Development of cost effective Gait mat for assessment of Depression

Thesis submitted in partial fulfillment
of the requirements for the degree of

Master of Science
in
Electronics and Communication Engineering
by Research

by

Mohammad Waqas Wani
2021702018
mohammad.wani@research.iiit.ac.in

International Institute of Information Technology
Hyderabad - 500032, INDIA
April, 2024

International Institute of Information Technology
Hyderabad, India

CERTIFICATE

It is certified that the work contained in this thesis, titled ***"Development of cost effective gait mat for assessment of depression"*** by Mohammad Waqas Wani, has been carried out under my supervision and is not submitted elsewhere for a degree.

Date	Advisor: Prof. Syed Azeemuddin	Advisor: Prof. Raghu Reddy

To *My Family and Friends*

Acknowledgments

My research journey at IIIT has been a great learning experience.I'd like to thank ALLAH for providing me the strength, courage and motivation for this journey. Further, I would like to thank my parents Abdul Jabbar Wani and Zahida Akhter for their constant support and advice. Finally I would like to thank my research advisor Prof. Raghu Reddy (Software Engineering Research Centre) and Prof. Syed Azeemuddin (Centre of VLSI and Embedded Systems Technologies), for providing the research opportunity and directing me in the right direction in my Masters programme. Syed sir helped me back my technical skills and motivated me to come up with innovative ideas to tackle hurdles. His expertise in the field of hardware testing and sensor calibration is what helped me explore the area of embedded systems. He also helped connect with other people working on similar problems as me.Raghu sir guided me to efficiently tackle the problem statements systematically. His style of approaching the issue in a systematic manner and critically analysing the different alternatives helped me a lot to come up with an optimal solution at every blockade of my research. Raghu Sir provided the necessary financial support whenever that was needed and I was very blessed to have that. My advisors constantly inspired me to take the best out of myself and learn new things on the journey. I would also like to thank Prof. Priyanka Srivastava for guiding me in the in the depression part as well as the analysis of the user studies. She was very helpful and give insights on statistics and final results.

I would also like to thank my research mates, PawanKumar Yendigeri, Vivek R and Rohan Lahane, for providing constructive support at every research milestone. I would specially thank my mentor Sai Anirudh Karre for his endless support and guidance throughout my Master's course. I also thank SERC Intern Hemachandra for his individual research contributions. I want to give a shout-out to my friends Mohammad Omama, Mohammad Hozaifa, Arpit Sahni, Srayan Chatterjee and Chetan Mittal. Arpit was very instrumental in helping me out when I was stuck. My research study would not have been possible without all their contributions.

Lastly, I thank IIIT Hyderabad and my research labs, CVEST and SERC, for helping me grow as a reliable hardware engineer.

Abstract

World Health Organization (WHO) estimates that approximately 5% of adults suffer from mental issues related to depression. The rate of increase in the number of patients suffering from depression is significantly higher that the available medical practitioners (specifically psychiatrists). As a result, diagnosis and treatment can be expensive. Alternative methods are being looked into for assessment of depression. In recent times, emerging technologies like Virtual Reality (VR) has been proposed to assess mental health issues in therapeutic settings. VR based applications provide personalized motivation and meaningful engagement for assessment and treatment. External sensors or devices aid VR applications in assessing physiological and behavioural measures related to depression. One behavioural measure is gait i.e., the pattern of walking of an individual. Gait has been identifed as an important parameter that changes with the mental state of a person and gait analysis techniques can be used to aid medical practitioners in identification of depression. The focus of this thesis is on designing and building a low-cost customizable mat for gait analysis.

As part of the thesis, we study the use of Virtual Reality technology in healthcare in general and more specifically on the detection of depression. We performed a systematic literature review, the results from the review helped us to categorise the different physiological and behavioural measures related to depression. We put together a list of VR applications that were used in the assessment of depression and developed a bare minimum checklist to design the scenes within VR applications for diagnosing depression.

We developed a mat using Velostat, a piezoresistive based low-cost sensing material for performing gait analysis. Initially, small size mats were designed and were analysed for crosstalk, full scan time, sensitivity and range. Then, a 1.8 x 1.8 feet mat was designed, and one of the gait parameters was calculated from it and compared with a commercial mat called Sensing Tex with an accuracy of 95%. After multiple iterations, we designed a 10.5 x 2 feet pressure sensing mat and used it to perform experiments. VR applications with scenes that evoke emotions like happiness, sadness and calmness were designed and used in the experiments. The results of the experiments showed positive as well as negative correlations between different gait parameters and their PHQ-9 values. Additionally differences in gait like the differences in stride length, velocity, and cadence were observed in the depressed and the non depressed were using descriptive statistics.However, inferential statistics were not conducted due to the limited sample size.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Consider a world devoid of advancements in science and technology, where traditional methods are still employed in healthcare, sports, farming, and other industries. Given the escalating needs of individuals across various sectors, would these conventional techniques have been able to satisfy the ever-increasing demands and adapt to the rapidly changing world? Most likely not. Consequently, we are compelled to seek alternatives that can cater to the requirements of the present era. As the popular saying suggests, necessity is indeed the driving force behind innovation. Therefore, it would be wise for us to proactively strategize and implement solutions instead of waiting for circumstances to force our hand. Taking into consideration the aforementioned, one of the escalating issues in the contemporary world is depression, a mental disorder that has adverse effects on an individual's emotions, behavior, and cognition. The World Health Organization reports that approximately 280 million individuals globally suffer from depression. The prevalence of depression has significantly increased worldwide since the outbreak of the COVID-19 pandemic. This surge can be attributed to the fact that people were predominantly confined to their homes, leading to a loss of physical connection with their loved ones, among other contributing factors. Consequently, researchers have regained their interest in exploring emerging technologies that can aid in the identification and treatment of depression.

The objective of this thesis is to design and build a technological solution for assessing depression. We propose a cost-effective solution for assessment of people at the borderline stage of depression or in the initial phase. Given the trend of disproportionate increase in patients vs pschotherapists, the traditional method of visiting a psychotherapist is expensive for many people and in some cases a social stigma. We propose a solution, apply and test the devised mechanism for validation.

1.1 Background

1.1.1 Depression

A precise and universally accepted definition of a mental disorder has yet to be established. However, several criteria have been identified to determine the presence of a mental disorder, including statistical rarity, subjective distress, impairment in daily functioning, and societal disapproval. Throughout history, mental illnesses were often attributed to the influence of evil spirits. However, with the advent of the Renaissance, mental disorders began to be viewed as conditions necessitating medical intervention. In the present era, the Diagnostic and Statistical Manual (DSM) serves as the official classification system for individuals with mental disorders. DSM has evolved over the years and currently we are in the fifth version of the DSM. According to DSM-V, Major Depressive Disorder is defined as having at least five symptoms during the same two week period that are a change from previous functioning, with depressed mood and/or loss of interest/pleasure being present. These symptoms include changes in appetite or weight, sleep disturbances, fatigue or loss of energy, feelings of worthlessness or guilt, difficulty concentrating or making decisions, and recurrent thoughts of death or suicide[1] [2].

The onset of depression symptoms typically occurs gradually over a period of days or weeks, although occasionally they may manifest abruptly. Depression is a recurring condition, akin to the common cold. However, it should be distinguished from feelings of grief or sadness resulting from the demise of a loved one or the loss of employment, as in grief, one's sense of self-worth remains intact and the duration is usually brief.

1. **Conventional Methods of assessment of depression** Since the Renaissance, there has been a shift in the perception of mental illnesses, particularly depression, as they began to be viewed from a medical standpoint. This change in perspective led to the adoption of various techniques and approaches to address these conditions. Individuals who exhibited behaviors such as talking to themselves, hearing voices, or displaying other peculiar actions were deemed mentally ill and confined to asylums. However, it is important to note that the criteria for classifying someone as mentally ill varied across different cultures worldwide, ranging from Latin America to West Africa to Malaysia and Southeast Asia.

   The historical context of mental illness diagnosis presented several challenges. In response to these challenges, measures such as inter-rater reliability were introduced. This refers to the degree of agreement among raters regarding the diagnosis. It became evident that although individuals with mental illnesses may not all suffer from the same specific illness, they share certain similarities. Additionally, scientific support was gathered to strengthen the accuracy of the diagnosis.

   In 1952, the official system for classifying individuals with mental disorders was designed. It was called Diagnostic and Statistical Manual of Mental Disorders (DSM). It is currently is in its fifth edition. DSM-V provides psychologists and psychiatrists with a list of diagnostic criteria for each condition, and a set of decision rules for deciding how many of these criteria need to be met [1].

