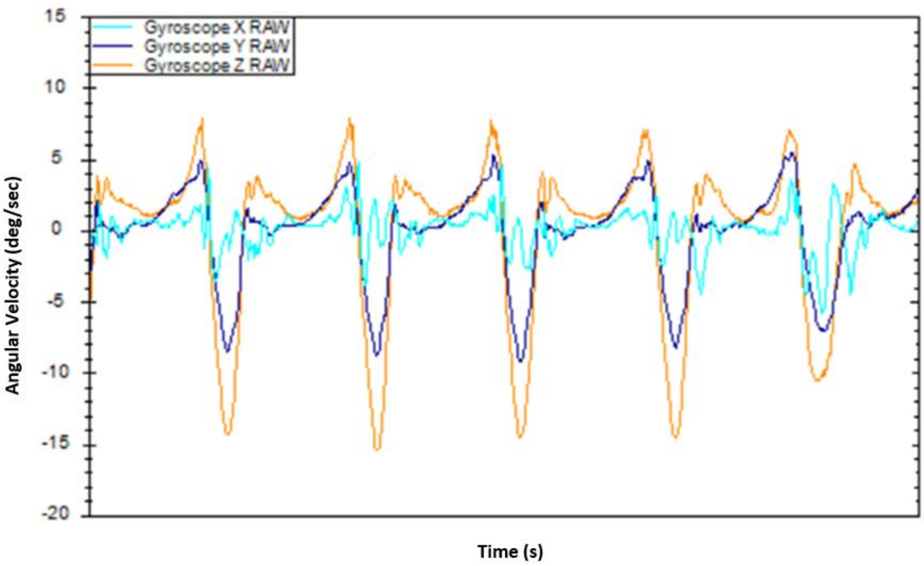


Figure 3.17 Angular Velocity of Shimmer

Fig 3.18 shows the PPG signal that measured by Shimmer sensor, it has a linear relationship with heart rate. Every wave represents a heartrate. Peak represents the contraction of the heart while valley means diastole.

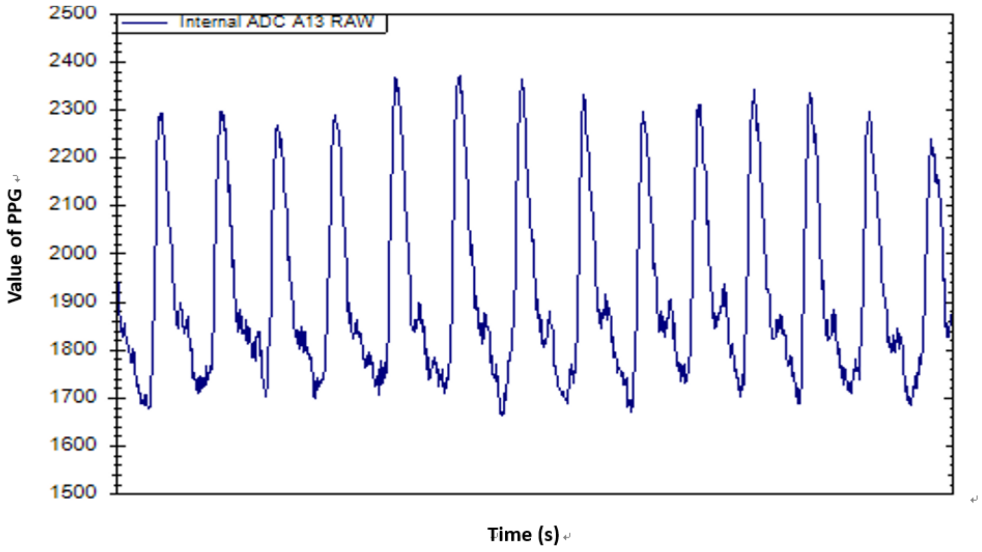


Figure 3.18 PPG signal measured by Shimmer sensor to extract the HR

Filter and calculate the PPG signal, the value of heart rate is obtained which shows in Fig 3.19.

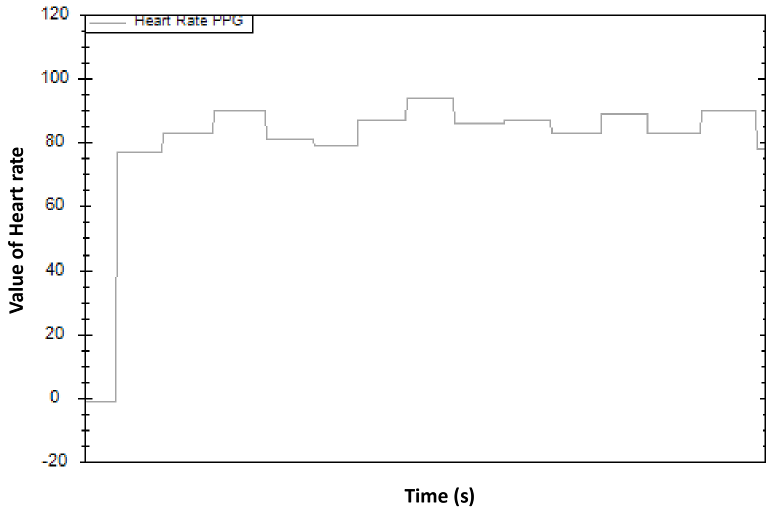


Figure 3.19 Heart rate calculated from the PPG signal

3.6 Other Hardware Components

In addition to the previous hardware components, there are other hardware devices that are required to use the IOS Gait Training application:

• MacBook Pro

• Computer

• iPhone 8

MacBook Pro: The Unity application is designed for computers running MacOS. For its development and testing a portable computer with the following specifications was used:

MacBook Pro	
MacOS Edition	MacOS High Sierra
Screen inches	13
RAM Memory	4,00 GB
Processor	Intel (R) Core i5 2.40GHz
Type of System	64-bit operating system, x64-based processor
Video card	Intel HD Graphics 3000 384MB

Table 3.2 Specifications of the laptop used to develop the IOS application

In terms of the specifications, designer should use similar or higher specification computer, to guarantee the efficiency of game development. For better quality image, a good processor and graphics card are recommended. Developing games in unity is a very important part of the rehabilitation application, it determines the following game procedures and directions.

Computer: A computer that running Windows 10 is utilized to connect Shimmer sensor and database, data from Shimmer is transferred to real-time database by running a C# file during training. It is a necessary data transfer station because Shimmer is a kind of sensor which more adapt to Windows System.

iPhone 8:

Figure 3.20 iPhone 8 used to test IOS application

iPhone 8 (Fig 3.20) as a component of Bridge Headset display AR scene for user, the mobile product which from Apple has the same size with iPhone 8 also can be used with structure sensor. The specifications of used iPhone 8 are shows in Table 3.3 [43]. High resolution provides better display effect of AR scenario, lighter weight won't bring burden on user, when project is built by Unity, Xcode will launched automatically then iOS application running and installing on the connected device. Corresponding structure sensor, the future device that used to test the application should be at least or higher than iPhone 6, the rehabilitation application requires the devices to have access to the internet, either through a mobile network (3G, 4G) or Wi-Fi.

iPhone 8	
Size	5.45 x 2.65 x 0.29 inches (138.4 x 67.3 x 7.3 mm)
Weight	148 grams
Screen inches	4.7-inch Retina HD IPS LCD
Resolution	1334 x 750 pixels
Operating System	iOS 12.3
Storage	64 GB
Processor	A11 Bionic chip with 64-bit architecture, M11 motion coprocessor
Camera	12MP rear with OIS, 7MP front

Table 3.3 Specifications of iPhone 8 used to test the iOS application

3.7 Data Storage and Transmission

This chapter is intended to describe data storage and transmission between database and physical rehabilitation application.

3.7.1 Data Structure in Firebase

The Firebase Realtime Database is a database hosted in the cloud. The data is stored in real time as a JSON format. Firebase can connect with multi-platforms, such as Android, iOS and web application, user can access the Firebase database by Firebase SDK which more convenience and simple.

The Firebase Real-Time Database allows users to access the database securely, the user connects to the database by code, and can develop relevant data analysis and application functions independently. Data can be imported and exported as json files, increasing the flexibility and diversity of database data.

Existing data always keep in the database when occurs an offline event. When the device is connected to the network again, the real-time database automatically synchronizes all local data changes with remote updates that happen during client offline, automatically merging all inconsistent data.

Firebase Real-Time Database Security Rules is an unique expression-based rules that used to specifies permissions and rules of reading and writing data, controls and manage all the data in the database.

After logging in to Firebase for authentication, developers can define the data and access methods they want to access based on their needs.

In this dissertation, All data that measured by smart carpet and Shimmer are storage in the Firebase real-time database, the structure of Firebase database shows in Fig 3.21, the data written in DB as characters, current user id is written in Firebase while scanning user QR code after launched the application, and is overwrite when another user is logging in.

The first part of database is the data measured by smart carpet, including user motion value of speed, steps, duration, and position. Child named by user id which read from current user id, such as “Liu”, “Ni”. The second part is the data from Shimmer sensor,

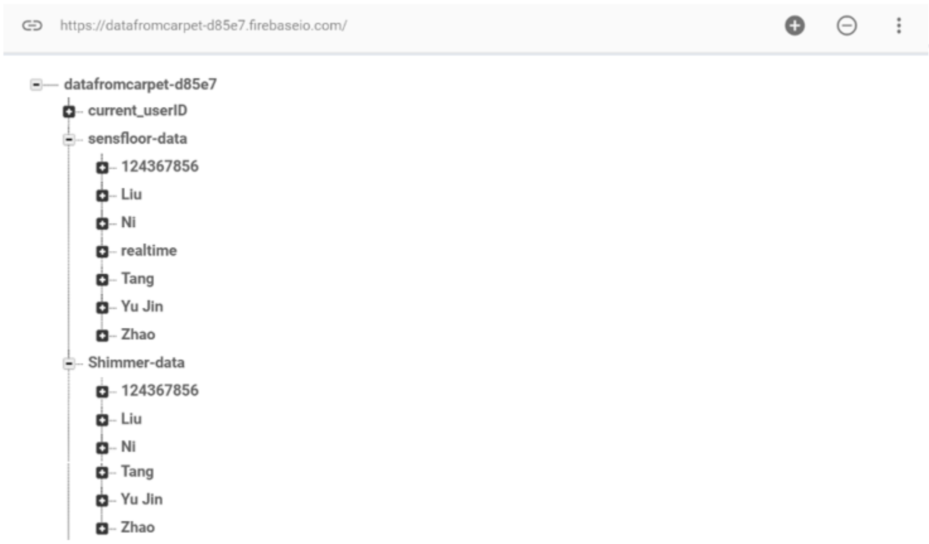


Figure 3.21 Structure of Firebase database

users’ GSR, heart rate and accelerometers in X, Y and Z axis are recorded. While transfer measured data to Firebase, current user id is read first, then every child has a user id node to record current user. Children name are unique Id that generated randomly (see Fig 3.22) which guarantee the security of user information. Measured data is recorded in each unique child and could be read and analysis by retrieve username.

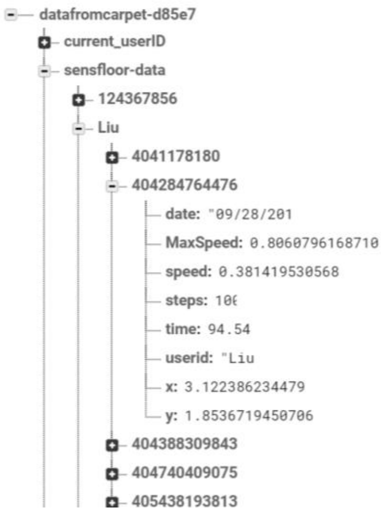


Figure 3.22 Structure of data measured by sensFloor

3.7.2 Communication with Firebase

Instead of a common HTTP request, the Firebase Realtime Database uses a data synchronization mechanism. Whenever data changes, any connected device receives updates in milliseconds. It provides a collaborative and immersive experience without the need to write network code.

Firebase apps stay responsive even when they're offline, because the Firebase Realtime Database SDK keeps data on disk forever. Once the connection is re-established, the client device receives any updates that were missed during the time and synchronizes with the current server state. Mobile devices or web browsers have direct access to the Firebase Realtime Database, so no application server is required. Both security and data validation are provided through Firebase Real-Time Database security rules, which are executed when data is read or written. Fig 3.23 shows the database rules used in my project, the mobile application could read the data by access a permission, just need to select a new application in Firebase then copy the initialization code to C# project or html file, the connection between Firebase and unity project is established.

模拟器

```
{
    "rules": {
        ".read": true,
        ".write": "auth != null"
    }
}
```

Figure 3.23 Firebase database Rules

```
var firebaseConfig = {
  apiKey: "AIzaSyBWJjGwyJqC-xzjCxXGA4vPWgmgxKkSjxk",
  authDomain: "datafromcarpet-d85e7.firebaseapp.com",
  databaseURL: "https://datafromcarpet-d85e7.firebaseio.com",
  projectId: "datafromcarpet-d85e7",
  storageBucket: "datafromcarpet-d85e7.appspot.com",
  messagingSenderId: "809254604757",
  appId: "1:809254604757:web:863469f7b29c3bb1"
};
// Initialize Firebase
firebase.initializeApp(firebaseConfig);
```

Figure 3.24 Firebase real-time database initialization code

The initialization code (see Fig 3.24) is a special key to access Firebase database, every DB has a unique apiKey which ensure the security of information, combine the firebase rules easier to write and read real-time data.

1) Firebase Shimmer Sensor Data Storage

The measurement data from Shimmer sensor is stored in the Firebase the implemented database structure being presented in Fig 3.25. Thus, a new node is generated when Shimmer sensor perform the update. The name of nodes is presented in a sequential number. The record data include the acceleration data provided by Shimmer sensor for the X, Y, Z axis, the value of GSR which may indicate the patient' stress status and also the heartrate values obtained by the processing of PPG signals.

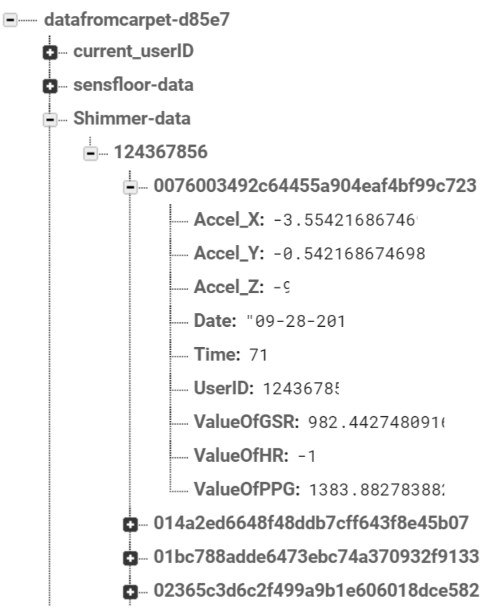


Figure 3.25 the Firebase structure of Shimmer sensor data

In Fig 3.26 is presented an example of code associated with the *write* of the Shimmer data to Firebase database. In the first line is defined the data structure in each *child*, a counter ensures the *child* name is incremented. Sending a request to Firebase is a prerequisite for write data, after that, it is necessary to choose a method of saving data. Several methods may be considered:

• PUT: Write data to the specified path or replace the data under the specified path. Using PUT will overwrite the data at the specified location, including all child nodes.

• PATCH: Update some of the keys in the specified path without replacing all data.

• POST: Add data to the list of data in the Firebase database. Each time a POST request is sent, the Firebase client generates a unique key.

In order to observe patient's physical state clearly, all the data needs to be saved, so the patch method is selected.

The last line of the code segment means read full length data.

```
string jsondata = @"{" + Num + ":{'Pos_X': " + Acceleration_X + ",'Pos_Y': " + Acceleration_Y + ", 'Pos_Z':
JObject data = JObject.Parse(jsondata);
string json = JsonConvert.SerializeObject(data);


var request = WebRequest.CreateHttp("https://datafromcarpet-d85e7.firebaseio.com/Shimmer-data.json");

request.Method = "PATCH";
request.ContentType = "json";
var buffer = Encoding.UTF8.GetBytes(json);
request.ContentLength = buffer.Length;
request.GetRequestStream().Write(buffer, 0, buffer.Length);
var response = request.GetResponse();

json = (new StreamReader(response.GetResponseStream())).ReadToEnd();

Num++;
}
```

Figure 3.26 Code segment of write data to Firebase

2) Firebase SensFloor Data Storage

HTML is defined by the World Wide Web Consortium, an organization that regulates standards for the Internet. Different writing rules are defined according to different version of HTML. HTML allows the developer to make text documents look engaging and pleasant. JavaScript is the most common method to write and achieve HTML. [52]. A basic HTML page is a document that typically has the file extension .html, though HTML frequently appears in the content of other file types as well. All HTML documents follow the same basic structure so that the browser that renders the file knows what to do.