   The conventional approach to diagnosing mental health conditions involved patients seeking assistance from mental health practitioners, such as psychiatrists. These professionals would distribute questionnaires to patients, which they were required to complete. Additionally, psychi-

[1] https://www.psycom.net/depression/major-depressive-disorder/dsm-5-depression-criteria

[2] chsciowa.org/sites/chsciowa.org/files/resource/files/$7_{-d}epression_{d}sm-5_{c}hecklist.pdf$

atrists would pose a series of standardized questions derived from the DSM-V. Subsequently, a comprehensive evaluation of the patient's mental well-being would be conducted, taking into account all the gathered information.

2. **Problems with the conventional methods** For numerous years, the conventional method of seeking assistance from a psychiatrist and receiving a diagnosis has been widely adopted for evaluating depression. However, this approach is not without its flaws. Firstly, the issues associated with this method are closely tied to the criticisms of the Diagnostic and Statistical Manual of Mental Disorders (DSM). One such criticism is the high likelihood of co-occurring disorders within an individual. For instance, individuals diagnosed with major depressive disorder often meet the criteria for one or more anxiety disorders.

   Another significant critique of the DSM is its categorical modeling, which classifies individuals as either depressed or non-depressed, without considering any intermediate states. However, further research has indicated that disorders like major depressive disorder do not simply exist in a binary manner. Instead, there exists a spectrum ranging from mild to severe depression. This categorical model is more akin to the concept of pregnancy, where a woman is either pregnant or not, but it does not accurately apply to major depressive disorder.

   Moreover, the assessment process is inherently subjective and relies heavily on the individual's memory, which introduces numerous challenges in accurately identifying and recommending appropriate treatment. Furthermore, when individuals self-report, they often have a tendency to either overestimate or underestimate their abilities, while informants may misjudge their capabilities due to their own misperceptions or lack of knowledge.

   Irrespective of these factors, one of the major hindrances to the existing detection system lies in its economic implications. Not everyone has the financial means to seek professional guidance from a psychiatrist, and furthermore, there is a shortage of individuals who are adequately trained to address depression.

3. **Emerging technologies for assessment and intervention of depression**

   The development of technologies for assessing depression aimed to shift towards a more objective and measurable approach, as opposed to relying solely on subjective questionnaires. Initially, specific parameters that could be correlated with mental health were identified, and subsequently, devices capable of measuring these parameters were designed.

   Various physiological and behavioral measures have been found to have a correlation with depression or an individual's emotional state. These measures include brain wave activity or **Neuro activity** [2], **heart rate variability** [3], **skin conduction** [4], **eye movement/pupil waves** [5] [6] and **gait** [7]. To measure these parameters, different wearable and nonwearable devices were created, such as EEG sensors, heart rate sensors, skin conductance sensors, pressure sensor mats, and accelerometers.

In addition to these advancements, several other technological approaches have been employed in the assessment and treatment of depression. Examples include online counseling, which involves interacting with a psychotherapist over the internet using interactive voice technology, as well as utilizing short messaging, home-based medical sensors with video conferencing, online health communities for support, wearable devices for monitoring vital signs and physical activity, and Virtual Reality (VR) for detection and intervention [8]. Recent research, as suggested by [9], has highlighted the reliability of gait as an indicator for mental health. Other researchers have also acknowledged this finding.

1.1.2 Gait Analysis

The human body and its sensory organs provide a wealth of information that can greatly assist medical practitioners if collected accurately and transmitted reliably. This data is primarily obtained from two key characteristics of a human being: physiological and behavioral. An example of a physiological characteristic is heart rate, which can now be easily tracked by the general public using affordable smartwatches during activities such as running or going to the gym.

On the other hand, Gait serves as a behavioral characteristic that encompasses sensory, cognitive, and motor functions involved in a person's walking pattern. Gait analysis involves evaluating how the body moves from one location to another [10]. Research has demonstrated that gait analysis has diverse applications in assessing various motor-related aspects. For instance, in the realm of sports, it can aid in enhancing the walking and running techniques of athletes [11]. In the healthcare field, gait analysis is utilized to evaluate specific movement disorders [9] [12], while the shoe industry employs it to examine the interaction between feet and different types of footwear [13].

1.1.3 Methods of performing Gait Analysis

There are primarily four ways to conduct Gait Analysis:

- **Camera** - Cameras are strategically positioned throughout the room, capturing the person's movements as they walk. Two distinct types of cameras are employed: the conventional RGB camera, exemplified by the Canon EOS M, and the RGB-D camera, such as the Microsoft Kinect, which provides depth information. When utilizing an RGB camera, neural network models are employed to identify and monitor the individual, while the Kinect, equipped with a Software Development Kit (SDK), enables gait analysis through the utilization of the person's Center of Mass [14] [15].

- **Accelerometer** - The utilization of an instrument known as the Accelerometer enables the attachment of said device to the participant's body, thereby facilitating the extraction of pertinent gait parameters from the data it collects [16].

- **Pressure Sensing Insole** - The insole of the shoe is enhanced with two components, rendering it intelligent. Firstly, a pressure sensing material is attached to measure the plantar pressure exerted by the wearer. Additionally, an accelerometer, gyroscope, and compass are incorporated to track the individual's movements. By wearing the smart insole shoe and conducting gait analysis, the individual's walking pattern can be analyzed [17].

- **Pressure Sensitive Mat** - A mat equipped with pressure sensing capabilities through the use of plastic optic fiber sensors, capacitive sensors, piezoelectric sensors, or piezoresistive sensors can serve the purpose of measuring plantar foot pressure and analyzing gait by measuring movement [18].

1.2 Virtual Reality

Virtual Reality (VR) lies in the intersection of real-world and virtual realms. Its fundamental principle lies in the simulation of an virtual environment, designed to deceive users into perceiving virtual objects as authentic entities [19]. Consequently, when creating a virtual environment, the key focus is on the visual perception of users. VR as a technology has gained significant attention in the past couple of decades. Its application in therapeutic contexts, where immersion and contextualization are crucial, has been particularly notable [20]. Through the utilization of VR HMDs (Head Mounted Devices), users are provided with the capability to visually perceive, audibly experience, and interact with immersive virtual environments. This thesis aims to investigate the link between gait and depression by rendering various types of virtual environments using the VR HMDs.

1.3 Scope of Research

The objective of this thesis is to develop a low cost Gait mat called VelGmat, which is based on Velostat material, for the purpose of gait analysis within a VR environment.

The research process is divided into several phases -:

- Review on the presently available technologies for detection and intervention of depression
- Design and Implementation of VelGmat
- Utilization of VelGmat for depression detection
- Integration of Virtual Reality(VR) with VelGmat
- Comparison of VelGmat with commercially purchased Pressure sensing mat

The research does not include the usability analysis of the mat; it is limited to a particular set of VR scenes in a controlled environment, and the results are based on a limited sample size and thus are not generalizable.

1.4 Summary of Contributions

The contributions from the thesis can be summarized as the following-

- **Design**
  - Proposed a cost effective Velostat based Gait mat for calculating gait metrics
  - Worked on different configurations and proposed a 42x25 sensor density for plantar pressure distribution
  - Tranformed data from VelGmat into JSON file compatible with commercial Sensing Tex Software
- **Application**
  - Proposed a cost effective pressure-sensitive mat for performing gait analysis for depression
  - Carried out a pilot study and compared readings of VelGmat with a commercially purchased mat
  - Performed gait analysis with Virtual Reality for depression studies
- **Literature**
  - Proposed a table listing the different types of VR scenes used for the detection and intervention of depression
  - Listed out all the hardware used to measure different physiological and behavioural bodily responses required for depression
  - Proposed a bare minimum checklist to create a novel scene in VR for depression studies

1.5 Thesis Structure

The thesis structure is divided into the following chapters-

- **Chapter 2** talks about the related work using systematic literature reviews
- **Chapter 3** discusses the applications of pressure sensitive mats and their properties
- **Chapter 4** presents the design of VelGmat
- **Chapter 5** discusses the design of the Virtual Environments with respect to the mat
- **Chapter 6** concludes the thesis by discussing the research's contributions, limitations and Future aspects.

Chapter 2

Related Work

In this section, we will detail the utilization of virtual reality (VR) in the healthcare domain, with a specific focus on its application in addressing depression. Furthermore, we will delve into the discussion of the essential sensors that are necessary for capturing and quantifying the various physiological and behavioral indicators associated with depression.

2.1 Methodology

We employ Kitchenham's Guidelines to conduct two systematic literature reviews (SLRs), with one focusing on the use of VR in general healthcare and the other specifically targeting depression.

2.2 SLR on using VR in Heathcare

In order to obtain a comprehensive understanding of the utilization of virtual reality (VR) in the healthcare field, a thorough literature review was undertaken. This review aimed to explore the application of VR as a means of assessing patients for specific disorders, as well as its potential for disease prevention and health enhancement through intervention. Given the vast scope of healthcare, the focus of this review was narrowed down to the implementation of VR in the areas of mental health detection, physiotherapy and rehabilitation intervention, pain management, fall detection, medical imaging, surgical procedures, and medical education.

2.2.1 Research Questions

The main aim of the literature review was to demonstrate the significance of virtual reality (VR) in identifying and treating disorders, as well as assessing its efficacy. The following research inquiries have been formulated to assist us in approaching our goal:

- RQ1 - *What VR scenes are useful for detection and intervention?*

- RQ2 - *What are the metrics/methods practiced in the conventional methods as well as the VR based methods for detection and intervention?*

- RQ3 - *Is the detection and intervention based on VR more effective than that of the conventional methods?*

2.2.2 Search Strategy and Filtration

Our search strategy was formulated by examining prior research and analyzing existing works. In order to address the research questions effectively, we compiled a comprehensive list of keywords. To enhance the scope of our search results, we incorporated synonyms into the finalized search string. The search string is divided into three parts S1,S2 and S3

S1: ”vr” OR ”Virtual Reality”

S2: ”healthcare” OR ”Medical care” OR ”medical management” OR ”medical aid” OR ”health maintenance” OR ”health care”

S3: ”Physiotherapy” OR ”mental health” OR ”medical imaging” OR ”medical visualization” OR ”surgery” OR ”rehabilitation” OR ”medical education” OR ”pain management” OR ”fall detection”

The ultimate search string utilized was S1 AND S2 AND S3. The purpose behind organizing the search string in this manner is to conduct a methodical elimination process. The search statement S1 is specifically limited to the abstract, while S2 and S3 are examined throughout the entire text of the paper. After multiple iterations and consultations with fellow researchers, we ultimately arrived at the finalized search string.

Search Quality Assessment: We have developed a series of ten questions aimed at refining the selection of research papers based on their significance and dependability. This survey employs a binary system, assigning a value of 1 for ”yes” and 0 for ”no,” where ”yes” indicates the paper is worthy of review and ”no” indicates the opposite. To qualify for review, a paper must accumulate a total score of 5. The questions included in the survey are as follows.

- Does it contain images of VR scene?

- Does it contain details of VR scene?

- Is the VR scene standalone or does it require feedback from outside?

- Are there multiple VR scenes relevant to that disorder?

- Does it have information about the conventional methods?
- Can we derive conventional metrics from the paper?
- Can we derive VR metrics from the paper?
- Does it have a user study of value for further research?
- Is there mention of findings, limitations, future scope, or discussions in the paper
- Does the paper make a judgement on VR being better, worse or same than conventional methods

Inclusion Criteria - Our study focuses on the examination of research papers written in the English language. Specifically, we consider papers published between January 2000 and June 2022. Our analysis encompasses papers that explore both immersive and non-immersive virtual reality (VR) applications for the purpose of detection and intervention. Furthermore, we include papers from various sources such as conferences, conference proceedings, and journals in order to ensure a comprehensive review.

Exclusion Criteria - Papers lacking full-text availability are not considered in our review. Research contributions in the form of articles, magazines, review notes, books, book chapters, and archives are disregarded due to the specific context needed for our research. Papers discussing VR and its broad applications in healthcare are also excluded.

Results: Our literature review encompassed digital libraries such as ACM, IEEE Xplore, Pubmed, Scopus, and Springer. We successfully identified and extracted the pertinent papers from ACM, IEEE Xplore, Pubmed, and Scopus. Initially, employing a search string, we obtained a total of 1617 papers, distributed as follows: ACM – 147, IEEE Xplore – 499, Pubmed – 492, and Scopus – 479. After eliminating duplicates, we proceeded with the first filtration process, which involved applying inclusion and exclusion criteria. Consequently, 1086 papers were excluded, leaving us with 549 papers for further consideration. In the subsequent iteration, we conducted a thorough review of the full text of these papers and excluded 395, resulting in 154 remaining papers. Finally, in the last iteration, we filtered the papers based on their relevance, metrics, and reliability, ultimately narrowing down the number of papers to 58. Figure 2.1 shows the details.

2.3 Contributions

Based on the finalized list of papers a table was created. This table included information about various VR scenes, the specific task to be carried out in the virtual environment, the type of VR technology employed, any additional hardware or sensors used, the specific disorder for which the VR scene was designed, and whether the VR scene was used for detection or intervention. These details presented in table 2.1 are specifically used to address RQ1. Additionally, the metrics for comparison were collected, and a comparison between VR and conventional techniques was conducted using these metrics.

Table 2.1: Illustration of Scenes in VR for Detection or Intervention in Healthcare

Scene description	Task to be Performed	Type of VR	External Feedback/sensors	Disorder	Detection/Intervention	Year	Reference
Ball on a table with a path laid out	Move the ball from left to right	Non immersive 2D screen	Infrared based sensor to detect gesture	Parkinson's	Detection	2017	[21]
Virtual ATM and Transport	Take out cash and get on a bus	Immersive HMD based	No	Dementia	Detection	2018	[22]
Customisable Avatar for Interaction	Interact with the avatar	Immersive HMD based	No	Depression	Detection	2021	[23]
A virtual clinic	Complete mental health assessment tasks	Immersive HMD based	Eye Tracking	Depression	Detection	2021	[24]
Human brain with neurons as enemy and avatar as player	Shoot the neurons	Immersive HMD based(Occulus Rift)	No	Pain Management for Chronic Pain	Intervention	2017	[25]
A Virtual Kitchen	Pick Up objects from one place and move them into another	Immersive HMD based (HTC Vive)	EMG Sensing Armband	Pain Management for Phantom Limb pain	Intervention	2021	[26]
House In a Snowy Land and a snowy Island	Explore the environment	Immersive HMD based (Occulus Rift)	No	Pain Management for Burns	Intervention	2019	[27]
A Virtual forest with animals , lakes ,trees	Explore and find the required item	Immersive HMD based(Occulus Quest)]	No	Pain Management for Burns	Intervention	2022	[28]
A Virtual City Square	Walk whilst avoiding the obstacles like cats, steps etc	Immersive HMD based(KEO - Proview XL-50	GaitRite Pressure sensing shoes for gait measurement	Fall Prevention for Hip Fracture	Intervention	2007	[29]
A Virtual Orchard with falling Oranges	Catch the oranges in a Basket	Immersive HMD based	5DT Ultra DataGloves	Rehabilitation for upper limbs after-Stroke	Intervention	2009	[30]
An avatar in a particular posture	Make that posture and pass through the avatar	Immersive HMD based (HTC Vive)	Kinect (to replace the hand controllers of HTC)	Rehabilitaion for Cerebral Palsy, Trauma and Stroke	Intervention	2019	[31]
A butterfly moving in a field with rain and projectiles falling	Protect with butterfly with bubbles from the avatar hand from rain and Projectiles	Immersive HMD based(HTC Vive)	CRUX(Compliant Robotic Upper-Extremity Exosuit)	Declining Motor Function due to aging	Intervention	2019	[32]
An Image Split into 9 Parts	Rearrange the parts to form a complete image	Immersive HMD based (Samsung Gear VR)	No	Cognitive Rehabilitaion after Stroke	Intervention	2021	[33]
A room with a virtual avatar with a ball	Play Catching the ball with the Virtual Avatar	Immersive HMD based (HTC Vive)	No	Motor Impairment Rehabilitaion after Parkinson, cerebellar ataxia	Intervention	2018	[34]
A virtual vertical and horizontal rope and a wall	Pull the vertical rope to climb up , pull the horizontal rope towards themselves, climb by overhead arm raising	Immersive HMD based (Occulus Rift)	No	Rehabilitaion after Dementia	Intervention	2020	[35]