The main structure of a HTML file is:

• Doctype: the first line of code, <!DOCTYPE html>, is called a doctype declaration and tells the browser which version of HTML the page is written in.

• HTML Root Element: the <html> element wraps around all of the other code and content in the document. This element, known as the HTML root element, always contains one <head> element and one <body> element.

• Head Element: the HTML head element is a container that can include a number of HTML elements that are not visible parts of the page rendered by the browser. These elements are either metadata that describe information about the page or are helping pull in external resources like CSS stylesheets or JavaScript files.

• Body Element: there can only be one <body> element in an HTML document because this element is the container that holds the content of the document. All of the content that you see rendered in the browser is contained within this element. In the example above, the content of the page is a headline and simple paragraph.

Beside the above HTML elements, in terms of the writing method, nesting is a key part of writing a HTML file. HTML like a container, including charts, graphs, articles, all contents that presents in the web. HTML will be able to be targeted by CSS and JavaScript because of nesting. Nesting means exactly what you'd think it might mean: each element goes inside another element, just like nesting dolls are physically "nested" within each other.

In this dissertation, a HTML file is used for data sampling delivered by smart carpet and then store the sampled data into the Firebase. The HTML file is executed by the Raspberry Pi computation platform which is part of SensFloor data transceiver SE_{10}. Fig 3.27 presents the header of HTML, it defines the name of web and creates a connection between SensFloor web application and Firebase real-time database.

```
<title>SensFloor </title>
<script src="http://192.168.5.5:8000/socket.io/socket.io.js"></script>
<script src="https://www.gstatic.com/firebasejs/5.8.6/firebase.js"></script>
```

Figure 3.27 Code Segment of HTML Header

To upload data to Firebase, the preparation of connection between Firebase and HTML should be established. The first step in connecting a Firebase project to the web is to configure the object. Firebase Real-Time Database rules determine which users have access to and write to database, data structure, and which indexes exist. These rules exist on the Firebase server and are always executed automatically. Each data reading and data writing request can only be completed when the rules are allowing it. By default, the rules do not allow anyone to access the database. This is to prevent the database from being abused before you have time to customize the rules or set up authentication.

```
<script>
        var config = {
        apiKey: "AIzaSyBWJjGwyJqC-xzjCxXGA4vPWgmgxKkSjxk",
        authDomain: "datafromcarpet-d85e7.firebaseapp.com",
        databaseURL: "https://datafromcarpet-d85e7.firebaseio.com",
        projectId: "datafromcarpet-d85e7",
        storageBucket: "datafromcarpet-d85e7.appspot.com",
        messagingSenderId: "809254604757",
        appId: "1:809254604757:web:863469f7b29c3bb1"
        };
    firebase.initializeApp(config);
```

Figure 3.28 Code Segment of Firebase configure

In Fig 3.28, apiKey is the key to pair Firebase with web, guarantees the security of the database. Database URL is the address of database, these code segment including in the part of scripts.

To write data to Firebase database, ref is to set a child saving data, the content in braces is the format in which the data is written. PosX, PosY, Velocity, counter and time period are the various measured in from smart carpet.

Saving data to Firebase has four methods:

• Set: write or replace data to a defined path.

• Update: update some of the keys for a defined path without replacing all of the data.

• Push: add to a list of data in the database. Every time you push a new node onto a list, your database generates a unique key. Calling push () will return a reference to the new data path, which you can use to get the key or set data to it.

• Transaction: use transactions when working with complex data that could be corrupted by concurrent updates. When working with complex data that could be corrupted by concurrent modifications, such as incremental counters, transaction operation is used to complete call back function in Java and Node.js.

```
firebase.database().ref('sensfloor-data/realtime').set({
        userid: CurrentUserID,
        x: posX,
        date: date,
        y: posY,
        speed: maxSpeed,
        steps: counter,
        time: Timeperiod/ 1000,
        MaxSpeed: speedRecord
    });
firebase.database().ref('sensfloor-data/'+CurrentUserID).child(uniqueId()).set({
       userid: CurrentUserID,
       x: posX,
       y: posY,
       date:date,
       speed: maxSpeed,
       steps: counter,
       time: Timeperiod/ 1000,
       MaxSpeed: speedRecord
    });
  });
```

Figure 3.29 Code Segment of write data to Firebase

Set method (see Fig 3.29) is used in this dissertation to store data while updating measured data. The first function is to use Get method read current user id, the second function is to write the id which read in the first function with measured date to real time database. Displaying data in Unity project is implemented by invokes the data from real time key in SensFloor-data reference, graphics in web application read data from user key. Two different data paths make data visualization convenience and efficiency.

3) Firebase Unity SDK

Firebase Realtime Database often used when testing scenes in the Unity Editor. To establish connection between database and Unity, the first step is to configure the SDK with the proper database URL. Call SetEditorDatabaseUrl with the url of the database which shown in Fig 3.30.

```
using UnityEngine;
using UnityEngine.UI;

using Firebase;
using Firebase.Database;
using Firebase.Unity.Editor;

public class stepsFromFirebase : MonoBehaviour
{

    public Text Steps;
    public Text Speed;

    // Start is called before the first frame update
     void Start()

     {
         // Set up the Editor before calling into the realtime database.
         FirebaseApp.DefaultInstance.SetEditorDatabaseUrl("https://datafromcarpet-d85e7.firebaseio.com/");

         // Get the root reference location of the database.
         DatabaseReference reference = FirebaseDatabase.DefaultInstance.RootReference;

         FirebaseDatabase.DefaultInstance
         .GetReference("testdata")
         .ValueChanged += HandleValueChanged;
     }
```

Figure 3.30 Code Segment of establish connection between Firebase and Unity

While smart carpet retrieve data to Firebase during the training, the Unity will read the updating data in real time, it combines with the rules of database, declare the address of database and define a database reference are necessary instructions in this context. Then transfer data to two text, it will show in Unity the information from database. There are many ways in Firebase to implement data retrieve and update:

• Get Value Async: this method is to read a static snapshot of the contents at a given path once that means data will be read once and all the data from this reference is obtained by using this function. It often used to create a static chart in web application to show all measured data in a period time.

• Value Changed: Read and listen for changes to the entire contents of a path. Value Changed event to monitor changes of a given path. When add a value changed monitor to a node, any change in this child will be known, some dynamic result obtained based on these events. Comparison with the get value async method, Value changed method more suit for dynamic information extraction. Add this method to the most recent node can get more effective result and avoid error occurs. This is a notice when using this method.

• Child Added: Child added is to retrieve lists of items or listen for additions to a list of items. Usually it utilizes with other related functions, such as Child Changed, Child Moved and Child Deleted. When user use push function to save date into Firebase, a list of items is generated with unique child name. Event triggers item list update and overlay. In this context, Child Added function monitor the increase of child, do some retrieve in the item list and get a feedback from the added child event.

• Child Changed: Listen for changes to the items in a list. It also usually used with Child Added function and Child Removed function to monitor changes to item lists. The Child Changed event is raised any time a child node is modified. This function also used to monitor the changes in the descendants of the child node.

In this dissertation, Unity retrieve data from a real time firebase database, a Handle Value Changed method is used, shows like Fig 3.31.

```
void HandleValueChanged(object sender, ValueChangedEventArgs args) {
    if (args.DatabaseError != null) {
        Debug.LogError(args.DatabaseError.Message);
        return;
    }
    // Do something with the data in args.Snapshot
    Steps.text = args.Snapshot.Child("steps").GetValue(false).ToString();
    Speed.text = args.Snapshot.Child("speed").GetValue(false).ToString();
    Debug.Log(args.Snapshot);
}
}
```

Figure 3.31 Code Segment of get data from Firebase

This dissertation uses the Firebase real-time database to read and store data as a data relay station. Firebase can communicate with both smart sensors and Unity project well, also demonstrates the advantage of easy and convenience.

Chapter 4 – Applications for Physical Rehabilitation

Gait training is a significant part of physical rehabilitation for patients that suffer stroke events. This gait training application materialize a serious game. The term Serious Game refers to digital games dedicated to serious purposes promoting learning, healthier behavior including physical exercises. This chapter introduces the computer application that was developed to be used by the patients, so that they can perform the training plan established by the physiotherapists. This chapter explores how the games were created and adapted to the individual characteristics of each patient.

4.1 Application Engine

The application engine is a key component when developing an AR rehabilitation game. It is a computer program or a set of libraries that could build AR scenario and add special effects, it provides various development strategies. There are several development engines that can be used to develop game applications with AR or VR, each one has certain features to help the developer in the development, for example, Unity 3D [45] and Unreal Engine [46]. Comparison with Unreal Engine, Unity 3D could:

• Develop applications for almost every platform, such as PC, iOS, Android, Xbox, PS and Web;

• More suitable for the small-scale application while Unreal Engine for the development of massive applications;

• Easy to operate and various guidance for developer.

The Unity 3D was decided to be the game engine for the current project due to its great rendering capability and features that it offers. In terms of programming languages, Unity 3D uses C# and JavaScript as mainly languages, which has a more advanced syntax system that could makes programming easier. Another advantage of Unity 3D is the powerful technical support and development resources, such as various documents and Asset Store [47] where it’s possible to download scripts, objects, textures, among others to develop applications.

Unity 3D provides an intuitive and multi-optional interface for developer, the game engine has a good integration with many kinds of smart sensors, for instance, structure sensor and Kinect. A unity package that included in structure SDK offers many necessary components to create an AR scenario, this is also a main reason why Unity is selected for this project.

Figure 4.1 illustrated a develop window in Unity 3D, the position and structure of development interface can be personality and organized according to the developer.

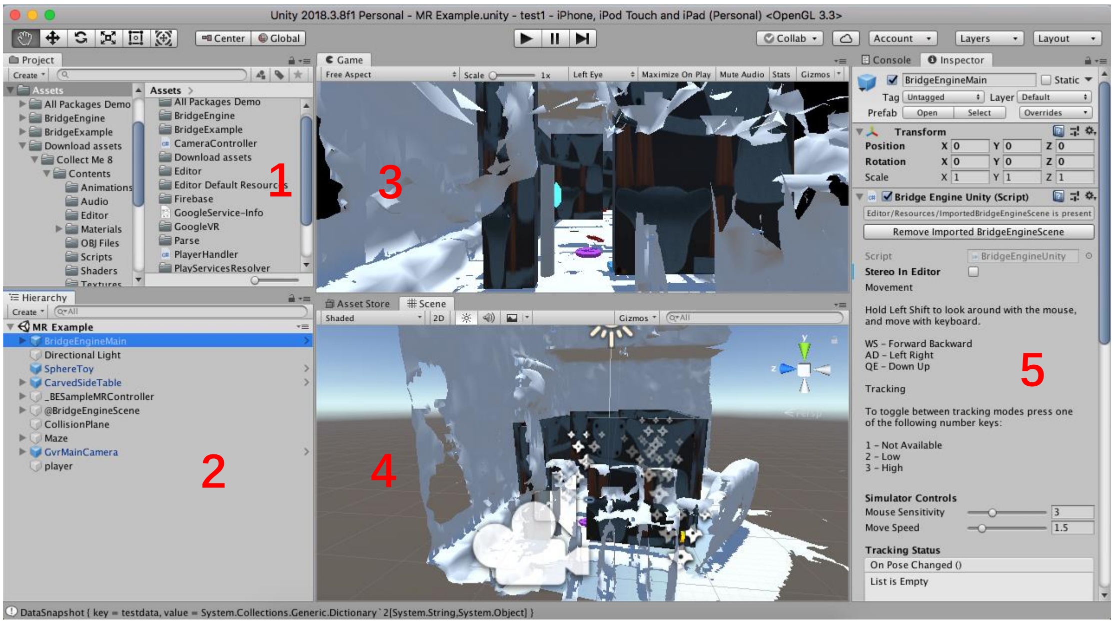


Figure 4.1 The programming interface of Unity 3D game engine

• 1 – Projects including Assets and Packages, Assets comprises all materials that used in this unity projects, such as textures, scripts, materials, prefabs and unity assets. They are participated in the application construction as important components.

• 2 – Hierarchy comprises all components of this unity projects. It can be selected directly from Assets list. Edit components by selected each object and carry out corresponding operations, express the hierarchical relationship of each object clearly.

• 3 – Main interface while running application, when the programmer runs the game to see what has already developed is the area where you can see the scenario created in the perspective of the end user. It also has a tab named by Console that is used for debugging processes;

• 4 – Scene is a window that create game objects and edit their inspections in the AR scenario, is the most important UI interface.

• 5– Inspector. For each object is possible to perform several operations, for example, associate scripts or create physics processes. Is very useful to visualize the various components associated with each object.

The version used by Unity 3D to develop the application was 2018.3.8f (64 bit).

Unity 3D control objects and scenes by various corresponding scripts, multiple objects could be controlled by one script. After programming a script, this script must extend the monobehaviour class and it's ready to be associated with an object, then drag the script to the object, and this is associated as a component.

Inspector is a tool that make user view the script as a component of the object clearly, and some public variables, is possible to visualize them and to define values for each of them, as illustrated in Figure 4.2.

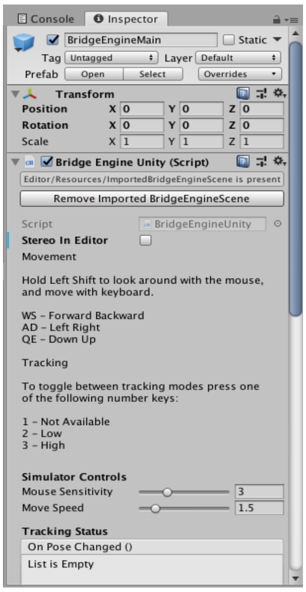


Figure 4.2 Example of a script with an object with its attributes and values

Unity could interact with multiple platforms. In this project, iOS platform is selected (see Fig 4.3), then select build and run, an XCode workspace automatically launched after unity project built, then select the test iPhone and build in XCode, the iOS application will install on iPhone, trust the Apple account is the premise of installation application.

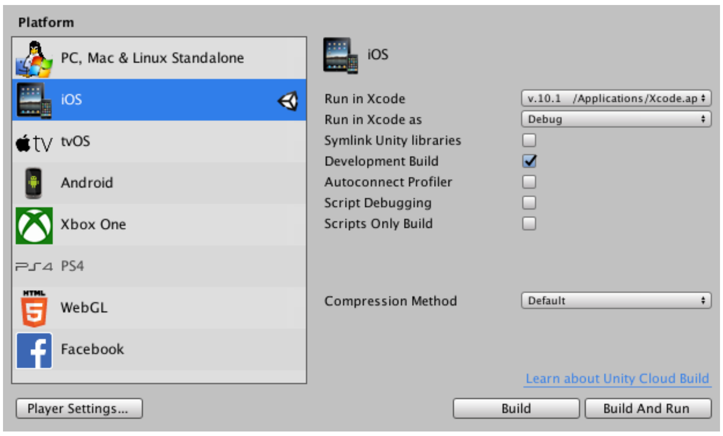


Figure 4.3 Platform Selection UI in Unity 3D

Many C# scripts are developed for the application implemented for physical rehabilitation. The implemented scripts permit to control progress of application. In this case, they are attached to the game object as a component. In these scripts, the collision are very important and are related to the interaction between game objects. Thus, after two rigid body objects were collided, the command inside the onCollision function is executed and can correspond to the sound increase or score increase. The player is bundled with the main camera to play the game from the first perspective, enhanced interactivity between virtual object and user.