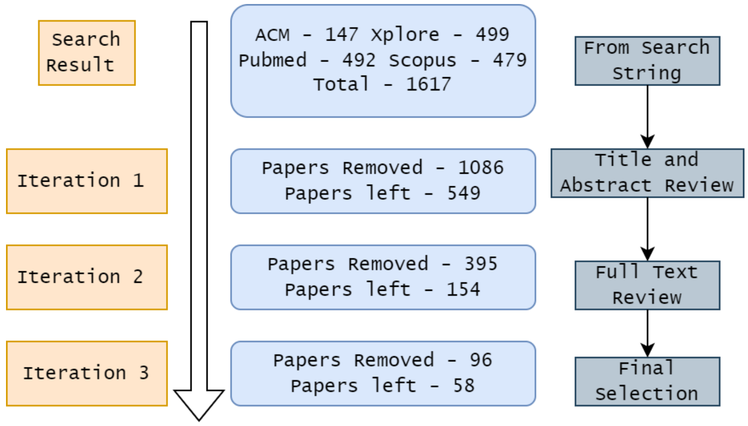

Figure 2.1: Filtration papers across iterations

2.3.0.1 Comparing VR applications with Conventional Methods

Mental Health – In this analysis, the extensive field of mental health was narrowed down to focus on depression, dementia, and Parkinson's disease. Traditionally, the assessment of dementia involves evaluating Instrumental Activities of Daily Living (IADL) through various methods such as self-reported questionnaires, informant-based questionnaires, and performance-based assessments [22]. Similarly, for depression, questionnaires like PHQ9 and guidelines from DSM (Diagnostic and Statistical Manual) V are commonly utilized. In the case of Parkinson's disease, conventional approaches involve the use of electromyography, gyroscopes, and accelerometers to measure tremors [21].

In the context of Virtual Reality (VR) for dementia, participants were able to engage in IADL tasks, such as withdrawing money from an ATM and taking public transportation, while their performance was qualitatively assessed based on their ability to correctly identify the appropriate bus. Additionally, quantitative measurements, including motion trajectory, distance, and speed (gait parameters), were recorded using a motion tracking system [22]. For depression in VR, participants interacted with a customizable VR avatar, allowing them to choose various characteristics such as age, skin color, hair, and gender. Simultaneously, self-compassion was measured and targeted for improvement [23]. In the case of Parkinson's disease, a VR game was developed where participants had to manipulate a ball, and metrics such as distance covered, velocity, and time taken were quantified [21].

The findings from this review indicate that VR offers advantages over conventional methods. This is primarily due to the inclusion of quantitative measures, such as physically performing IADL tasks with motion tracking, and tracking the accuracy of task completion [22]. These measures provide more objective data compared to subjective questionnaires and consultations with psychiatrists, which are susceptible to bias. Furthermore, additional sensor data, such as eye tracking, can be obtained to further quantitatively monitor patient behavior [24]. However, it is important to consider issues related to simulator sickness in VR and account for them during the assessment process.

Physiotherapy and Rehabilitation – VR Healthcare has seen numerous applications in the field, particularly in successful physiotherapy and rehabilitation programs. The primary objective of physiotherapy and rehabilitation is to train individuals with impaired physical or cognitive functions in order to restore and regain those functions [36]. Traditionally, therapeutic treatment involves the application of specific exercises to improve muscular strength, posture, endurance, balance, walking, and mobility in individuals who have limitations in their limbs due to a certain disorder. Various tools such as treadmills and obstacle-avoidance steps are utilized for this purpose. Additionally, rehabilitation is typically conducted in an organized multidisciplinary stroke unit [37]. The duration, capacity, and intensity of exercise play crucial roles in achieving effective rehabilitation outcomes. In conventional methods, therapists rely on their observation and judgment as evaluation metrics. At times, it may be necessary for physiotherapists to provide treatment at the patient's home. The assessment of physiotherapists is based on subjective measures and empirical experiences [38]. Common metrics used for rehabilitation include discharge time, total amount of learning achieved, speed of the learning process, as well as factors like motivation, enjoyment, and engagement.

In the case of virtual reality (VR), goal-directed movements are incorporated into the exercises, and emotional stimuli are provided within the VR scene. Patients' movements, trajectories, angles, and forces can be tracked in VR. VR-based exosuits offer variable power, sensitivity, and efficiency [32]. VR allows for the easy recreation of real-life scenarios relevant to rehabilitation and physiotherapy [30] [31] [34]. Furthermore, VR enables the collection and analysis of data to monitor and evaluate rehabilitation progress. The memory resources of VR can also accommodate multiple exercise setups within a single system.

Therapy and Rehab programs require intensive, repetitive, assist-as-needed, and task-oriented approaches, all of which can be easily achieved through the use of VR technology. In contrast, conventional techniques are inherently repetitive, which can lead to a disconnection between the patient's mind and a decrease in motivation. When considering metrics such as motivation, enjoyment, and engagement, VR offers several characteristics that contribute to user motivation and engagement. These include novelty, visually and audibly striking graphics, interactivity, feedback, socialization, optimal challenge, extrinsic rewards, intrinsic curiosity, goal-oriented tasks, and meaningful play. As a result, VR outperforms conventional techniques due to its ability to enhance engagement and motivation, which in turn promotes persistence and facilitates high training intensity [39]. Furthermore, the immersive and realistic environment provided by VR has been validated through the measurement of immersion and realism using the Witmer and Singer presence questionnaire, a widely accepted technique for assessing such experiences in virtual environments [40]. Additionally, the evaluation of task independence, which refers to the frequency of assistance required by the patient, revealed that VR requires less assistance compared to conventional techniques. In a study [41], a high percentage of improvement was observed in VR compared to conventional techniques, although no statistically significant difference was found in the outcome measures, which included standard questionnaires.

Surgery – The traditional approach to teaching surgery follows the ”see one, do one, teach one” model. However, there have been advancements in this method, such as the utilization of video recordings of surgeries for later review. These recordings serve as a means to improve the learning process. The key metrics used to evaluate surgical performance include operating time and operating performance [42].

In the context of virtual reality (VR) in surgery, 3D models are employed during the planning phase. These models are tailored to each patient, creating patient-specific VR scenes [43]. VR technology allows for the replay of surgical procedures, accompanied by accurate physiological data of the patient [44]. Additionally, VR enables the capture of errors and near misses during surgery [45]. Furthermore, VR can be utilized to assess the skills and composure of surgeons during surgical procedures [46]. Moreover, VR offers a platform for training surgeons in handling surgical crisis scenarios [47].

The traditional surgical apprenticeship has long been criticized as an inefficient model for training. While carpenters learn their craft on wood and turners practice on scrap metal that is never used or displayed, surgical trainees perform their training on actual patients. Numerous studies have shown that the ”see one, do one, teach one” model, commonly used in surgical training, is not effective [48]. However, virtual reality (VR) offers a promising solution by allowing the training of a large number of medical personnel [49]. VR application has been found to improve the assessment of skills and mental composure, with the use of eye tracking cameras [46]. In a study comparing VR based training to standard laparoscopic training, VR based training resulted in reduced operating time and errors [50]. Additionally, VR training improved accuracy and reduced unnecessary movements compared to conventional laparoscopic training. Despite their effectiveness, VR surgical simulators are known to be expensive [51]. VR has also been successfully utilized for team training in surgical crisis scenarios [52]. Another study found that VR planning systems are accurate pre-operative planning tools [53]. However, in the teaching of Surgical Hand Preparation, VR applications did not demonstrate any perceivable benefits [54].

Medical Education- The traditional approach to medical education involves the use of textbooks, diagrams, and instructors who teach the class and provide demonstrations in laboratories. Instructors often utilize plastic models to aid in interpretation and explanation. Additionally, standard training manikins are employed for instructional purposes. In some cases, cadavers are utilized to illustrate anatomy dissection to medical students [55]. The evaluation of medical students primarily revolves around their knowledge and skills.

With the advent of virtual reality (VR), the process of imparting medical education has undergone a transformation. VR allows students to visualize 3D anatomical structures, providing a more immersive learning experience. Furthermore, VR simulations enable the replication of entire human organs, such as the human bladder, allowing students to witness procedures like the insertion of a medical catheter to drain accumulated urine [56]. Virtual manikins and haptic feedback systems in VR facilitate cardiopulmonary resuscitation (CPR) training [57].

Moreover, CPR training in VR offers the advantage of recording and comparing metrics such as grasp power, depth, and frequency. These quantitative measurements can be used to track individual progress over time and make comparisons between different participants [58]. In addition, VR technology allows for the creation of virtual patients, providing doctors with opportunities to practice empathy in realistic scenarios.