Fig 4.4 illustrates an example of code which implement a function of control player, A C# Script named Player Handler is attached to player object and used to manipulate the player, player is bundled with GvrMainCamera to ensure patient in the first perspective during the training. The following code is the preparation work before the collision function is executed. In the following coed, 'Using' is to declare useful namespace, the System Collections namespace contains interfaces and classes that define various collections of objects. Unity Engine namespace is the necessary namespace for script component. Unity Engine UI namespace is declared when using user panel and text, The System namespace contains fundamental classes and base classes that define commonly-used value and reference data types, events and event handlers, interfaces, attributes, and processing exceptions. In this script, defined audio clip, game object and text are used in the game process as event handler. All define shows in inspection of player, drag the corresponding audio file or game object to the

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using System;

public class PlayerHandler : MonoBehaviour
{
    // Start is called before the first frame update

    private Vector3 cameraPosition;
    private GameObject camera;
    public AudioClip coinPick;
    public AudioClip wallCollision;
    public AudioClip StartCollision;
    public AudioClip EndCollision;
    AudioSource saw;
    public int score;
    public Text ScoreText;
    public Text WinText;
    public int finalScore;
    public bool enter = true;
    public GameObject Player;
```

Figure 4.4 Template of declaration code

defined space then implement expected effect.

4.2 First Tests

In order to combine bridge headset with Unity project, the first step is to import the bridge engine SDK to a blank project. The bridge engine SDK has a unity package that provide Google VR components for designer. A tutorial [48] introduces how to initially build an AR scenario in unity project, it is the basis for subsequent operations, Fig 4.5 shows the test performer with Bridge Engine SDK, the white environment represents the scanned physical, it could be replaced when different environment is scanned, it

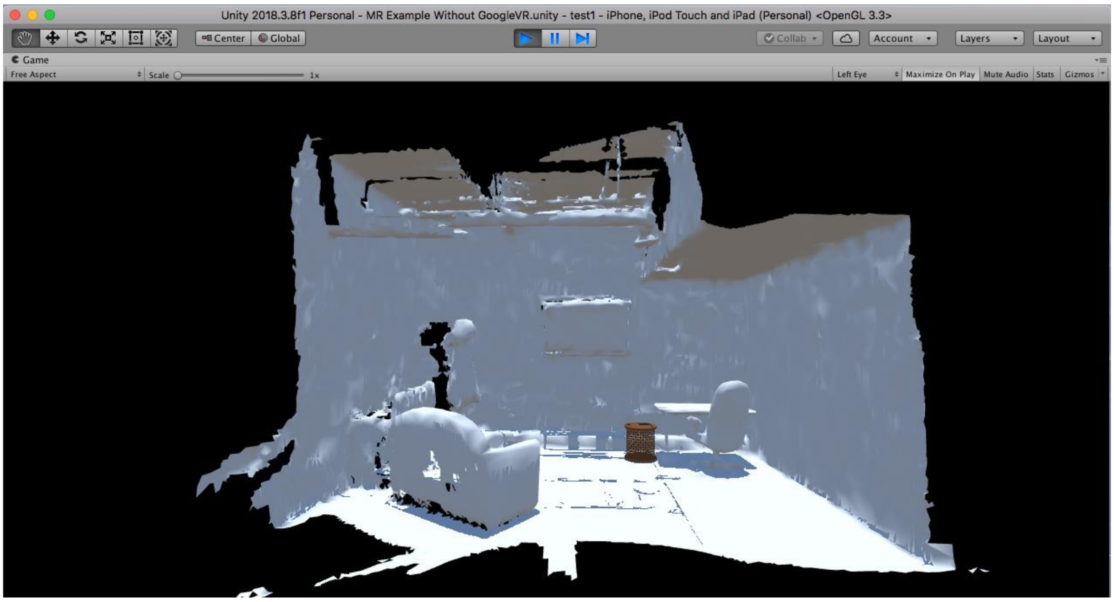


Figure 4.5 First test performer with Bridge Engine SDK

could be add to the Unity project by import a Bridge Engine Scene file. Several buttons control the movement of player, forward and backward movement controlled by holding shift button and W, S; left and right controlled by A and D with Shift; up and down controlled by E, Q. The easier way to manipulate the game is using mouse and shift. Virtual game objects could build on the basis of scanned environment.

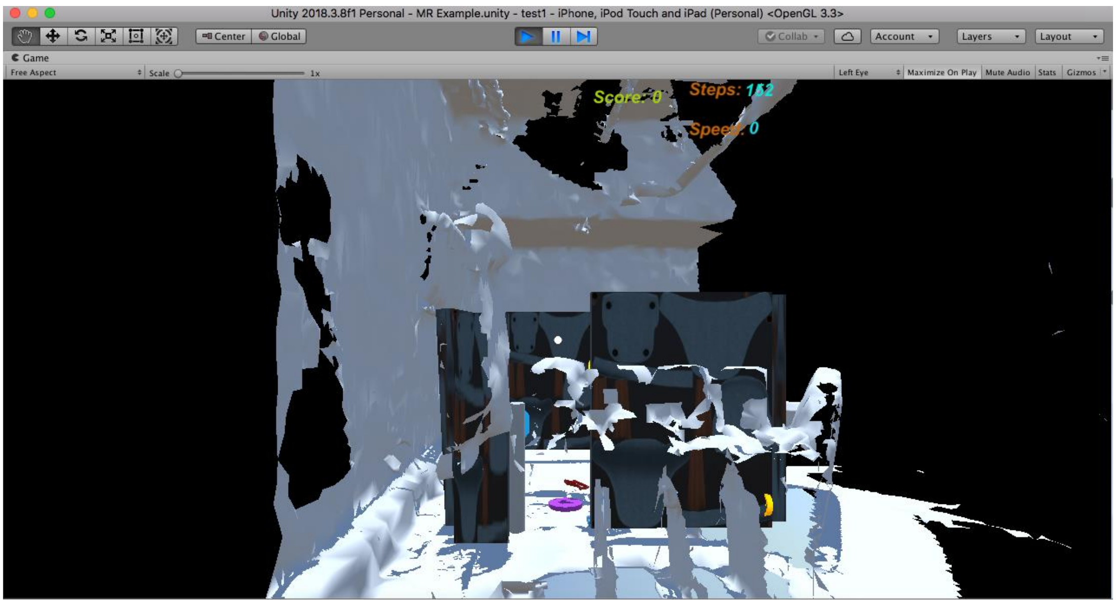


Figure 4.6 First test with game development

After exploring the provided examples, some tests were done to start developing the first game for the application. Figure 4.6 illustrates the first test to develop one of the future games of the application, using Structure sensor SDK.

The objective of the first test is to train the user to walk in an environment characterized by virtual objects in real world. If the user touches the designated objects he will get points. Additional information is shown on the screen according with the data produced by the SensFloor. These values will change dynamically when user walk on the smart carpet. Fig 4.7 illustrates a scenario that was created for stroke patients that are motivated to make gait rehabilitation using the serious game.

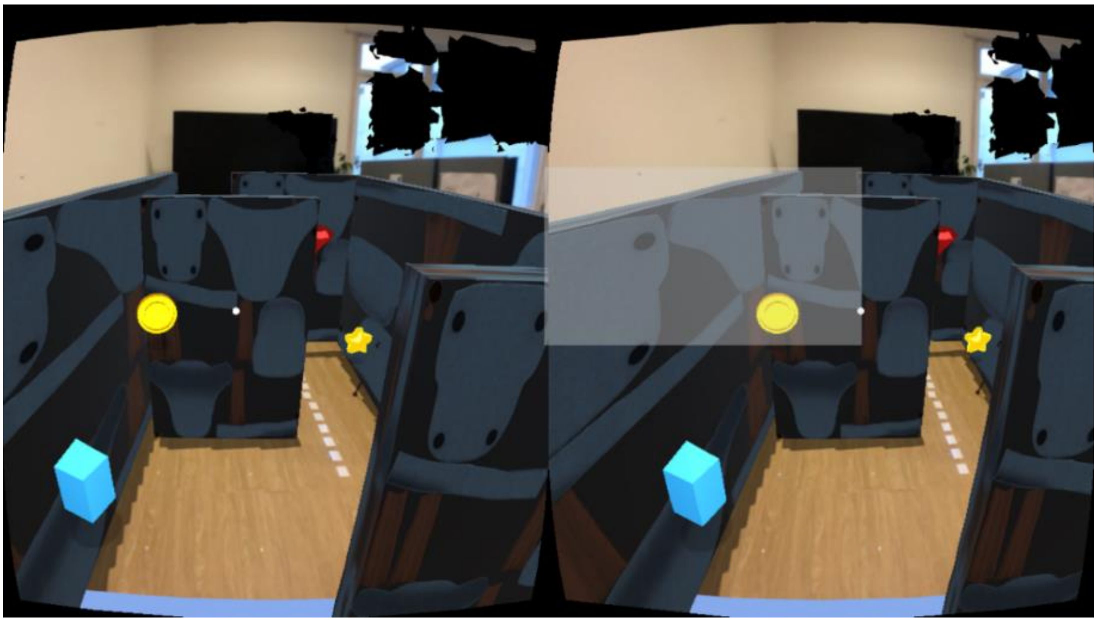


Figure 4.7 Scenario created in Unity

4.3 The IOS Application

Fig 4.8 illustrates the flowchart of the implemented rehabilitation App. To confirm the identity of user, a QR Code reader is designed to write current user ID to database, which guarantees the individualization of recorded information that can be later used by the physiotherapist. After patient logged in correctly, unity engine started on the mobile device, the real environment will be scanned to achieve augmented reality. A 6-Dof controller used to master the application, and a selection interface will show before start playing game, which provides different duration. When user finished training, the final score is upload to the Firebase with user ID.

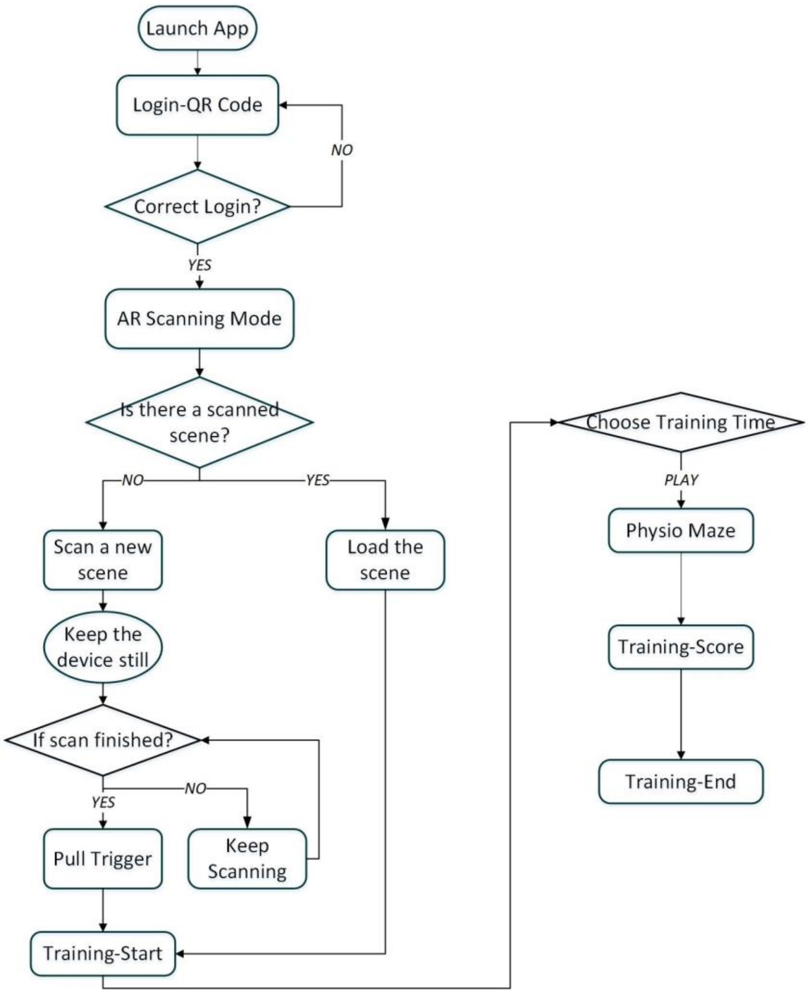


Figure 4.8 iOS Application Diagram

The first step after launching the iOS application is scanning the environment, user should follow the prompts, the first UI is a preliminary setting (Fig 4.9). User can choose if enable stereo VR mode, wide vision lens and other settings. To carry out AR scenarios, stereo VR mode should enable, wide vision lens is used to have broader perspective. iPhone should always connect with structure sensor since mobile application is launched, connection problem will trigger a warning shows ‘Please connect structure sensor’ as Fig 4.10 represent.

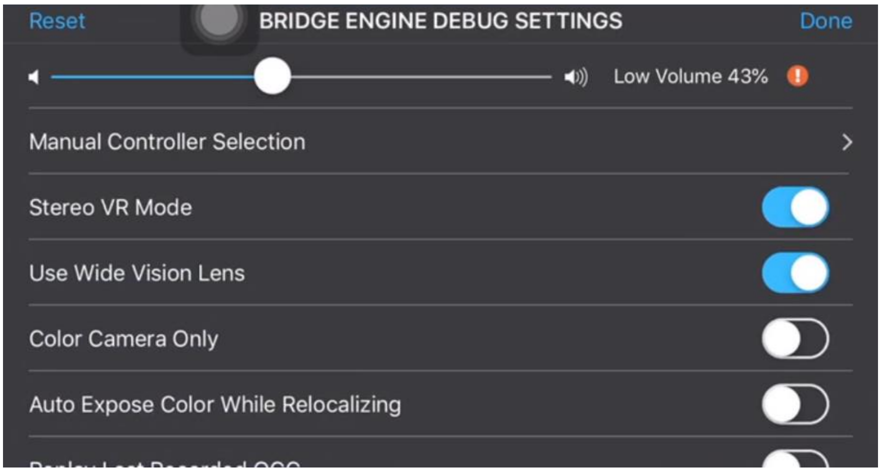


Figure 4.9 UI of Bridge Engine Debug Setting

Figure 4.10 The warning when connection problem appears

It is not difficult to scan a game environment with structure sensor, the overall game space is a cuboid sized in 2m x 4m x 3m, it suitable for the range of structure sensor. Thus, if the user will walk the virtualization gaming space will be completely accomplished. The output stream from the Structure Sensor alone consists of a point dataset, with a resolution of 640 × 480 pixels, where every pixel records the distance from sensor to the target. The infrared sensor records the reflectance intensity of the infrared (IR) light pattern projected by the IR projector onto the target while system on a chip (SOC) triangulates the 3D scene. Both Scan and Load could active AR scenario (see Fig 4.11), select Scan to start scanning a new environment, it is selected when the first test. Trigger Scan and keep the device still, the scanning mode will launch automatically (see Fig 4.12), the place where the actual environment has appeared is the real world that has been scanned while black means not yet, user should move slowly to scan the whole environment. Bridge engine scene will save to iPhone automatically when completed scanning, thus selecting load, the scene is loaded and the activation the AR scenario is carried out.

Figure 4.11 Select to Activate Mixed Reality

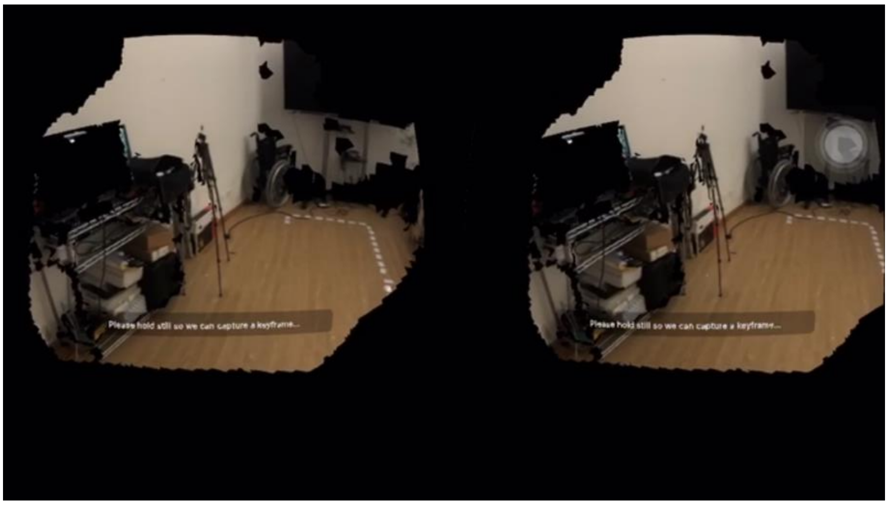


Figure 4.12 Scanning Mode

After loading the virtualized real environment, AR scenario will be shown on the screen together the virtualized real scenario, to provide a walking training gaming scene for the stroke patients. The name of the developed serious game is “Physio Maze”. It requires to the patients to walk in a maze according to a specify route. As important rule is that the patients can’t touch the wall so it requires well balance ability. Virtual objects must be collected too and the user will catch objects preserving his balance.

Considering user will walk in the AR environment and interact with virtual objects, a player model is designed to represent user in the unity project, complete collision, trigger, etc. Player is a rigid body with mesh collider attributes, attached script file command the instructions for score, sound and collision, Fig 4.13 is the inspector of player mode in Unity project.

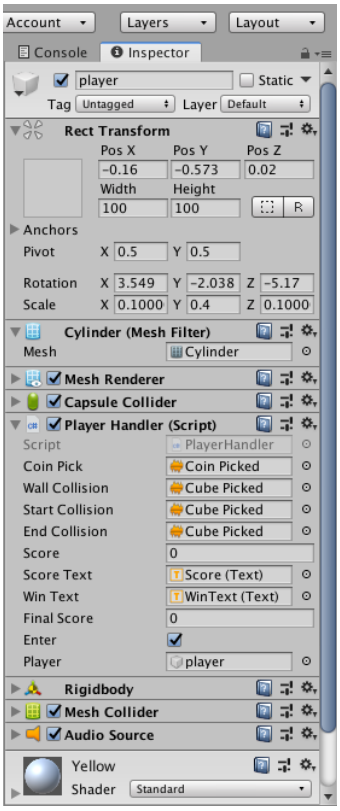


Figure 4.13 Inspector of Player Mode

4.3.1 Authentication

User information is a very important part of the current rehabilitation system. QR Code login method is a common strategy for video games because it only needs a camera of device instead of typing identity manually. In addition, QR Code has other advantages such as:

- Contains more information
- Decoded accurately
- Encryption measures can be introduced
- Low cost and easy to make

In this context, the log in method of physical rehabilitation system is selected to use QR Code, each user has their own QR Code to login the application. Fig 4.14 presents a user QR code card that includes user' name.

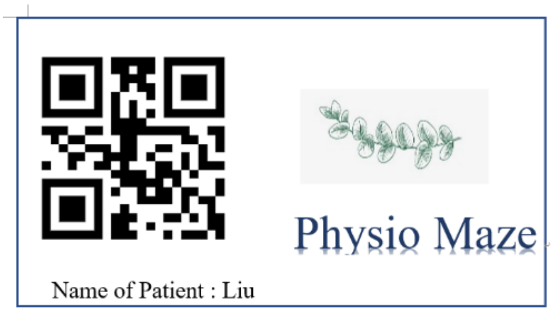


Figure 4.14 QR Code card of User

After launched the rehabilitation app on iPhone, iPhone camera is called to recognize the user's QR Code (see Fig 4.15) and beep automatically starts when scanning code. After that, all measured data in the training is related to the current user' name. Data is sorted by the current time and current user which will show more clearly both in the web page and the database.

Figure 4.15 QR Code recognize by iPhone camera

```
IEnumerator Start()
{
    // When the app start, ask for the authorization to use the webcam
    yield return Application.RequestUserAuthorization(UserAuthorization.WebCam);

    if (Application.HasUserAuthorization(UserAuthorization.WebCam))
    {
        mCamera = new DeviceCamera ();
    }
}
public void StartWork()
{
    if (mCamera != null) {
        mCamera.Play ();
        rawimg.texture = mCamera.preview;
        InvokeRepeating("checkRunningCamera", 0.1f, 0.05f);
    }
}
/// <summary>
/// Checks the running camera.
/// </summary>
void checkRunningCamera()
{
    if (mCamera != null && mCamera.isPlaying() && mCamera.Width () > 100) {

        CancelInvoke ("checkRunningCamera");
        this.rawimg.transform.localEulerAngles = mCamera.GetRotation();
        this.rawimg.transform.localScale = mCamera.getVideoScale ();
        RectTransform component = this.rawimg.GetComponent<RectTransform>();
        float y = component.sizeDelta.x * (float)this.mCamera.Height() / (float)this.mCamera.Width();
        component.sizeDelta = new Vector2(component.sizeDelta.x, y);
    }
}
```

Figure 4.16 The Code Segment of Invoke Device's Camera

Following code segment (Fig 4.16) present a function that code reader check running camera and invoke device camera. For the device which has two cameras, a selection is designed to choose a camera. But only rear camera is used in this rehabilitation system, so always set the rear camera to running camera. User' name will print on the screen when camera recognizes user QR code.

4.3.2 Physio Maze Serious Game

The main scenario of the serious game is represented by a maze (see Fig 4.17) sized in 2m by 4m which has the same size with smart carpet, the patients who wear bridge headset will walk in this virtual maze. Considering the motor ability of patients, a specific pathway is given. The signs on the ground are considered to help them complete walking training. Patients will go to the exit following these arrows (see Fig 4.18). To improve their ability of balance, users are not allowed to touch the walls during training, otherwise the score decreases by 1. Rings, diamonds, coins, stars (see Fig 4.19) are designed to be collected which results in an increase of corresponding score. There are sounds associated with each step, picking-up of objects, touch to walls, enter and exit the maze. Steps and scores will be shown in real-time on the screen. Timer starts when training started, warning sounds play when user not finished the training in 180 seconds and fall occurs (background music stops and bell rings). Depending on these detailed designs, the engagement of the patients on this kind of tretement is higher comparing with the classical between balance training.

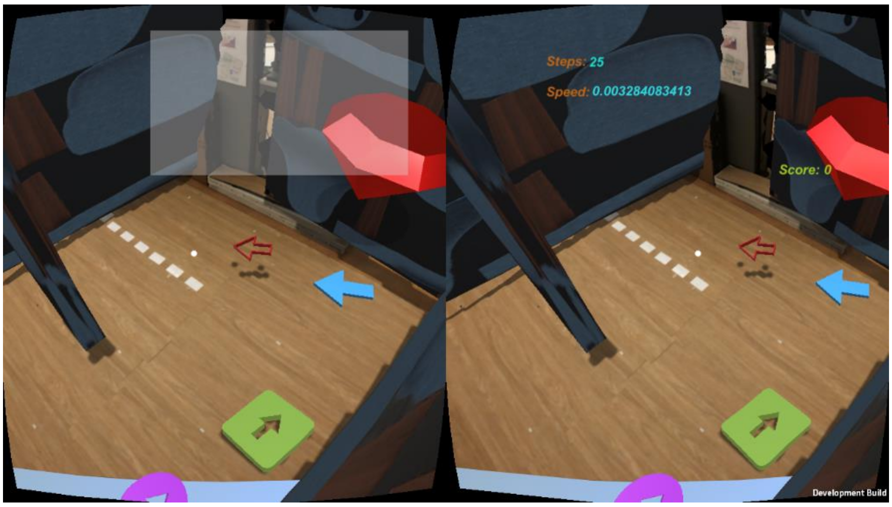


Figure 4.17 Physio maze in Unity project interface

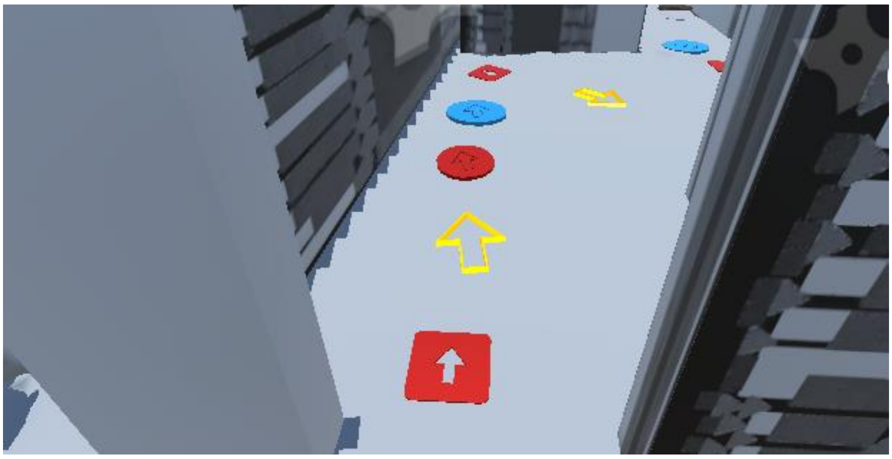


Figure 4.18 Arrows in Physio Maze

Virtual objects are designed to put on each corner of the maze, to make sure patients could walk to the corner then complete turning, when user collides with these virtual objects, effects of animations is triggered, both sounds and animation make patients more immersive in the training.

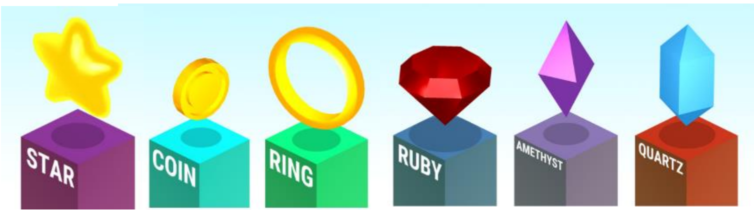


Figure 4.19 Objects in the Physio Maze

During the gait training, data from Firebase interacts with the unity project, patients' velocity, steps and score shows in the right upper corner of the screen, when the patient finishes the game, the information will store into the Firebase database.

Controller is designed to change training background and choose game parameters in the physical rehabilitation training, as shown in Fig 4.20, first background is the environment material that scanned by live camera, change to other background just pull trigger, the remaining two with a meshed texture, green grid always present while

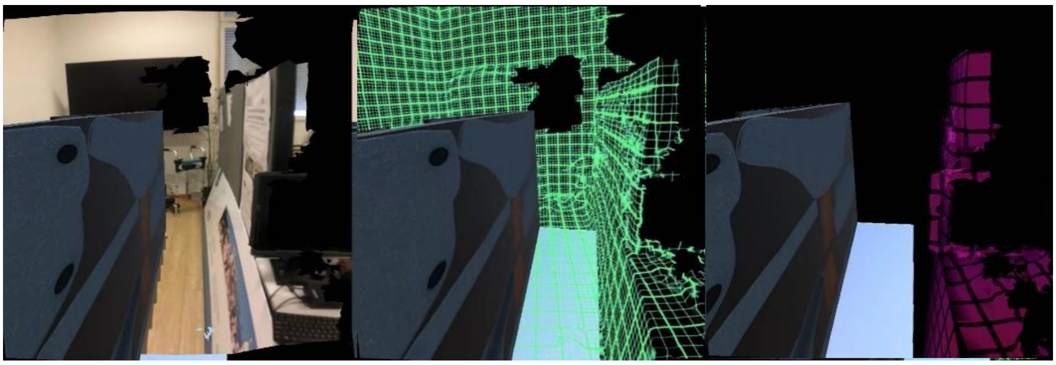


Figure 4.20 Three Different Training Background

pink background shows only when user near the real objects. This design avoids collisions with real objects makes training safer and reliable.

At the entrance and the exit of maze, some messages designed to prompt user, such as: "Go into Physio maze and start training!" and "Congratulations! You finished training". Fig 4.21 presents a prompt template in the training. when user walk near the exit, the message will automatically pop up with a celebrate sound.

Figure 4.21 User Prompt Message

4.4 Web Application

A web application is designed for physiotherapists to check their patients training data

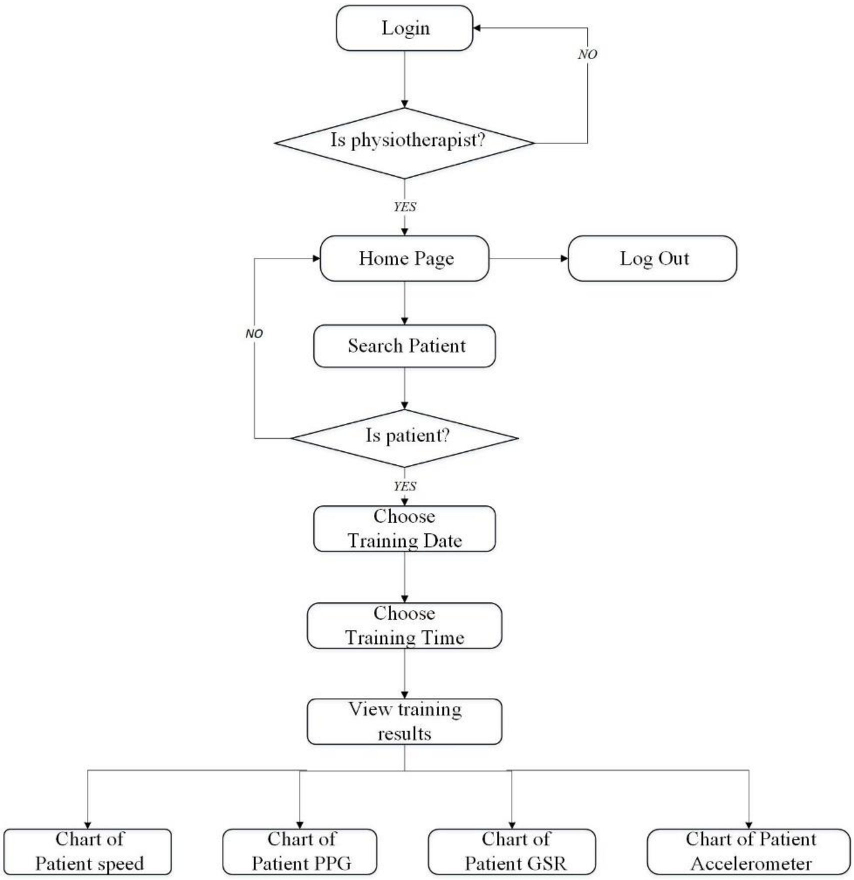


Figure 4.22 Diagram of Gait Training Web Application

and making future physical rehabilitation plan. To ensure the security of user's information, the physiotherapist is required to login first, registration is necessary when the first access. Physiotherapist has access to check all training data of their patients in the database and get a visualization charts in the website.

Physiotherapist need to registrate at the first time visiting the web application, type in the personal information such as username, password, institution and e-mail. Then a new account will be created for physiotherapist as represents in Fig 4.23.

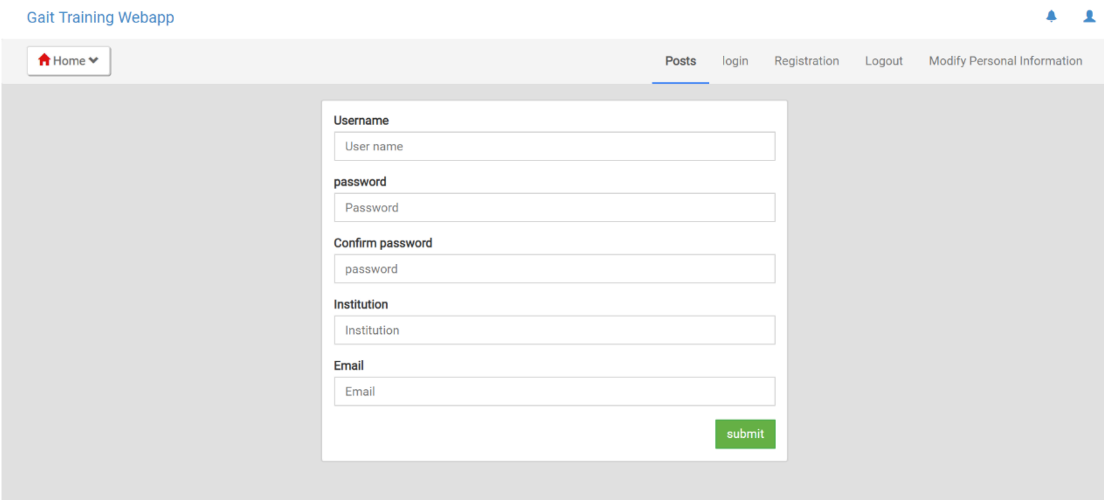


Figure 4.23 Registered User Interface of Gait Training Web Application

Physiotherapists get the data permission by log in (see Fig 4.24), type in the username and password then click 'submit'.

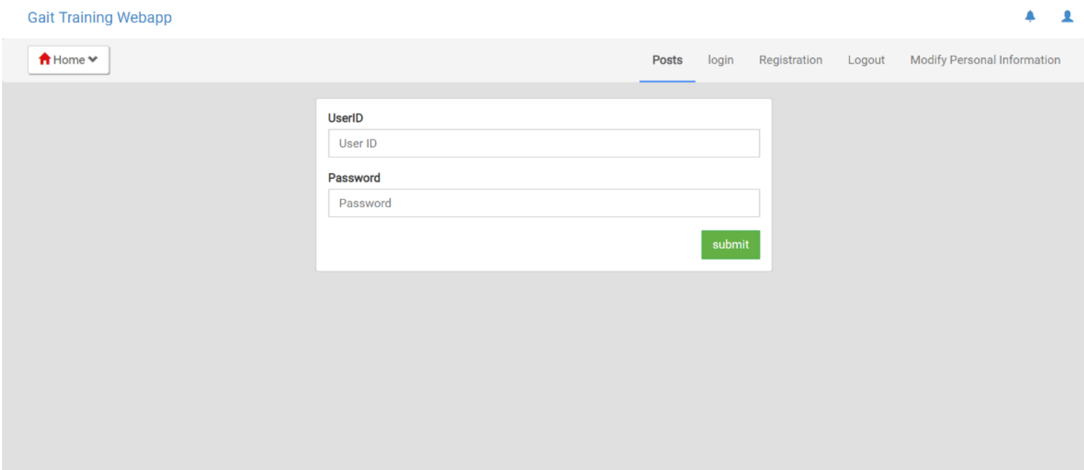


Figure 4.24 Login User Interface of Gait Training Web Application

After login, physiotherapist could choose their patient by search patients' name (see Fig 4.25), prompt message ask therapist to type in the name their patients to submit. Then a selection bar (see Fig 4.26) appears automatically to choose the date and time of patients' training, 'Get Chart' button is used to generate patients' training charts by invoke data from Firebase database.

Figure 4.25 Patient Searching user interface

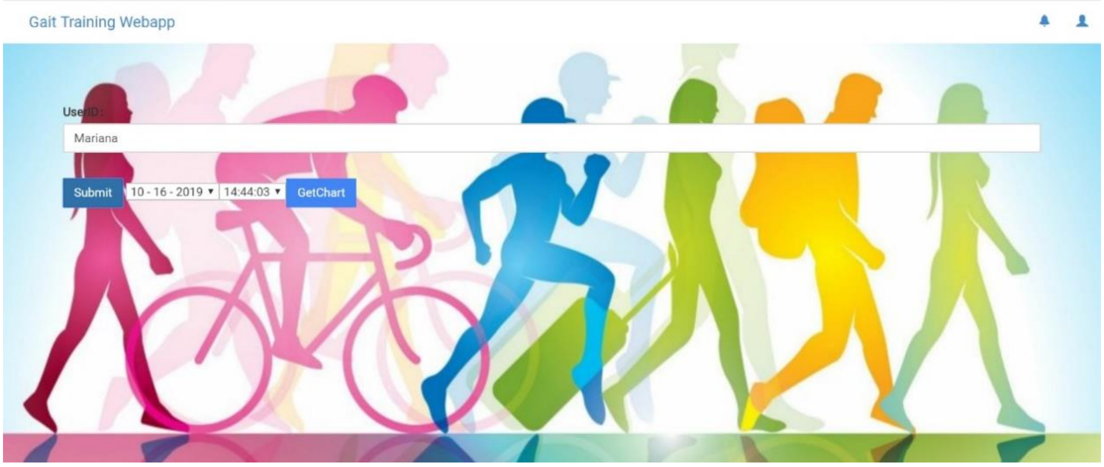


Figure 4.26 User Interface of select training date of one patient

Five graphics will show while click ‘Get Chart’ button, they are heart rate chart of patient, GSR value of patient and acceleration in three directions. These metrics are considered shown to physiotherapists because the health status and balance characteristic of patients are well presented. More detailed results will be explained in the chapter 5.

The physiotherapist is an important participant in physical rehabilitation. They make physical diagnosis mainly based on subjective and objective evaluation. The gait training web application provides an objective basis for the physiotherapist's diagnosis. The physiotherapist makes a raining plan by combining the actual data that could reflects the substantive problems, to help patients recover efficiently.

Chapter 5 - Results and Discussion

This chapter includes the experimental results of the developed system. Test results from three volunteers, data collected by the corresponding sensors, the transmission between measured data via Wi-Fi, Bluetooth and C#API.

5.1 Results of Volunteers Test

The information of three healthy volunteers is recorded during walking training. These three volunteers are wearing the Shimmer 3 GSR+ sensor and are walking on the smart carpet. The first volunteer is a 24-year-old female, the pathway and velocity of her training presents by blue line in Fig. 5.1 and Fig 5.3, the second volunter is a 25-year-old male, his training data shows by the red line in Fig 5.1 and Fig 5.3, the last one is a 23-year-old female whose data recorded by the green line in Fig 5.1and Fig 5.3. Designed path presents by a black line in Fig 5.1. Volunteers' routes have the same shape as designed, but the difference is also obvious, it can be seen that the second volunteer is better at turning, the route is smoother, and there is no repeating or intersecting route in the comparision of three route maps. The average speed of these three volunteers are: 0.15km/h, 0.2km/h, 0.15km/h, the maximum speed is 0.35km/h, 0.42km/h, 0.38km/h as shown on the dotted line in Fig 5.3. In additional, the male volunteer is faster than other volunteers, completed the training in less time, the step frequency of every volunteer can be calculated from the data in Table 5.1, their step frequency are 1.2steps/s, 1.5steps/s, 1.2steps/s, the male volunteer has ligher step frequency. The second volunteer has better motor capability. Set the map's left top corner as origin of coordinate in meters, maze entrance is in (0.1, 0.35) and maze exit is in (3.8, 0.6). There are five distinct speed drops in the three velocity lines, because there are five necessary turns in the pathway. When the direction of the user's movement changes, his speed will drop accordingly, and it is easier to speed up while user walking straight.

Volunteer	Steps	Score	Time/s	Motor capability
1	74	10	62	Good
2	78	13	53	Excellent
3	75	11	64	Good

Table 5.1 Test Results of three volunteers

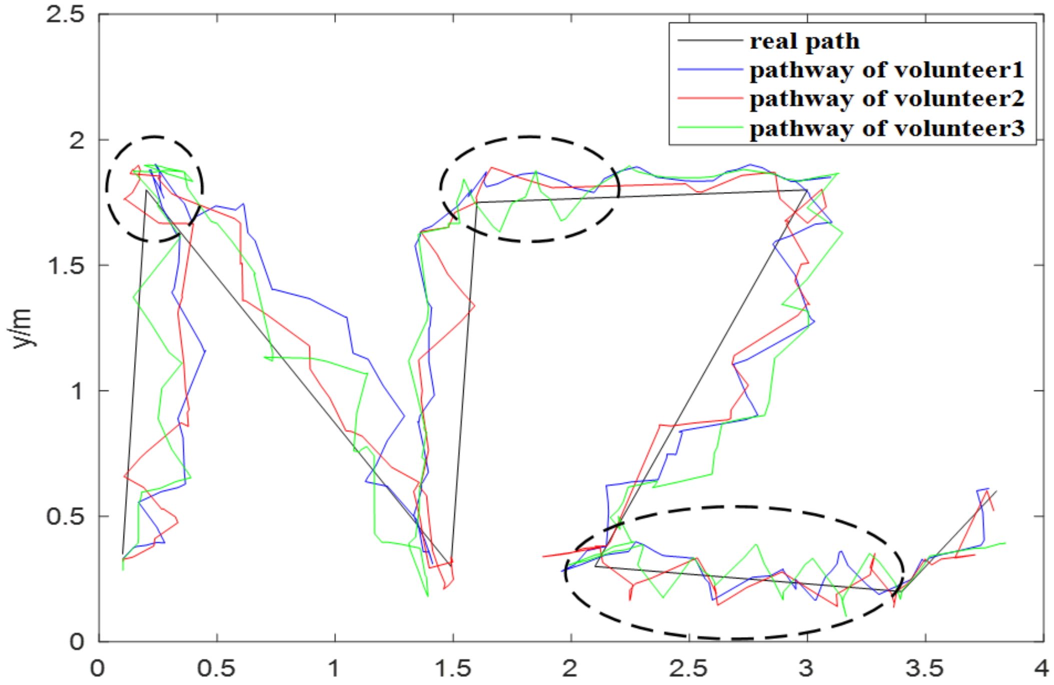


Figure 5.1 The pathways of the three volunteers

In terms of path offset, the error between real path and volunteers' path shows clearly in Fig 5.2, the value of error is the difference between volunteers' coordinate and ideal coordinate. Table II lists max error, standard deviation and variance of each volunteer. Value of variance presents the repeatability of error, means the first volunteer has more consistent route.