Using VR applications, the anatomy of important organs such as the ear, bone, and others can be visualized and explored up to the level of intricate details. There is active manipulation of 3D structures rather than passive viewing.

Conventional pre-clinical training employed the use of cadavers, but financial, ethical and supervisory constraints have become a major shortcoming [55]. VR was able to improve knowledge and skill outcomes to medical students [59]. In [60], VR simulators were effective in assessments comparing novice, skilled and expert medical clinicians. Medical education in VR gives an objective, proficiency-based system, enhances educational efficiency through structured curriculum and objective, standardized assessments. Training occurs in safe environment optimizing patient safety. VR applications can improve limited patient availability occurring with shortages of clinical training sites. Improves limited exposure to rare conditions.Improves limited access to cadaveric training. Improves training of new and more complex techniques.Can be more cost-effective method training [61]. VR was very useful and effective in teaching during the COVID 19 pandemic where oral presentation, clinical reasoning and prorounding abilities of the students were reported to be increased [62]. Challenges with respect to VR are simulator sickness , its side effects, user's attitudes [63]. Exhaustive morphology can be explained in VR which is helpful for microsurgeries , standard training manikins do not represent human torso compression forces so VR is helpful designing manikins which guides somatosensory interactions and promotes game based learning [58]. Also VR solves the problem of the limitation of the early availability of manikins and cadavers.

Medical Imaging - Medical Imaging plays a crucial role in the analysis of diseases, surgical planning, and academic training. Traditionally, data visualization techniques have relied on two-dimensional spaces to present information. However, with the advent of Virtual Reality (VR), doctors are now able to visualize three-dimensional data. In addition to visualization, the 3D models can also be manipulated, allowing for a more comprehensive understanding of the medical images [64]. By utilizing VR headsets, radiologists can benefit from high-resolution screens that aid in the analysis of X-ray images. Furthermore, VR technology enables the extraction of high-quality eye-tracking data and pupil dilations, providing valuable insights for medical professionals [65]. Moreover, VR offers the advantage of depth perception, enhancing the accuracy and precision of medical imaging. When evaluating the effectiveness of medical imaging, important metrics include the time taken for analysis, the occurrence of errors, usability, and the overall task load involved [64].

Medical imaging techniques, such as computed tomography (CT) or magnetic resonance imaging (MRI), generate extensive collections of two-dimensional (2D) and three-dimensional (3D) data that are crucial for diagnosis and surgical planning. The integration of Virtual Reality (VR) has the potential to offer a more intuitive and efficient means of interacting with this data. By manipulating 3D images within a VR environment, surgeons can effectively plan surgical procedures [64]. In a study conducted by [66], VR demonstrated superior performance in terms of task time compared to traditional 2D imaging techniques, while exhibiting comparable error rates. However, it is worth noting that the task load was higher when using VR in comparison to conventional methods. The inclusion of depth perception in VR provides a more comprehensive understanding of the inherently three-dimensional nature of the human body, addressing the limitations of interpreting data from conventional methods. Currently, the main challenges in implementing VR in medical imaging revolve around achieving real-time performance and minimizing latency [67].

Pain Management- Pharmacological interventions are commonly employed in conventional pain management methods [27]. Additionally, traditional touch therapy techniques such as healing touch, therapeutic touch, and Reiki are utilized. Laser therapy is also employed for pain management. Hypnosis and cognitive behavioral therapy are other approaches used in pain management. Furthermore, distraction techniques such as engaging in conversation about age-appropriate interests, reading a book or watching a video, and listening to music are employed. In the case of individuals with amputated limbs, a technique involving visualization of the amputated limb is utilized to create the belief that the missing limb has been visualized [68]. The metrics used to assess the effectiveness of these interventions include pain intensity, pain unpleasantness, and the amount of time spent thinking about pain.

Virtual reality (VR) interventions involve the creation of a VR scene with a pleasant environment, such as a beach or a snowy field, where the level of stressor and distracting stimuli can be controlled based on user feedback [69]. Tactile feedback can also be incorporated into VR interventions. The attractiveness of the VR environments can be modified and measured using a five-item, 5-point Bipolar Adjective scale.

The immersive and engaging nature of VR makes it a useful tool as a preventive intervention from stressful situations like drawing blood, treating burns, etc. VR-mediated interventions demonstrated significant improvement for pain symptoms in patients experiencing chronic pain. Taken together, these findings showed that currently available lines of evidence on the effect of VR-mediated therapy in chronic pain management, despite pointing towards possible therapeutical benefits of the VR-based intervention, are overall inconclusive and that more research on VR-assisted therapy for chronic pain is needed [70]. Furthermore, as stated in the study conducted by [71], there was a notable distinction in statistical terms, albeit lacking any significant clinical impact, favoring virtual reality (VR) over traditional proprioceptive training when it comes to alleviating pain intensity.

Fall detection- Conventionally, balance exercises have been known to be challenging. These exercises typically involve participants standing with their feet close together, standing on one leg, practicing controlled movements of their center of mass, and receiving verbal instructions about misconceptions related to the fear of falling. However, in VR, an environment can specifically designed to incorporate obstacles that can be customized. Additionally, the level of cognitive load can be adjusted to provide a more tailored experience for the participants.

To evaluate the effectiveness of these VR exercises, various metrics are recorded. Gait data, for instance, is collected using external equipment such as gait rite. Furthermore, fall data can also be recorded and stored for analysis [72]. Remarkably, studies have shown that VR exercises focused on fall detection have yielded exceptional results. Participants experienced a significant improvement in their fear of falling, with a reported 98 percent enhancement. Moreover, their confidence in maintaining balance also increased, along with notable improvements in their gait [72].

However, it is important to note that the sample size in this particular review is relatively small. Therefore, further research is required to make a conclusive decision regarding the overall effectiveness of VR exercises for balance improvement and fall prevention.

2.4 SLR on using VR for Depression

Virtual reality applications can greatly assist mental health practitioners in expediting the process of detecting and intervening in depression, thereby improving the condition or reducing its severity. It has been observed that VR can aid in identifying mental health symptoms by offering ecologically valid environments tailored to each individual [73].

2.4.1 Research Questions

The main aim of this section of the thesis is to provide a comprehensive overview of the ongoing research in the field of VR pertaining to the identification and treatment of depression, and assess its efficacy. To accomplish our goal, we have formulated the following research questions:

- **RQ1** - *What VR Scenes are used for the detection and intervention of Depression?*
- **RQ2** - *What are the external hardware used as a complement to immersive and non immersive VR devices during detection and intervention of Depression?*
- **RQ3** - *Are VR based methods of detection and intervention of Depression effective?*

2.4.2 Search Process and filtration

We formulated our search strategy by considering the prior systematic literature reviews from health-care domain. Considering the practices from the healthcare domain, we came up with our research questions. A list of keywords that would correspond to the research questions was prepared. The search string was finalized using the keywords and synonyms were also included to broaden the search results. The search string is divided into two parts **S1** and **S2**

S1: *"VR" OR "Virtual Reality" OR "Virtual Environment"*

S2: *“Depression”*

The finally constructed search query is **S1** AND **S2**. This search query aids in the methodical exclusion of irrelevant literature. The search statement’s scope, encompassing **S1** and **S2**, is limited to the *”abstract”* section rather than solely the title, in order to obtain the pertinent papers. The final search query was derived after multiple iterations involving discussions with fellow researchers regarding the search keywords and their combinations. The literature review was conducted on the ACM, IEEE Xplore, Pubmed and Science Direct digital libraries. We extracted the relevant papers from the above libraries, suiting our search strategy and the inclusion and exclusion criteria.

Inclusion Criteria - This study exclusively focuses on research papers written in English. The timeframe for the papers considered spans from January 2000 to December 2022. Due to the significant rise of virtual reality (VR) in recent decades, a deliberate choice was made to include only papers published after the year 2000. The scope of the study encompasses papers that explore both immersive and non-immersive VR applications for detection and intervention. Furthermore, papers from workshop proceedings, conference proceedings, and journals are all incorporated in the analysis.

Exclusion Criteria - Papers whose full text is not available are not considered for review. Research contributions published as articles in magazines, review notes, books, book chapters, and archives are excluded from the review as the context of the publications may not directly contribute to this research.

Search Quality Assessment: We have developed a series of seven inquiries aimed at refining the selection of research papers based on their significance and dependability. This survey employs a binary system, where a response of ”yes” or ”no” is represented by the numbers 1 or 0, respectively. A research paper must accumulate a total score of 4 from the seven questions in order to be considered for review. The questions are outlined below:

- Does the paper have a user study of value for further research?
- Does the paper make a judgment on VR being better, worse, or the same as conventional methods
- Can we derive VR metrics from the paper?
- Does the paper contain images of VR scenes?
- Does the paper contain details of the VR scenes?
- Are there external hardware complementing the immersive and non immersive VR devices?
- Is there mention of findings, limitations, future scope, or discussions in the paper

Results: A total of 584 papers were obtained from our initial search using the specified search string. Among these, 16 papers were sourced from ACM, 39 papers from IEEE Xplore, 451 papers

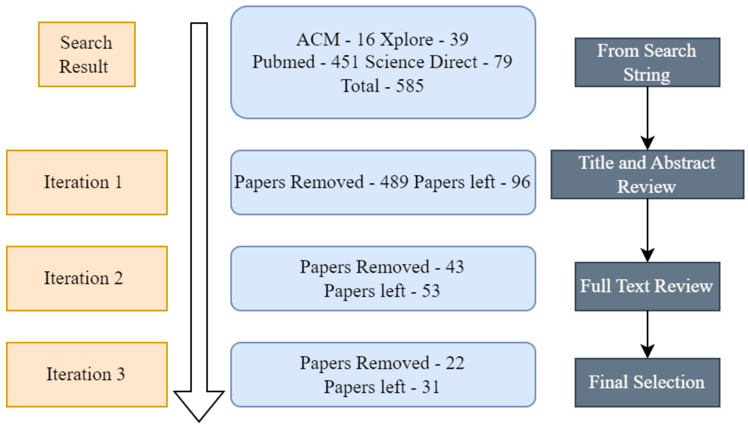

Figure 2.2: Paper Finalization after Search Strategy

from Pubmed, and 79 papers from Science Direct. Since Pubmed is a medical journal, we only selected systematic reviews to ensure that redundant papers and irrelevant information were excluded from our study. In the first iteration, we eliminated duplicate papers and then applied inclusion and exclusion criteria to further refine the paper collection. The detailed count of filtered papers at each iteration of our review process can be found in Figure 2.2. Ultimately, our study considered a total of 31 research papers.

2.5 Contributions

Following are major contributions of this literature review:

- We complied VR Scenes developed in the available literature to study depression in Table 2.2
- We illustrated various physiological and behavioral response measures used to study depression along with the hardware used to monitor them in Figure 2.3
- We presented our overall review insights into categories such as "Comparison among available conventional methods", "Meta Studies", "Quantifiability and Dynamism" etc. from literature to judge the effectiveness of VR in detecting and intervening in depression.
- We provided a few recommendations to future practitioners considering designing novel VR scenes for studying depression.

2.5.1 VR scenes used for depression studies

The Virtual Environment is the primary stimulus that provides the user the experience of a customized, immersive, and engaging environment. In the VR Scenes, we have included scenes as well as games because games inherently comprise a sequence of scenes.

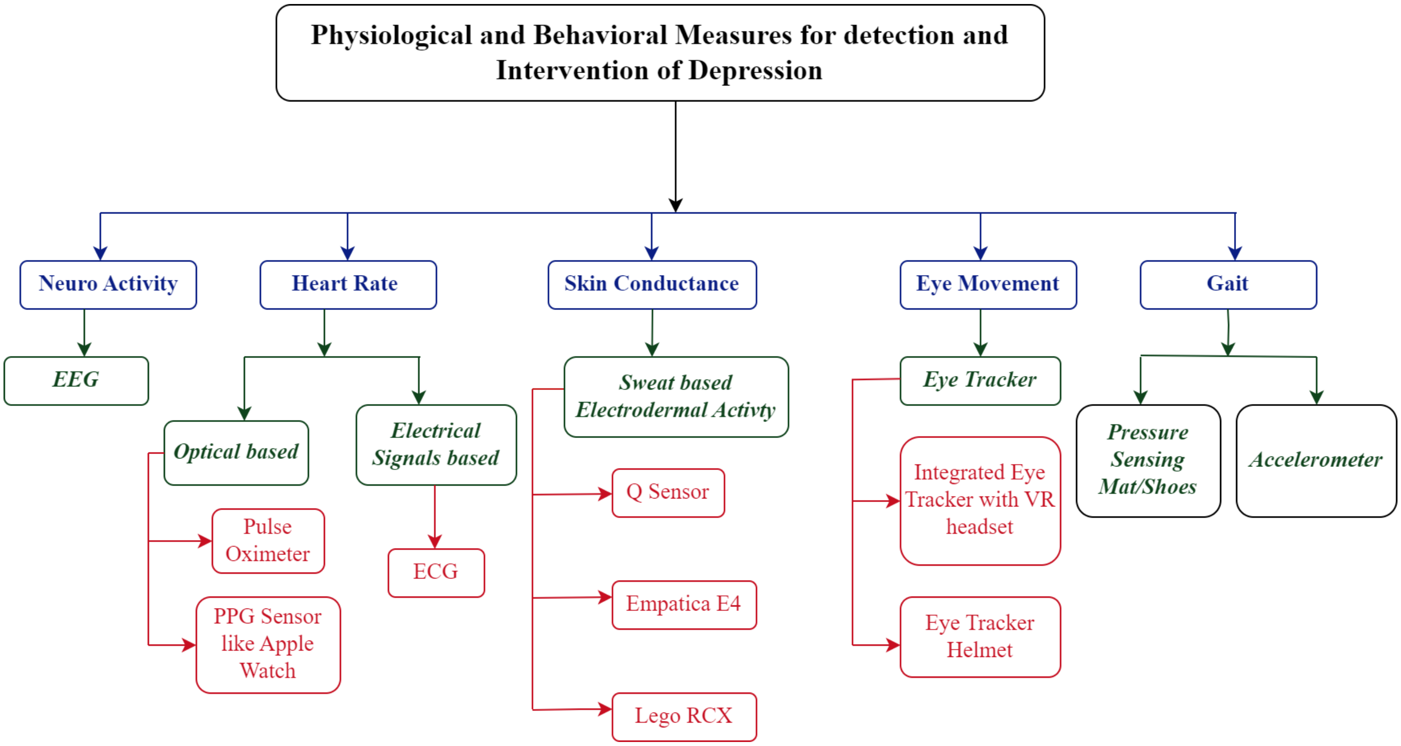

Figure 2.3: Categorization of the Sensors used in detection and intervention of depression

2.5.2 Hardware/Sensors to measure the physiological and behavioural measures

Prior to delving into the discussion regarding external hardware, it is crucial to provide a brief explanation of immersive and non-immersive VR experiences. In the immersive VR experience, a Head Mounted Device (HMD) or CAVE type setting is utilized as a display medium, whereas in non-immersive VR, the environment is projected onto a screen. Referring specifically to non-immersive VR, the visual representation of the virtual scene is showcased on a laptop, as mentioned in [6], as well as on PCs and projectors, as cited in [74] [75] [76].

In addition to the HMDs or PCs, there are other hardware components present to capture and record the **physiological and behavioral** responses of the participants towards the VR scenes being presented. The physiological and behavioural measures shown to have a correlation with depression or emotional state of a person are brain wave activity or **Neuro activity** [2], **heart rate variability** [3], **skin conduction** [4], **eye movement/pupil waves** [5] [6] and **gait** [7]. The sensors used to measure these parameters are mentioned in Figure 2.3. Information pertaining to the sensors is laid down below.

Electroencephalography (EEG) stands as an electrophysiological monitoring technique, facilitating the capture of the brain's electrical activity. This non-invasive method has found utility in the examination of cognitive behaviors, particularly the intricate patterns of brain wave activity closely associated with conditions such as depression [77]. In [78], a three-electrode EEG collector, was employed as a cost-effective alternative to the more elaborate 64 or 128 electrode systems.

Furthermore, in the study detailed in [2], a pair of EEG setups was utilized: one featuring seven sensors and the other employing five sensors. Complementing these EEG recordings, continuous heart rate data was collected and stored through the use of an Apple Watch. This monitoring was rooted in photoplethysmography, an ingenious technique incorporating LED lights and photodiode sensors discreetly positioned on the watch's underside. This approach effectively measures data from the cardiovascular system, notably showcasing its reliability in assessing heart rate, particularly in scenarios involving anxiety. Impressively, the sensor has a wide operational range, spanning from 30 to 210 beats per minute while requiring minimal active participation from the study participants.