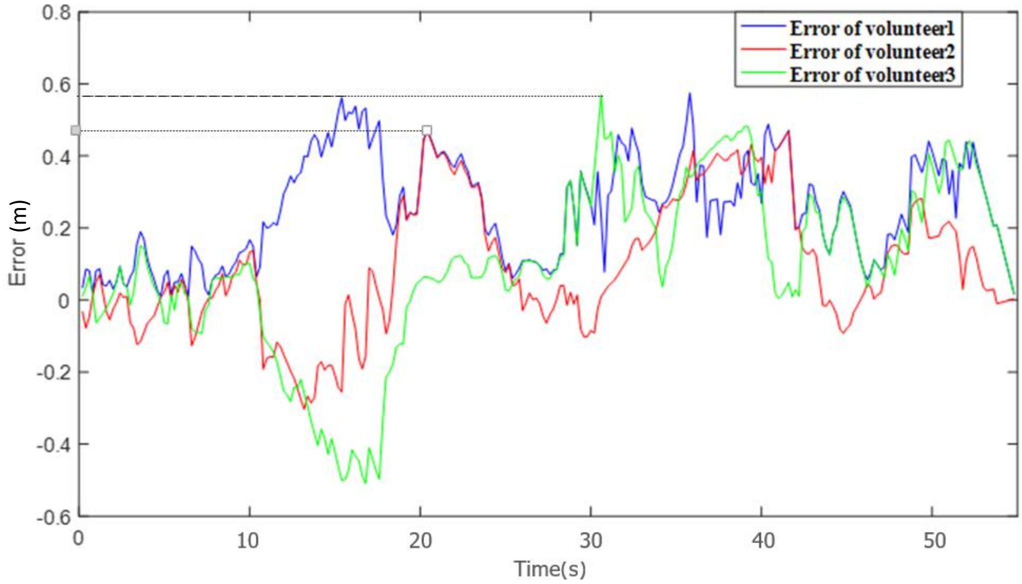


Figure 5.2 The pathway error of three volunteers

Volunteer	Max Error	Mean	Variance
1	0.588	0.154	0.021
2	0.476	0.095	0.033
3	0.587	0.096	0.054

Table 5.2 Path Error of Three Volunteers

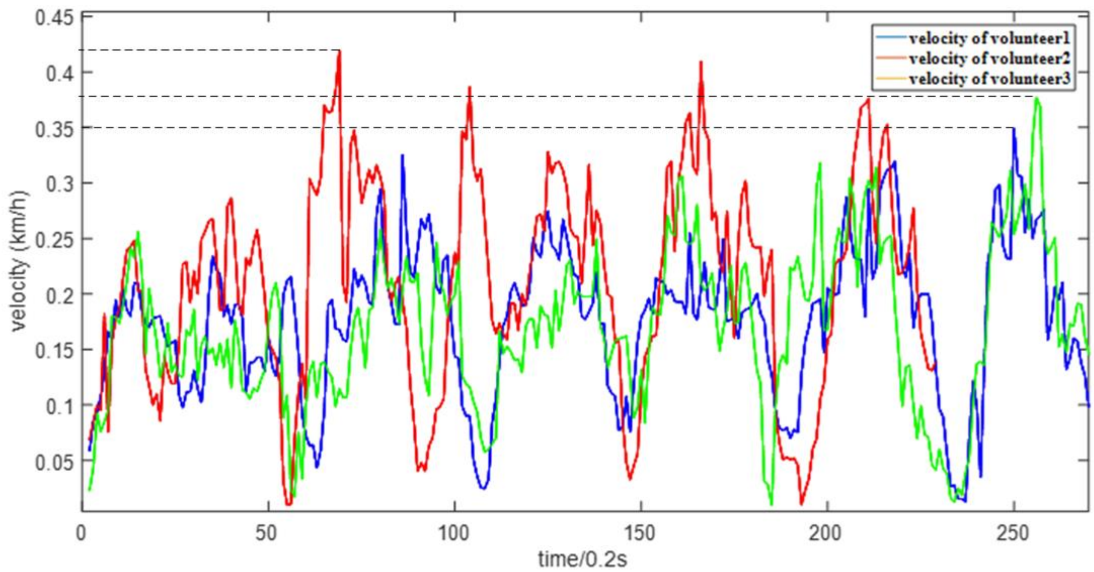


Figure 5.3 The walking velocity of three volunteers

The value of GSR demonstrates users' pressure status while training, the value of GSR will improve when user encounters difficulties in the training process, such as turning in the maze. Fig 5.4 shows the stress status of three volunteers while maze training.

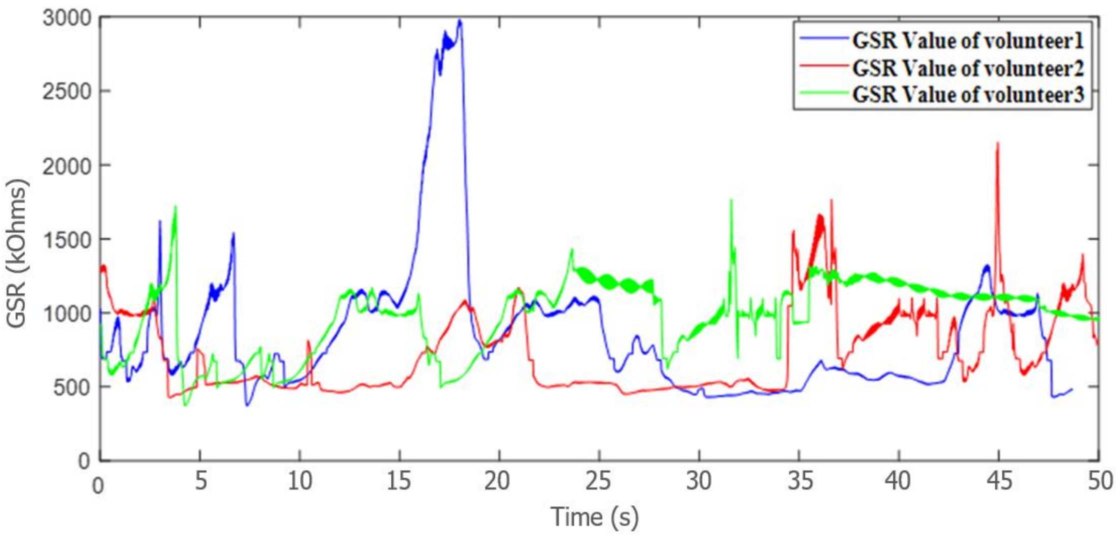


Figure 5.4 The GSR value of three volunteers

Based on the test results, the male volunteer completes the training in the shortest time, and more approach to the designed path; the third volunteer is the slowest and has a bit deviation on localize exit. In terms of motor capability, the second volunteer has smoother route which means better balance and better turn, the first volunteer has repeated path in the first corner (circle in Fig 5.1) means turning action should be strengthened, the third volunteer has many short polygonal lines in her pathway which presents shakes during the training based on the ellipse part in Fig 5.1.

5.2 Analysis of the Value of GSR

Changes in skin electrical conductivity can be caused by unconscious changes in body temperature regulation or emotional arousal. A GSR sensor measures the subtle

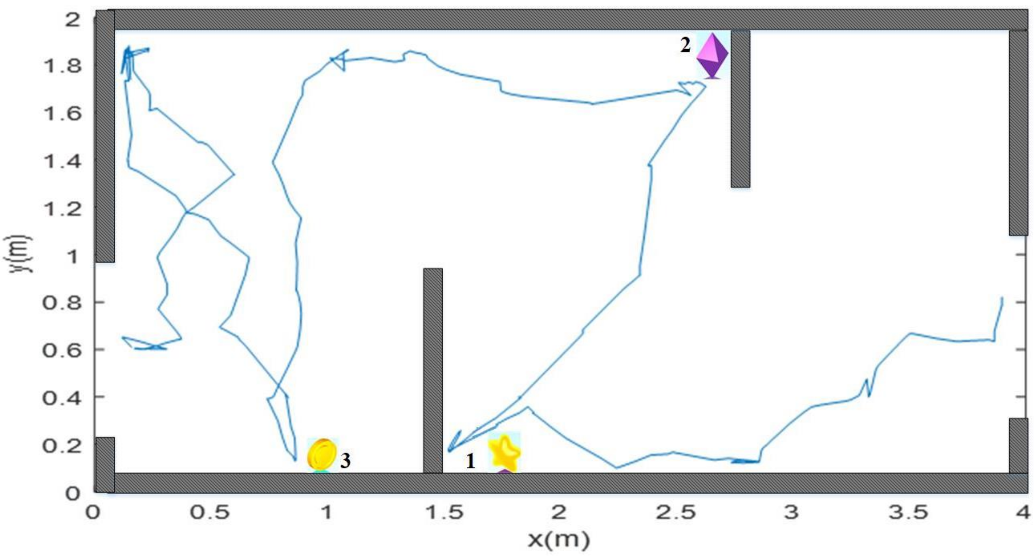


Figure 5.5 Planform of Physio Maze with a User Pathway

changes in skin conductivity, this means a small emotional fluctuation of the user could be measured. Both positive and negative emotions can cause GSR feedback, make the skin conductivity increased, GSR represents the intensity of users' emotion [51].

During the training period, users' emotion may fluctuate influenced by some instructions, such as collect the objects and make turns. GSR is a physical parameter that could represent the stress level. Record the value of GSR in real time makes the relationship between user' emotion and physical training clearly. Fig 5.5 presents a planform of the rehabilitation game including a user pathway, the virtual object in the maze has the same position as marked below, the rectangles that colored in dark grey are the walls making up the maze. The user walks into AR training scenario from entrance (right side of the map) which designed with 80cm width in order to allow users enter and exit (left side of the map) smoothly, arrows and objects are used to guides user out of the maze. Each marked instruction was recorded to analysis users' motion

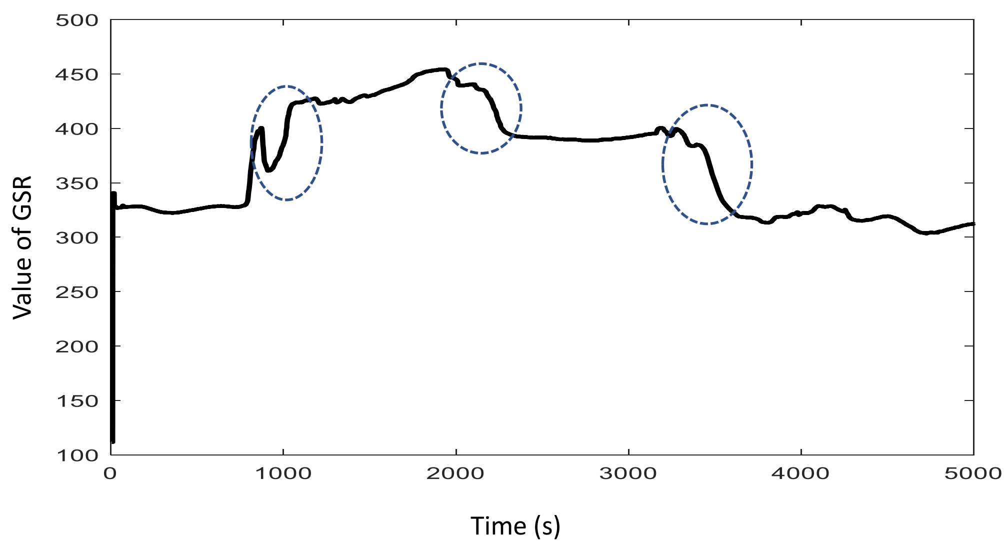


Figure 5.6 Value of GSR while user test

status and emotional status.

The value of GSR is changing while patient collect the objects (see Fig 5.6), there are three obvious fluctuations on the value of user's GSR, shows on the three circles in Fig 5.6, corresponding three instructions during the game, collections makes patient immerse future change the value of GSR and the first collection play biggest role in user's emotion.

5.3 Simulate of Stroke Patients

A simulate test of stroke patient is implemented in this part. The volunteer simulates patients characterized by one sidebody motion impairement. Shimmer is tied to the wrist in the unmoveable side (left wrist). The first element is the pathway, comparison Fig 5.7 and Fig 5.8, stroke patient shake his body and has more z-shaped route, the repeated routes are to collect the objects (see the elliptical circles in Fig 5.7 and Fig 5.8), circle 1 and circle 2 corresponding same objects. Same situation reflected on the time and speed (see Table 5.3).

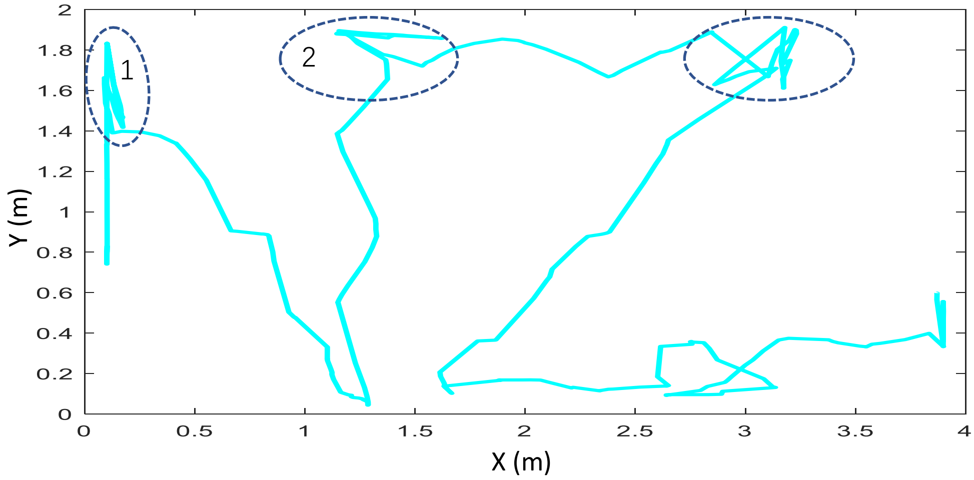


Figure 5.7 Pathway of healthy Volunteer

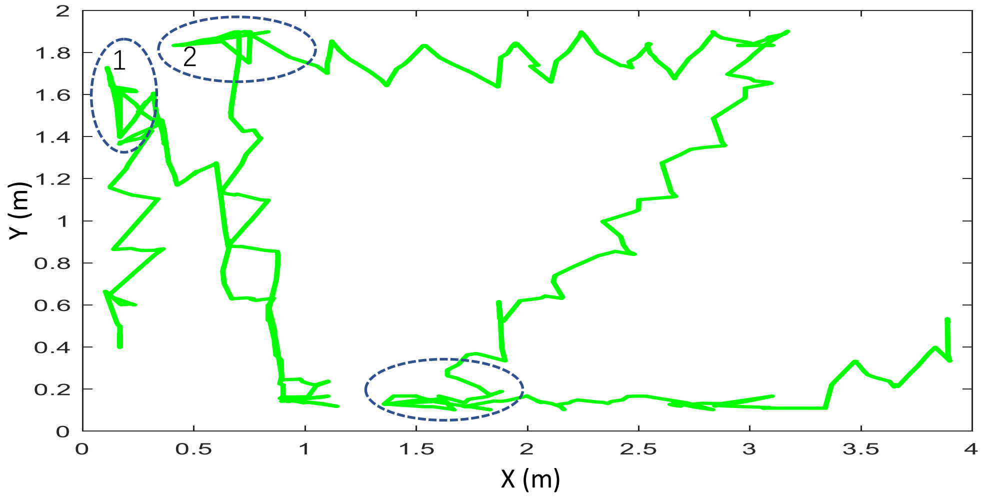


Figure 5.8 Pathway of stroke Volunteer

Stroke patient has slower speed which is almost a half of healthy people, more time required in the game duration and steps, that demonstrate stroke patients need more walking training and gait training, but the objects are easy to collet both for healthy tester and stroke tester.

	Max speed (m/s)	Average speed (m/s)	Duration	Steps	score
Healthy	0.75	0.38	43	47	6
Stroke	0.38	0.20	85	70	6

Table 5.3 Result of health and stroke tester

Shimmer 3 has an embedded IMU which could monitor patients' hand rotation and swing amplitude, it could quantitative training parameters when tied on no movement side of the patients. The comparison between hand's gyroscope in X, Y, Z axis are presents in Fig 5.9 and Fig 5.11.

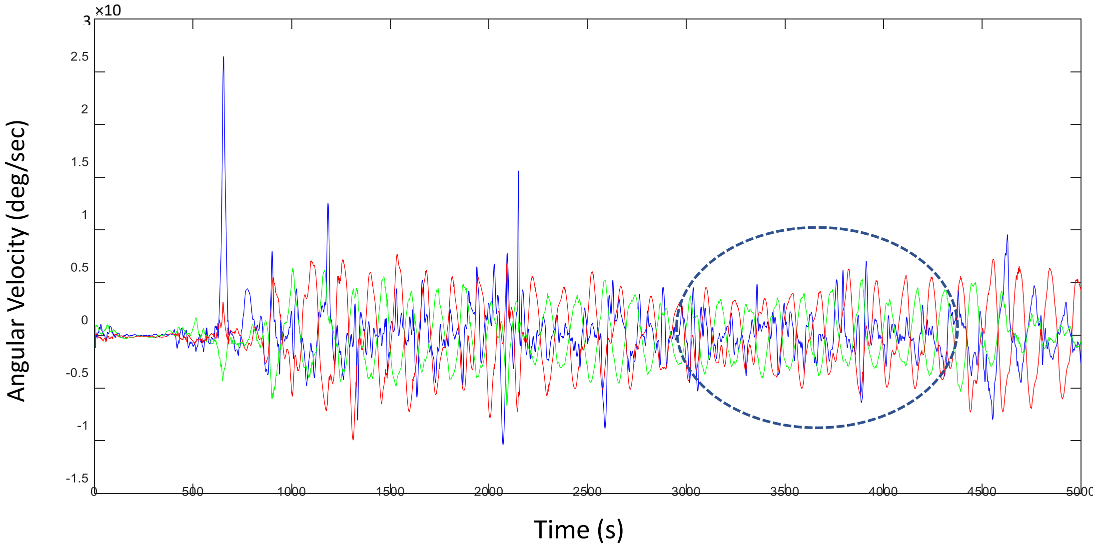


Fig 5.9 Healthy tester with gyroscope on the left wrist in X, Y, Z axis

In Fig 5.9, blue, red, green line means the gyroscope in X, Z and Y axis, the value represents angle of rotation in each direction. Comparison with Fig 5.9, Fig 5.11 presents obvious hand rotation in X axis, which demonstrate the symbol of stroke, hand inversion while walking. It is more prominent in the magnified view (Fig 5.10 and Fig 5.12) of Fig 5.9 and Fig 5.11. The angle of the hand in X-axis during normal walking does not exceed 50 degrees, and the angle of the hand inversion of the stroke patient is about 90 degrees during the walking which at an abnormal level.

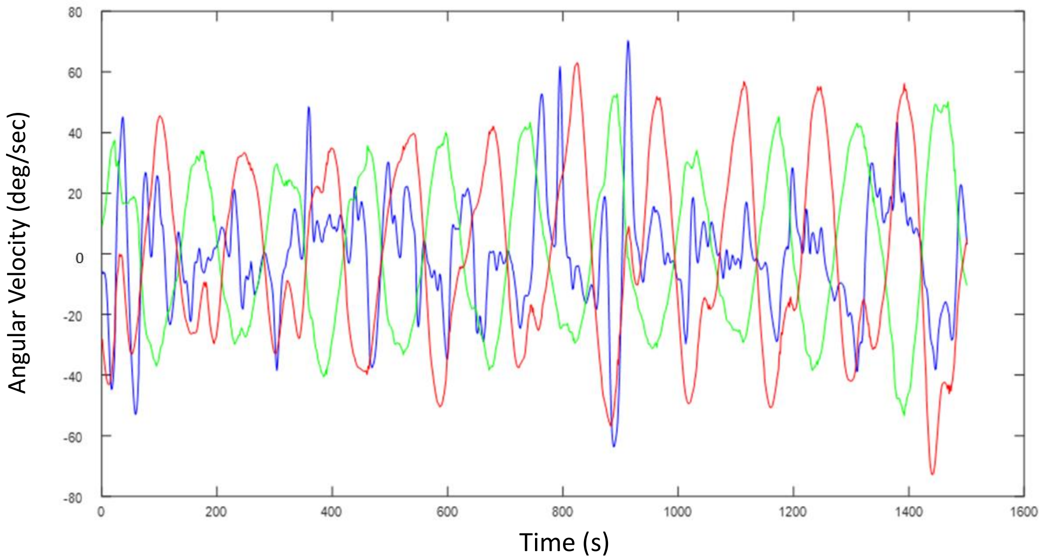


Figure 5.10 Magnified View of health tester left wrist gyroscope in X, Y, Z axis

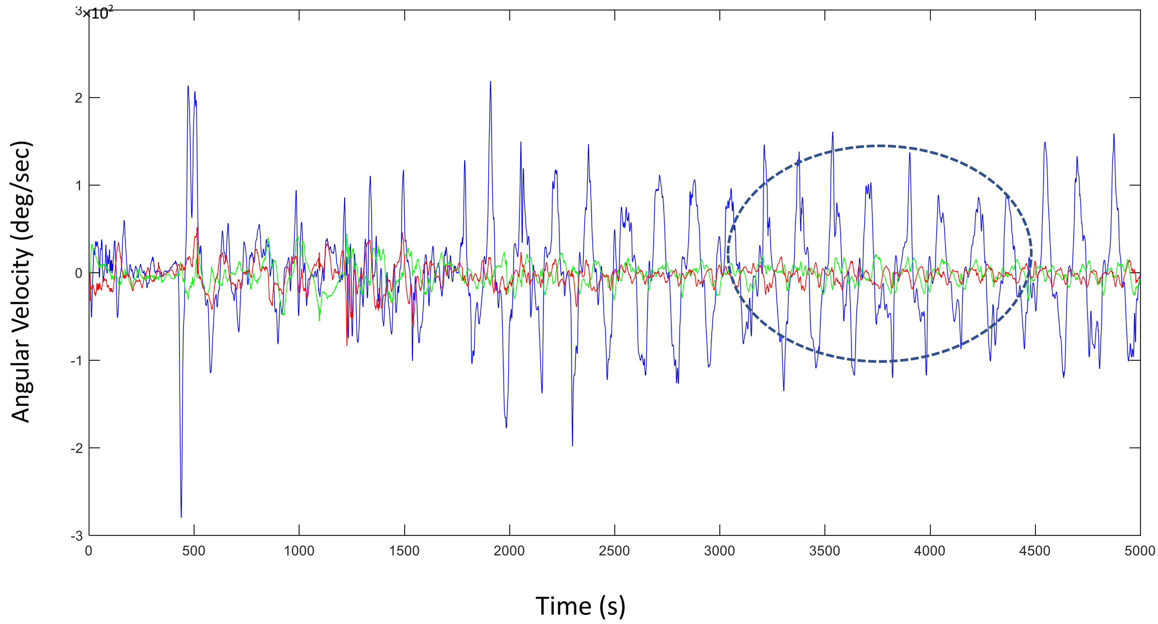


Figure 5.11 Stroke patient left wrist gyroscope in X, Y, Z axis

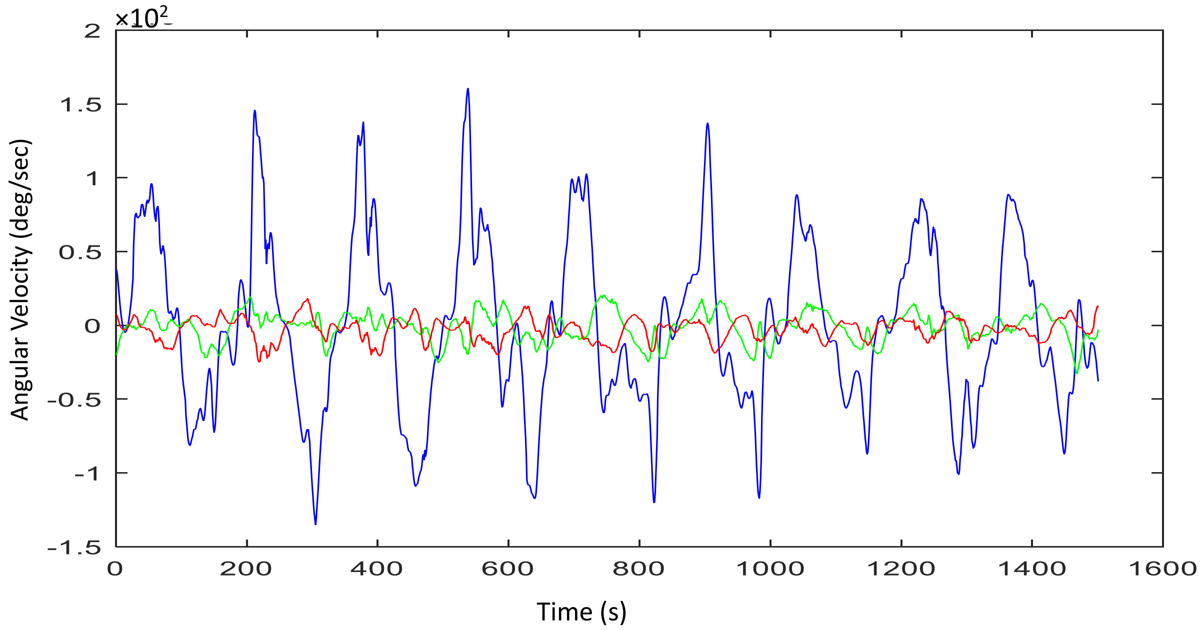


Figure 5.12 Magnified View of Stroke patient left wrist gyroscope in X, Y, Z axis

5.4 Data Visualization in Web Application

Web application provides scientific evidence of patients for physiotherapist, such as heart rata value and GSR value in per second, which is benefits to check historical data, make diagnosis and future rehabilitation plan. Followings shows the data visualization in web application. Fig 5.13 is the heart rate of one patient during 14:44 to 14:48 in the 16th oct, 2019. This is a line chart and when place mouse on the line, information of current time and heart rate is presented. Green line represents the heart rate value, -1 is occurs because move of patients brings the possibility of poor contact.

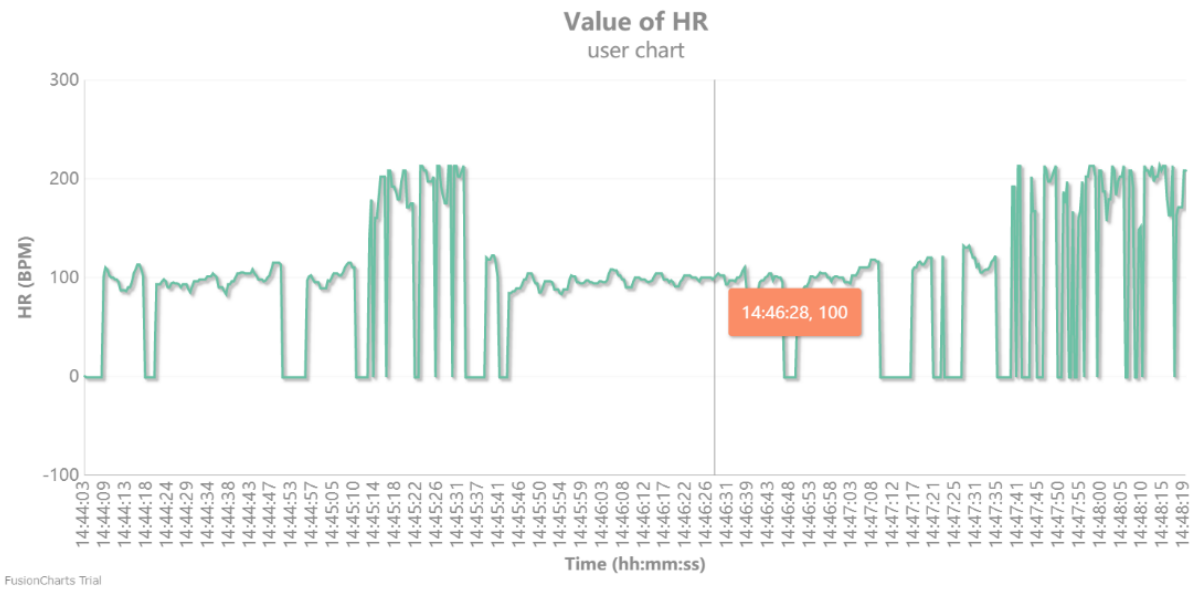


Fig 5.13 Patient’s value of Heart Rate

Fig 5.14 shows the value of galvanic skin response in the same duration, value of each point on the line presents when place mouse on the point. Emotional status causes variation of GSR.

Fig 5.14 Patient’s value of GSR

Fig 5.15, Fig 5.16, Fig 5.17 illustrates the accelerometer in X axis, Y axis and Z axis at the same duration, physical therapist could check the value of various at a specific time, the trend of line chart present a motion characteristic of wrist rotation and physical health status of patient during the training.

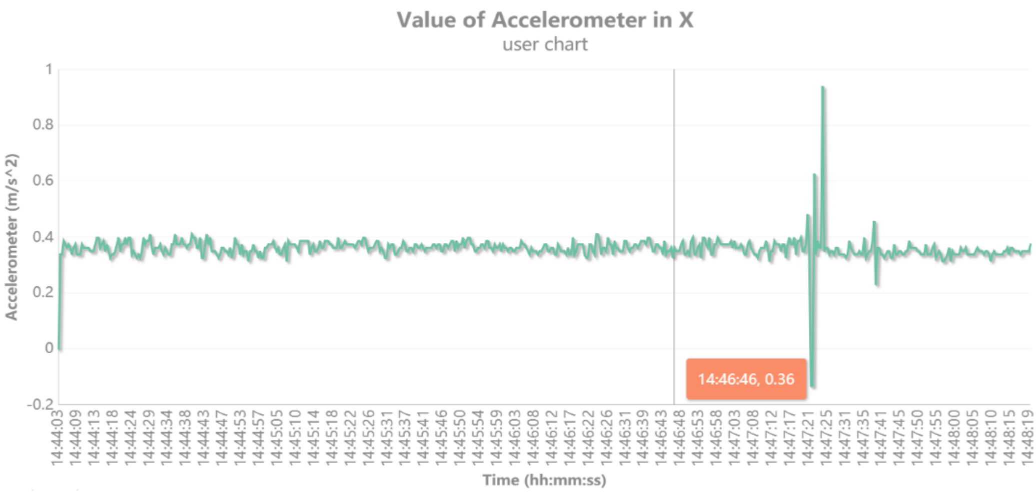


Fig 5.15 Patient’s value of Accelerometer in X axis

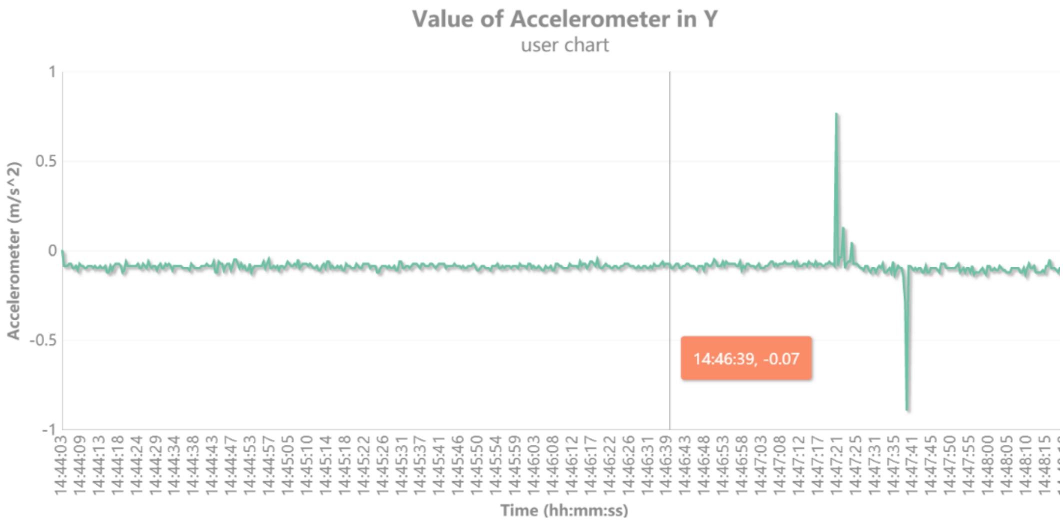


Fig 5.16 Patient’s value of Accelerometer in Y axis

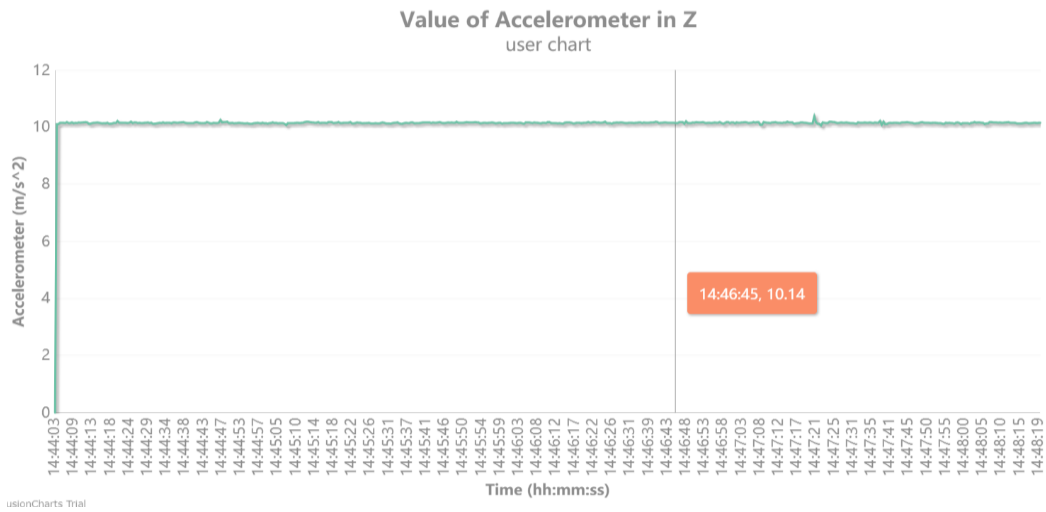


Fig 5.17 Patient’s value of Accelerometer in Z axis

Chapter 6 - Conclusion and Future Work

6.1 Conclusions

This dissertation presented a system that was developed to be used in the physiotherapy area. The system permit the gait training, and physiological health status monitoring for stroke patients. This system combines AR physical rehabilitation system and Internet of Things (IoT). The system can measure the gait speed and number of steps using the sensing floor. Additionally, a Shimmer sensor is used as health status monitor. The data is uploaded to Firebase then used in AR scenario developed by unity project. Firebase is an important medium combining sensors and mobile applications. The adoption of physical monitoring device is a highlight of this study, based on the data measured by smart sensors, the rehabilitation is more effective. In addition, a web application is designed and developed for the physiotherapist who can search their patients and obtain the visualization of analyzed training data.

Regarding the development phase of the project, a study was initially undertaken to understand how augmented reality applications should be created and adapted to the needs and preferences of each patient. Subsequently, the AR scenario was developed to respond to these needs and preferences. The AR scenario was developed through the Unity 3D game engine. The designed technology is aiming to help stroke patients recover and improve professionals' work in their area by effective monitoring of patients and objective assessment of the results of physical therapy sessions. The system provides two main tools, an application that allows patients to perform therapy exercises by playing the AR game and another for the physiotherapists to visualize the results and manage their patients. All the measured data during the training are stored on a real time database, allowing communication between the two applications.