In addition, the study described in [2] also harnessed the capabilities of a Q sensor for the measurement of skin conductance. Affixed to the wrist, this device incorporates a small sensor at its base, enabling the recording of Electrodermal Activity (EDA) in the skin. The observed fluctuations in EDA are subsequently relayed to specialized software (Q-live). The underlying principle of this technology lies in its ability to employ electrical signals of a remarkably low power, measuring less than five micro watts, to gauge skin conductance.

In the research outlined in [79], an oximeter served as a valuable instrument for measuring both heart rate variability and peripheral capillary oxygen saturation (SPO2) levels. These metrics, in turn, were leveraged to assess the emotional state of the participants. Notably, a body of research has underscored the intricate connection between heart rate and various forms of stress, where heightened stress levels have been associated with the onset of depression [3]. Furthermore, heart rate variability has emerged as a useful indicator for gauging psychological well-being and the presence of mental stress [80].

In another research a Galvanic Skin Response sensor(GSR) which senses changes in sweat gland activity that accurately show a person's emotional state was used [81]. The two metrics for the GSR are skin conductance and skin resistance. It is attached to the fingers on the index and the middle fingers where the current is sent from one and the other measures the difference. The readings are stored and displayed in a graph where peaks are highlighted and values are smoothed by averaging them..

Li, Mi, et al. in [6], looked at pupil diameter employing specialized eye movement helmets for data collection. Unlike behavioral signals like facial expressions and speech, pupil diameter offers a direct and unfiltered insight into emotional expression as it increases on a joyful emotional expression and decreases on a sad emotional experience. [5]. The researchers called this dynamic physiological signal as pupil wave. This unique attribute positions them as an objective and reliable signal for assessing an individual's mental state. Furthermore, when coupled with emotion-inducing virtual reality (VR) scenarios, the use of pupil waves enhances the authenticity of the emotional experience.

In the user study in [75], The skin resistance signal acquisition is done by LEGO RCX Mindstorm. The working principle is that a constant voltage is applied to the skin by the electrodes and the current that passes over the skin is detected and displayed. The constant voltage is applied by the GSR amplifier to the skin by electrodes. The voltage is very small that it cannot be perceived. The current that passes over the skin, as the voltage is applied, can be detected and displayed. Silver(Ag) plates are used to construct the electrodes and Spectra 360 electrode gel is applied for better skin contact. Readings are sent to the GSR interface that converts them to a graph.

In [82], the collection of Neuroactivity using EEG signals was conducted by utilizing a Muse headband equipped with 4 channels (TP9, FP1, FP2, TP10), while maintaining a sampling rate of 256 Hz.

In [83], a VR headset integrated with an eyetracker was employed as a sensing technology for Eyetracking. This technology facilitated the acquisition of non-self-report data from VR simulations, enabling the examination of eye movement abnormalities associated with mental health disorders. The eye-tracking data encompassed various parameters, including: (1) Gaze Origin, which represents the starting point of a ray emitted from the eye, (2) Gaze Direction, a three-dimensional vector indicating the wearer's line of sight, (3) Fixation point, denoting the location where the eyes converge, and (4) Confidence Value, a numerical value ranging from 0 to 1 that signifies the reliability of the sensor.

The investigation [84] entailed the collection of Neuroactivity data through the utilization of EEG from 64 electrodes positioned in accordance with the international 10–20 system (AF3/4, AF7/8, FPz, Fz, Fp1/2, F1/2, F3/4, F5/6, F7/8, FCz, FC1/2, FC3/4, FC5/6, FT7/8, Cz, C1/2, C3/4, C5/6, T3/4, T7/8, TP7/8, CP1/2, CP3/4, CP5/6, Pz, P3/4, P5/6, P7/8, PO3/4, PO5/6 PO7/8, O1/2, POz, Oz, HEOR, HEOL, ECG, VEOU, VEOL) and referenced to CPz. The EEG amplifier manufactured by Neuroscan was employed for data recording at a sampling rate of 1000 Hz. Throughout the experiment, the impedance of all electrodes decreased below 10 kΩ. To eliminate high frequency noise, baseline drift, and power line interference, a 60 Hz online bandpass filter and a 50 Hz notch filter were implemented.

In [85], the Empatica E4, a wristband wearable designed for research purposes, was utilized. This device incorporates two silver-plated electrodes to measure electrodermal activity, specifically skin conductance, at the inner wrist. The sampling rate for this measurement is set at 4 Hz. Additionally, the wristband includes a photoplethysmography (PPG) sensor that determines the heart rate. The PPG sensor operates on the principle that higher blood oxygenation results in greater light absorption. By emitting green and red LEDs, the sensor measures the blood volume pulse (BVP) based on the reflected light, which varies according to blood oxygenation. The heart rate is calculated from the BVP signal, which is sampled at a frequency of 64 Hz. The gait, or walking pattern, was recorded using a 3-axis accelerometer. Alternatively, a pressure sensing mat could be employed for gait recording [86]. Furthermore, in [87], ECG signals, which track the heart's electrical activity, were recorded alongside neuroactivity using EEG signals. The session was also captured on video using a handheld camera mounted on a tripod.

To summarize, we have classified the physiological and behavioral measures, along with their corresponding sensors, as depicted in Figure 2.3.

2.5.3 Testing the Efficacy of VR scenes

To tackle the challenges of costly depression healthcare and the scarcity of specialized healthcare professionals, it is crucial to establish the effectiveness of VR within the realm of emerging technologies as we move forward into the future. We have identified various measures as outlined below:

User Study - One of the most prevalent methods employed to evaluate the effectiveness of VR applications is by conducting user studies. In a particular investigation [78], a total of 12 participants were involved, and out of these, 11 individuals expressed their satisfaction with the efficacy of VR and their willingness to utilize it again. Similarly, another study [88] encompassed six participants who were exposed to VR scenarios containing stress-inducing elements. The participants' reactions were assessed through the administration of questionnaires such as the Edinburgh Postnatal Depression Scale (EPDS) and the Generalised Anxiety Disorder questionnaire (GAD-7). This initial exploration yielded positive results, as all six participants reported experiencing improvements in their well-being, including enhanced relaxation, mood, self-esteem, sleep quality, and appetite subsequent to the therapy.

Furthermore, a separate study [89] examined the impact of VR on mood enhancement among a group of 20 participants, consisting of an equal number of males and females. However, it is crucial to acknowledge that alongside the positive effects, certain side effects such as eye strain, nausea, and headaches were observed. Although most participants found these side effects tolerable, it is noteworthy to mention that individuals with epilepsy may be more susceptible to experiencing adverse symptoms when utilizing VR technology.

A comprehensive investigation was carried out to detect depression, involving 295 participants from various institutions such as Beijing Anding Hospital Capital Medical University, Beijing University of Technology, and military regions 1 and 2. This study demonstrated a notable improvement in depression detection accuracy compared to previous methodologies [6].

Another research endeavor [90] focused on a group of 16 females and two males who were diagnosed with moderate to moderately severe depression. The implementation of virtual reality (VR) intervention in this study resulted in a significant increase in positive emotions and a decrease in negative emotions. However, a separate study involving 18 participants, as documented in [2], did not reveal any statistically significant disparities in heart rate elevation or self-reported anxiety between the baseline and VR recovery phases. This observation remained consistent regardless of whether the participants had higher or lower anxiety scores.

Ability to Elicit Emotion - Immersive VR has demonstrated its ability to evoke stronger emotional reactions, making it a promising tool for future studies on emotions [82]. In a study involving 41 healthy students, as described in [85], researchers observed significant increases in arousal levels when participants engaged with VR compared to traditional face-to-face imaginative experiences conducted with an experimenter. These findings were based on three physiological metrics: the frequency of Skin Conductance peaks per minute, average SC levels, and mean Heart Rate.

Similarly, a comprehensive study documented in [87], which included a substantial group of 463 participants, confirmed that VR driving simulations have the capacity to evoke emotions and elicit corresponding physiological responses. This further supports the notion that VR can effectively engage individuals emotionally.

Furthermore, the investigation presented in [91], which involved 30 participants, established a noteworthy connection between the emotional valence of the VR experience and participants' spatial and temporal navigation within the virtual environment. Specifically, the study found that positive and pleasant experiences in VR encouraged participants to explore the virtual space more extensively compared to encounters characterized by negative emotions. This highlights the influence of emotional experiences on individuals' engagement and interaction within virtual environments.