The interactive experience of Augmented Reality brings benefits to patients avoiding to repeat limb motion actions, which increases patients’ motivation. Based on the physical parameters that are recorded during the training, a therapy plan could be adjusted according to the data feedback. An optimized training plan may reduce the recovery period and improves the efficiency of rehabilitation training. The mobile application has potential in physical rehabilitation of stroke patients, both younger and elder. Rules and environment of application are flexible to implement various therapy plans. Physical measurement data is provided to therapists and recorded in Firebase Database as useful evidence in treatment.

Through the head-mounted 3D display device adds virtual elements to the real world, and the smart sensors provide information about the patients' motion characteristics. Additional physical monitor sensors provide the scientific data foundation not only for physiotherapists but also for patients, suitable for the patient-centered concept of physical rehabilitation. This research helps the patient to get rid of the heavy rehabilitation equipment, brings convenience to the physiotherapist. The patient can carry out gait training by himself the recorded information is used to perform comparisons with the current status. At present, the tests of this system have been almost completed. The data from test volunteers are recorded in the database, which is very valuable for future data analysis.

6.2 Contributions

This dissertation's main contributions are:

- Development of iOS application based on Unity 3D, providing gait training for stroke patients;
- Design and development of a web application, implement filter data and data visualization;
- The implementation of AR rehabilitation system based on iPhone and depth sensor, that it is part of patient headset, that collects the distance between sensor and environment objects then process and generate a model of real environment which can be used in unity project;
- Integration of biomedical sensor and smart carpet as part of AR system that assures patients' real time health status monitoring as so as, fall detection;
- Development of data storage system on Firebase technology;
- Publication of one paper in IEEE conferences: Yu Jin, João Monge, Octavian Postolache and Wangqiang Niu, "Augmented Reality with Application in Physical Rehabilita tion", ISSI 2019, International Symposium on Sensors and Instrumentation in IoT Era.

6.3 Future Work

This project still has new features and there are several improvements that can be done regarding the capabilities of the system. Thus, it can be mentioned:

- Perform an extended study on regarding the selection of the movements that are more appropriate for gait training and stroke rehabilitation. Considering a greater variety of training plans by the study;
- Make the gait training game more adaptable to patient characteristics increasing the game personalization;
- An inertial measurement unit (IMU) module can be considered to place on the patient's waist, to monitor the balance state of the patient while walking or standing;
- Multi-aspect analysis of the data that obtained by smart sensors, perform an improved, extensive training plan according to each patient and physiotherapists.

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Appendix A – Articles

Article: **Augmented Reality with Application in Physical Rehabilitation.**

This article has been accepted and presented in ISSI 2019 Aug 29-30,2019, Lisbon, Portugal, 2019 International Symposium on Sensors and Instrumentation in IoT Era Conference.

Augmented Reality with Application in Physical Rehabilitation

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***Abstract*— Gait training is a significant part of physical rehabilitation for patients that suffer stroke events. AR (Augmented Reality) represents a promissory solution for training assessment providing information to the patients and physiotherapists about exercises to be done and the reached results. The paper presents an IOS application developed in unity 3D for stroke patients, immersing patients in a mixed environment that combine real-world and virtual objects. The human computer interface is materialized by an iPhone, head-mounted 3D display and a set of wireless sensors for physiological and motion parameters measurement. The position and velocity of the patient during the gait training is recorded by a smart carpet that includes capacitive sensors connected to a computation unit characterized by Wi-Fi communication capabilities. Several AR training scenarios and the corresponding experimental results are included in the paper.**

***Keywords*—Augmented reality, physical rehabilitation, physiological parameters, motion sensors, localization sensors**

I. Introduction

More than 6 million of people that suffer stroke events are requiring physical rehabilitation services. Traditional physical rehabilitation has the following shortcomings: heavy physiotherapy assessment equipment; high costs associated with long therapy periods and the need of fulltime physiotherapists; lack of objective evaluation of rehabilitation processes, less or no feedback to the patients, no data record and no data analysis.

Smart rehabilitation technologies can bring observable parameters and more accurate feedback elements on treatment [1]. Therapy application with the AR system was widely used in body rehabilitation and physical exercise in recent years. A training system for hand rehabilitation which proposed in [2] enables patients to simultaneously interact with real and virtual environments. A serious game based on Augmented Reality in [3] also has good result in the upper-limb rehabilitation. Users with AR rehabilitation systems get rid of heavy medical equipment, get more relax in the training process. Due to the diversity and flexibility of therapy application, function and metrics could extend according to the requirement of rehabilitation, which demonstrates the efficiency and convenience of the AR system.

Augmented Reality (AR) is the extension of Virtual Reality (VR). Different from VR, AR creates an environment including both real-world and virtual objects [4]. In AR scenarios, users could perform actions with the assessment devices. Thus, the user could see an augmented scene characterized by information of real world and additional virtual information at the same time, a very known example, being Pokemon Go [5]. The upper limbs training for stroke patients in [6] presents a virtual cup on the table and lets patients do corresponding actions, is a good template on integrating AR and physical rehabilitation. The principle of AR is traditional pattern recognition technology: some real information is marked in the necessary objects, through computer and other technologies, followed by the simulation and superimposition, the virtual information is applied to the real world, perceived by human senses [7]. AR bring user a sensory experience, the real environment and virtual objects are superimposed in real time on the same picture or space, becoming augmented effects that we see.

Over the past few years, AR has evolved to the stage where it can be efficiently adapted in many kinds of electronic devices [8]. In this context, this paper promotes a novel method for stroke patients. Based on IOS application developed in Unity 3D that aims to assist patients on walking training in a portable and cost-efficient manner. This application uses Google VR tools to localize patients during the motion rehabilitation exercises, let patients walk into the AR scenario the indoor localization being provided by a smart carpet. The stress level and cardiac condition of the user is obtained using wireless smart sensor that measure galvanic skin response (GSR) and heart rate. The rest of the paper is structured as follows: Section 2 presents a brief summary of related work in the field of augmented reality applications for physical rehabilitation. The whole system description is presented in section 3. Section 4 describes the walking training application, shows some details in design process and the aspects that were considered throughout the development process. Results demonstrates in Section 5, including users' information during the physical rehabilitation. Finally, discussion and conclusion are considered.

II. Related Work

Impairment of limbs function is prevalent among stroke survivors, motivating the search for effective rehabilitation therapy [9] for reduce time. Augmented Reality features bring benefits to people with physical disabilities. Funny and unburdened therapy system could achieve high efficiency of physiotherapy sessions that presents higher acceptance from the patient side. Limbs motion therapy is an indispensable part of the treatment to improve muscle strength and dexterity [10].

Currently, researches in physical rehabilitation based on AR system utilize many kinds of somatosensory devices. Somatosensory sensors are a type of human shape monitoring device, such as Microsoft Kinect, Leap and Myo. Kinect provides great body movements recognition technical [11], Leap and Myo improve the hand gesture recognition performance [12][13]. A training environment based on augmented reality and assistive device for post-stroke hand rehabilitation was proposed by Xun Luo in 2005 [9]. Post-stroke usually weakness on their upper limb, trembling and lost the ability to catch objects stably. In this case this research aiming at improving patients' standard of living, exercising their upper-limb muscle and helping patients recover their motor ability. The user wears a head-mounted display, uses a glove with an orthosis to complete grasping actions. The AR system bring immersive experience to the patients. But one considering problem is that heavy devices bring corresponding difficult to patients' arm.

NeuroR [14] is a system for motor rehabilitation after stroke, similar with [15][16], it combines AR with psychological exercises. Patients can visualize themselves and their surroundings with NeuroR, just like standing in front of a mirror. The virtual upper limb is superimposed on its true upper limb and the true upper limb is removed from the virtual image to avoid phantom upper limb visualization. It developed a series of proposed exercises, including low-complexity exercises such as shoulder flexion, shoulder abduction, shoulder adduction and wrist extension, as well as high-complexity exercises such as stretching and grasping the target, dragging it to the desired position and releasing it. NeuroR can be used to check the effectiveness of visual stimulation and motor imaging training in hemiplegia rehabilitation. But in terms of information feedback, NeuroR can't provide real-time data in measured physical characteristics and accuracy of actions while this IOS application can. NeuroR training patients by repeating mechanical actions while patients have more options in this gait training.

Ana Corrêa et al. reported in [17] propose the usage of AR tool for upper limb rehabilitation considering Occupatonal Therapy sessions. For this study, they selected Duchenne Muscular Dystrophy patients with physical and functional limited abilities let the patients carry out actual experiments and analyzed the results of the experiment. The results are presented in the form of a table. But it did not step future by analyzing patient data in the rehabilitation process.

YouMove presented a system in [18] that allows users to record and learn physical movement sequences. The recording system is designed to be simple, allowing anyone to create and share training content. A large-scale augmented reality mirror is used in this training system. YouMove system trains the user through a series of stages that gradually reduce the user's reliance on guidance and feedback. Motor rehabilitation is a traditional way to help patients rid away disorder.

Most of the above studies require heavy equipment on patients' limbs, the rehabilitation training focus on repeating easy mechanical actions and need a specific therapy environment. In terms of training process, no physical monitoring data recording and feedback. In this study, the application of the sensing floor localizes patients and obtained their motion characteristics such as velocity and steps. Comparing with repeating simple actions, bridge headset makes them feel immersive and relax. It is very interesting and helpful device in motor rehabilitation of stroke patients.

III. System Description

The block diagram of the walking training system is presented in Fig.1.

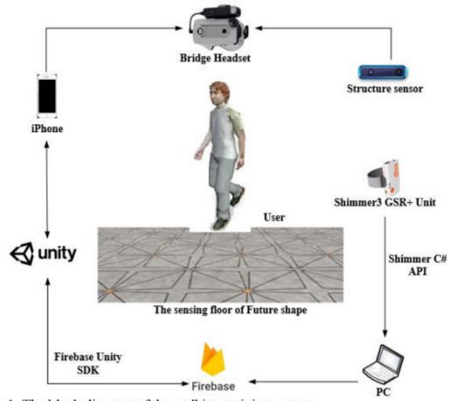

Fig.1. The block diagram of the walking training system.

A. *System Architecture*

To improve patients' muscle strength and walking balance, patients wear a bridge headset and a wireless sensor (shimmer3) on the wrist. The patient is walking in a virtual maze or on a virtual water surface. Steps, speed and game score are recorded in real time using the IOS application developed by Unity 3D and launched in iPhone. Patients' heart rate and GSR are measured by smart sensor, that transmit the data to a PC, then uploads the data to Firebase project with public rules by shimmer API. Finally, unity application reads the values of physical metrics associated with patient state.

B. *Depth sensor*

A depth sensor (Structure sensor from Occipital) is a part of AR equipment for physical rehabilitation assessment. The depth sensor could be connected with iPhone or iPad and consists of a laser-emitting diode, infrared (IR) radiation range projector, IR sensor and the iPad's or iPhone's RGB sensor can send data to a system on a chip for processing[16]. Structure sensor gives to the mobile device the ability to capture real world in three dimensions that is denominated virtualization of real environment.

Structure sensor gives also to the user the ability to build mobile applications that interact with the three-dimensional geometry of the real world. As shown in fig.2 [19], Structure sensor will give the user the depth information. When the target point (black dot) is projected at depth Z on plane farther from the IR speckle pattern reference plane (green dot). The blue circle shows the location of the IR camera, *b* express the distance between IR projector and IR sensor equal 65mm, *c* express the distance between IR sensor and RGB camera. IR projector shoot a red light to an object, then the IR sensor will receive the reflected light, so that the depth will be measured by the angle of the reflected light. X_{ref} is the horizontal distance of the reference point to the IR projector and X is the horizontal distance of the actual point being measured from IR projector. Z_{ref} is the depth of the point on the reference pattern, Z is the actual depth to the target point, d is the distance between pattern u and u_{ref}.

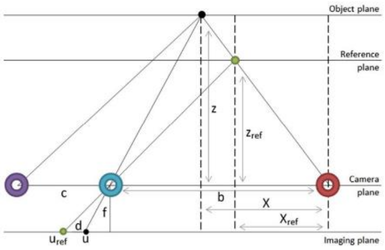

Fig.2. illustration and depth measurement of structure sensor.

This model demonstrates the possibility of converting 2D points into 3D coordinates, future obtaining the depth information measured by the 3D scanning sensor [19].

The Bridge Headset that is used by the patient as interface with AR scenes is composed of structure sensor and iPhone. The components of AR Bridge Headset are shows in Fig.3, Structure Sensor is fixed at a sensor mount while iPhone at a phone enclosure. Bridge relies on precise calibration between the iPhone's color camera and Structure Sensor to create immersive experience. A glass lens doubles the iPhone's field of view to 120° in the bridge which create a wide view of the world. Bridge Engine fuses this with the depth data from Structure Sensor and presents a stereo view [20]. Volume of iPhone could be controlled by external buttons. Bridge headset combine iPhone and structure sensor flexibly and bring immersive experience to users. Weight distributing side straps reduce the pressure on the head of the user.

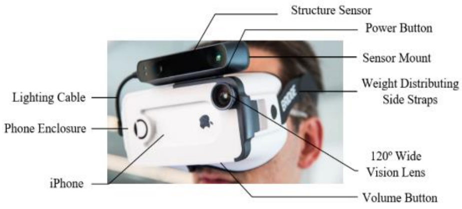

Fig.3. Architecture of Bridge Headset.

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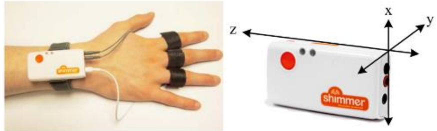
C. Shimmer Sensor

Shimmer 3 GSR+ Unit is wearable physiological parameters monitoring device based on MSP430 microcontroller (24MHz, MSP430 CPU), wireless communication transceiver and Bluetooth Radio – RN-42, the power supply is expressed by a 450mAh rechargeable Li-ion battery [21]. The core functionality of Shimmer is extended via a range of daughterboards which provide 3-axis accelerometer, 3-axis gyroscope, 3-axis magnetometer and physiological information [22]. The Shimmer3 GSR+ (Galvanic Skin Response) Unit (Fig.4) that is used in this application provides connections and preamplification for one channel of Galvanic Skin Response data acquisition (Electrodermal Resistance (EDR) Measurement /Electrodermal Activity (EDA). The GSR+ Unit is suitable for measuring the electrical characteristics or conductance of your skin, as well as capturing a PPG signal and converting it to estimate heart rate (HR), using the Shimmer ear clip or optical pulse probe.

The GSR evaluation is used for stress measurement on patients during the rehabilitation period. Connection between users' hand and Shimmer according to Fig.4a. The Shimmer GSR+ sensor monitors skin conductivity using two reusable electrodes attached to two fingers of one hand. The coordinate system shows in Fig.4b. Measured data of GSR, angular velocity and acceleration are stores and uploads to Firebase Real-time Database.



a) b)

Fig.4. Shimmer Sensing (a. Connection between Shimmer and user b. Coordinate system of Shimmer)

Shimmer has an embedded gyroscope module SR47-2-0 which could monitor angular velocity and acceleration in each direction. Gyroscope indicates the motor state of patient's limb, the rotation of Shimmer presents patients' hand rotation and when it rotates along a specify axis, the corresponding curve will change dramatically. Considering walking balance has a certain relationship with the amplitude of limbs. In Fig.5, The angular velocity of user's hand in X, Y, Z axis are presented by red, blue, silver lines, the uniform frequency demonstrates speed of movement is relatively stable. The value of angular velocity is almost less than 50 degrees and user's arm swing in a constant speed shows good motor capabilities.

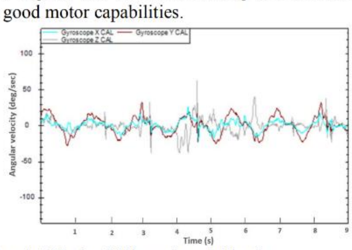


Fig.5. Angular Velocity of Shimmer in each Direction.

D. SensFloor

SensFloor, from Future Shape, is a large area capacitive sensor floor, it can be installed beneath any kind of flooring-invisible and discreet [21]. This system can monitor the user's direction, speed, and position and calculate the number of persons on the floor. One significant function of SensFloor is to detect the fall, which bring safer physical therapy environment. Persons walking across the floor (as shown in Fig.6) trigger signals which are sent wirelessly to a transceiver, an embedded Raspberry pie could transmit measured velocity and steps to Firebase by Internet, further read to the unity project and shows in the training scenes.

Fig.6 The Sensing Floor indoor localization system.

IV. Gait Training Application

An IOS application named "Fantasy gait training" using Unity 3D in conjunction with bridge engine SDK was developed. The IOS app provides a walking training plan for stroke patients. Two levels of complexity were implemented. Level 1 named "Physio Maze" and level 2 named "Physio Path". The first level requires patients to walk in a maze according to a specify route, patients can't touch the wall so it requires well balance ability, this level will be more suitable for younger patients. The environment of the second level is walking area which looks like a water surface, fixed step size required in this level, patients only need to follow the stones and walking with uniform velocity, it is easier and more suitable for older stroke patients.

A. Scanning Real-World and Preparation

Before launching the application, preparations of SensFloor and depth sensor should be completed. Execute a html file to connect smart carpet and application. Then scan started, virtual objects could be added to the real world based on scanning. This work is implemented by structure sensor's camera and iPhone's camera. Structure sensor provides a scanning range from 40cm-3.5m, the scanning process is manipulated by the controller: a board will appear in the space and indicate the following steps, patients scanning the real world according to instructions shows on the board, the scanned 3D Model of real world as a mesh material used in the unity project, then load unity project, virtual objects will show in front of the patient, combine with the real world bring immersive experience to user.

B. Level 1 – Physio Maze

In Fig.7 are presented two scenarios including a 2 by 4 maze, Thus the patients who wear bridge headset will walk in this virtual maze. Considering the motor ability of patients, a specific pathway is given. The signs on the ground are considered to help them complete walking training. Patients will go to the exit following these marks. To improve their ability of balance, users are not allowed to touch the walls during training, otherwise the score decreases by 1. Rings, diamonds, coins, stars are designed to be collected which results in an increase of corresponding score. There are sounds with each step, picking-up of objects, touch to walls, enter and exit the maze. Steps and scores will be shown in real-time on the screen. Timer starts when training started, warning sounds play when user not finished the training in 180 seconds and fall occurs (background music stops and bell rings). Depending on these detailed designs, the engagement of the patients on this kind of tretement is higher comparing with the classical between balance training.

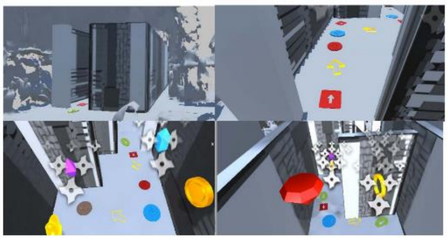


Fig.7. Training Scene Level 1.

C. Level 2 – Physio Path

The second level of the serious game is to provide a walking pathway for elder stroke patients. There is a simple water surface with many stones and a fountain sized in 2 by 4 (shows in Fig.8). The principle of design is familiar with Physio Maze, but the difference is there is no clear direction provided for patients, no clear distance between every two stones (stones play same roles with arrow blocks in level 1). The user is required to step on the stone in each move without order, scores increase with a correct step. Audio plays with game starts and collision occurs.

Fig.8. Training Scene Level 2.

V. Results and Discussion

The information of three healthy volunteers is recorded during walking training. These three volunteers wearing the wearable sensor and walking on the smart carpet. The first volunteer is a 24-year-old female, the pathway and velocity of her training presents by blue line in Fig.9 and Fig.11, the second volunter is a 25-year-old male, his training data shows by the red line in Fig.9 and Fig.11, the last one is a 23-year-old female whose data recorded by the green line in Fig.9 and Fig.11. Designed path presents by a black line in

Fig.9. Volunteers' routes have same shape as designed, but the difference is also obvious, it can be seen that the second volunteer is better at turning, the route is smoother, and there is no repeating or intersecting route in the comparision of three route maps. The average speed of these three volunteers are: 0.15km/h, 0.2km/h, 0.15km/h, the maximum speed is 0.35km/h, 0.42km/h, 0.38km/h as shown on the dotted line in Fig.11. In additional, the male volunteer is faster than other volunteers, completed the training in less time, the step frequency of every volunteer can be calculated from the data in Table.1, their step frequency are 1.2steps/s, 1.5steps/s, 1.2steps/s, the male volunteer has ligher step frequency. The second volunteer has better motor capability. Set the map's left top corner as origin of coordinate, maze entrance is in (0.1, 0.35) and maze exit is in (3.8, 0.6). There are five distinct speed drops in the three velocity lines, because there are five necessary turns in the pathway. When the direction of the user's movement changes, his speed will drop accordingly, and it is easier to speed up while user walking straight.

TABLE I. TEST RESULTS OF THREE VOLUNTEERS

Volunteer	Steps	Score	Time/s	Motor capability
1	74	10	62	Good
2	78	13	53	Excellent
3	75	11	64	Good

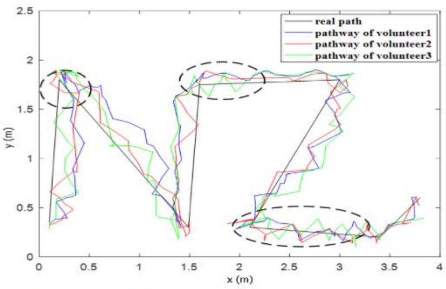


Fig.9. Realpath and Pathway of volunteers.

In terms of path offset, the error between realpath and volunteers' path shows clearly in Fig.10, the value of error is the difference between volunteers' coordinate and ideal coordinate. Table □ lists max error, standard deviation and variance of each volunteer. Value of variance presents stability of error, means the first volunteer has more consistent route.

TABLE II. PATH ERROR OF VOLUNTEERS

Volunteer	Max Error	Mean	Variance
1	0.588	0.154	0.021
2	0.476	0.095	0.033
3	0.587	0.096	0.054

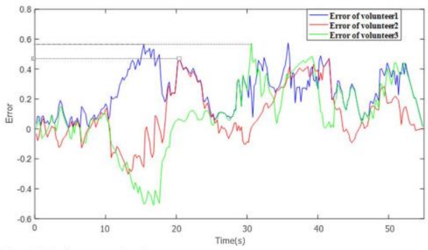


Fig. 10. Path error of volunteers.

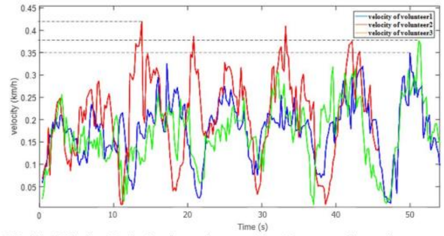


Fig.11. Velocity Evolution for volunteers for AR suported exercise.

The value of GSR demonstrates users' pressure status while training, the value of GSR will improve when user encounters difficulties in the training process, such as turning in the maze. Fig 12 shows the stress status of three volunteers while maze training.

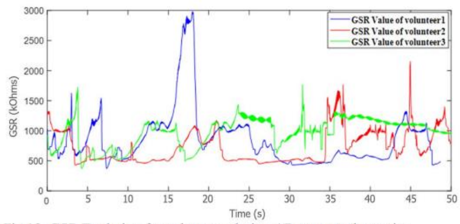


Fig.12. GSR Evolution for volunteers during AR supported exercise.

Based on the test results, the male volunteer completes the training in the shortest time, and more approach to the designed path; the third volunteer is the slowest and has a bit deviation on localize exit. In terms of motor capability, the second volunteer has smoother route which means better balance and better turn, the first volunteer has repeated path in the first corner (circle in Fig.9) means turning action should be strengthened, the third volunteer has many short polygonal lines in her pathway which presents shakes during the training based on the ellipse part in Fig.9.

The interactive experience of Augmented Reality brings benefits to patients without repeating boring limb actions, which increases patients' motivation. Based on the physical parameters that are recorded during the training, a therapy plan could be adjusted according to the data feedback. An optimized training plan may reduce the recovery period and improves the efficiency of rehabilitation training.

This mobile application has potential in physical rehabilitation of stroke patients, both younger and elder. Rules and environment of application are flexible to implement various therapy plans. Physical measurement data is provided to therapists and recorded in Firebase Database as useful evidence in treatment.

VI. Conclusion and Future work

The system combines AR physical rehabilitation system and Internet of Things (IoT), measured speed and physical characteristic by sensing floor and physical monitoring sensor upload to Firebase then used in unity project, shows in the IOS-based training application. Firebase is an important medium combining sensors and mobile application. The adoption of physical monitoring device is a highlight of this study, based on the data that measured by smart sensors, the rehabilitation is more effective.

Through the head-mounted 3D display device adds virtual elements to the real world, and the smart sensors provide information about the patients' motion characteristics. This research helps the patient to get rid of the heavy rehabilitation equipment, brings convenience to the physiotherapist. The patient can carry out gait training by himself the recorded information is used to perform comparisons with the current status. The preliminary tests of this system underline the flexibility and scalability as so as the acceptance from the user part. The data from test volunteers are recorded in the database, which is very valuable for the future data analysis.

New scenarios according to the rehabilitation type will be considered in the future together new metrics suggested by physiotherapists. More tests and a data analysis and visualization GUI including the processed data from the smart sensors represent part of the future work.

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