Improved Detection and Intervention - In the research described in [6], the main objective was to identify depressive states by analyzing eye movements that were carefully recorded during interactions with emotionally charged Virtual Reality (VR) scenarios. The researchers utilized pupil-wave data, which is a metric that directly reflects the user's emotional state, to facilitate this assessment. To achieve this, they developed a new computational framework that consisted of a dual-channel one-dimensional convolutional neural network (CNN). This CNN architecture incorporated cascade parallel multi-scale convolutional residual blocks and width-channel attention modules, and it was effectively utilized for assessing both depression and anxiety levels. Importantly, the results of this study showed a smaller margin of error compared to previous methodologies.

In a separate investigation mentioned in [92], a group of 29 older adults participated in a study that focused on the impact of VR interventions on happiness levels. The intervention group, which experienced VR interventions, demonstrated a significant increase in happiness when compared to the control group, which did not receive any interventions.

When comparing these findings with conventional methods, the study documented in [6] highlighted the advantages of collecting and analyzing eye movement data as a quantitative and testable approach for assessing depression. This method overcomes the recall bias associated with conventional methods, such as visiting a psychiatrist and answering questions. Additionally, in [93], the VR-based method of using joyful, sad, and fearful childhood avatars showed better results in depression intervention compared to conventional methods that involve simply looking at childhood photos and trying to evoke emotional scenarios. These results emphasized the superior effectiveness of VR in the context of depression intervention. Lastly, in [74], it was found that a cognitive behavioral program with VR was equally as effective as standard Cognitive Behavioral Therapy for treating depression, and the statistically significant differences were in favour of VR.

Overall, these studies demonstrate the potential of VR interventions and the utilization of eye movement data in improving mental health assessments and interventions, surpassing the limitations of conventional methods.

Meta Studies - In a comprehensive examination outlined in [94], which involved a meta-analysis of 11 studies and 6 Randomized Controlled Trials (RCTs), the researchers reached a compelling consensus. They found that the use of VR applications had a distinct and favorable impact on patients who were dealing with depression. Additionally, in a thorough analysis of 18 RCTs discussed in [95], the research team examined the effects of VR-based games that incorporated physical movement, specifically among the elderly population. The results shed light on a positive influence on memory, cognitive abilities, and depression within this particular group. However, it is important to note that the literature presents varying perspectives. For example, the meta-analysis featured in [96] concluded that serious games showed promise in alleviating depression. On the contrary, the investigation reported in [97] indicated that gaming did not surpass traditional methods in this regard, highlighting the need for more high-quality RCTs to establish a definitive stance.

Quantifiability and Dynamism - The study discussed in [88] highlights the dynamic characteristics of stress-inducing elements present in the VR environment. These stressors can be adjusted by the therapist, who has the ability to modify their properties such as frequency, duration, and whether they are administered individually or simultaneously. To obtain a quantitative measure, the neuroactivity is assessed and recorded through various means including EEG signals, heart rate, pupil waves, skin conductance, and gait analysis while the participants are immersed in the VR environment. These recorded data can then be forwarded to an expert for further analysis. This quantitative approach proves to be more reliable than relying on subjective tendencies associated with memory recall bias.

Negative User Feedback - In the study outlined in [98], a group of 32 individuals took part in a VR intervention. Notably, out of these participants, 9 individuals, accounting for approximately 28%, reported experiencing feelings of dizziness. However, it is important to highlight that a significant majority, precisely 87.5% of the participants, expressed a strong inclination towards incorporating VR into their future experiences. In a related investigation described in [99], which focused on elderly individuals as subjects, a sample size of 5 participants was utilized. Unfortunately, the findings revealed that most of these elderly participants could not comfortably use the VR headset for more than 5 minutes due to the onset of dizziness. Additionally, in the context of the research documented in [89], participants raised concerns about various discomforts while engaging with VR, including eye strain, nausea, and headaches. These adverse effects are important factors to consider when implementing VR interventions.

2.5.4 Novel VR Scenes for Depression Studies

The details of various VR scenes and the corresponding recorded physiological and behavioral measures are presented in Table 2.2. The observed sensors used to measure these parameters are depicted in Figure 2.3. Through a comprehensive analysis of the findings from this review study, we have developed a minimal checklist that outlines the essential requirements for designing VR environments that are specifically tailored for the study of depression, incorporating the necessary sensors.

- **Measures Selection:** Prior to empbarking on the design of a VR scene, it is imperative to thoroughly contemplate the physiological and behavioral metrics that are necessary for evaluation.
- **Content Impact:** The efficacy of a VR scene is contingent upon its ability to evoke significant reactions in the quantifiable physiological parameters. Therefore, careful consideration should be given to the design of the scene's content in order to optimize its impact on these metrics.

- **Baseline Values:** In order to ensure accurate and insightful comparisons, it is imperative to establish baseline values for the metrics of interest before engaging in VR stimulation. In situations where these initial values are not known, it becomes necessary to calculate them through measurements taken prior to the stimulation process.

To illustrate these principles in action, let us examine a practical example. Suppose we are conducting a study aimed at measuring physiological responses, specifically the increase in heart rate and perspiration, among a group of individuals. In order to carry out this experiment, we can create a virtual reality scene where participants are placed on a plank situated atop a tall structure (Content Impact). By directing the participants' gaze downwards, we can effectively manipulate their focus and elicit variations in heart rate and skin conductance. To ensure a reliable comparison, it is important to capture baseline heart rate and skin conductance values when participants are in a state of comfort and relaxation.

The concept of a virtual lunchroom showcases the adaptability of VR scenes, as participants can explore a virtual space while experiencing different levels of mockery from virtual guests. This particular scenario can be personalized by modifying the number of virtual guests and their placement in the scene, allowing for an increase or decrease in the impact of the content. Throughout this process, metrics such as skin conductance, heart rate, and gait can be monitored to assess the participants' reactions. By comparing the baseline values with those obtained from the various scenes with varying content impact, valuable insights can be gained.

Moreover, it is important to highlight that VR environments created for therapeutic purposes can also serve as tools for identification. To illustrate, a VR setting that showcases a personalized avatar to promote self-compassion can be adapted into a means of detection. By incorporating an eye-tracking mechanism and enabling individuals to choose from various emotional avatars (such as positive, negative, or calm), it becomes feasible to capture and evaluate pupil wave patterns to gauge the severity of depression. This concept has been exemplified in the research conducted by Li et al. [6].

Table 2.2: Illustration of Scenes in VR for Detection or Intervention on Depression Studies

Scene description	Task to be Performed	Type of VR	Metrics Recorded	Disorder	Detection/Intervention	Year	Reference
A Hike Through the woods and a dolphin swimming	Head Movement : The neuro-feedback from the head will control the sunlight in wood and the speed in Dolphin	Immersive HMD based	Neuroactivity	Depression	Intervention	2017	[78]
Top view of a city with large buildings	Stand on a plank on top of a building and look down	Immersive HMD based	Neuroactivty, Heart Rate, Skin Conductance	Anxiety	Intervention	2019	[2]
Middle class house with stressors like newborn baby crying, telephone ringing, fire in the kitchen	Explore the combination of two or more stressors	Immersive Virtual Glass based	No	Post Natal Depression	Intervention	2020	[88]
Natural scenes like mountains, island and bodies of water categorized in seasonal scenes viz summer, winter, autumn, spring	Explore the environment for as long as possible	Immersive HMD based	No	Depression	Intervention	2020	[89]
Places of Philippines having natural beauty	Explore the environment	Immersive HMD based	Heart Rate, Skin Conductance	Stress	Intervention	2020	[79]
A Negative text message in a dark background	Change the message into a positive one or crumble it, punch it or stab the message to make it disappear	Immersive Cardboard based VR headset	No	Depression	Intervention	2021	[100]
Customized Avatar	Customize the eyes, hair, gender as well as the environment as a room, beach, castle and interact with the avatar	Immersive HMD based	No	Depression	Intervention	2021	[101]
Different environments that elicit sadness, calm or joy	Explore the Environment	Non immersive Laptop based	Pupil Waves	Depression	Detection	2022	[6]
A Virtual bar and a beach	Explore the environment	Non immersive PC based	Skin Conductance	Alcoholic Depression	Intervention	2013	[75]
Forest and a shelter tower in a grass field with flowers	Explore while growing sunflowers showed office work like emails	Immersive HMD based	No	Stress	Intervention	2017	[98]
Nature with trees and grass and roller coaster ride	Explore the Environment	Immersive HMD based as well as non immersive laptop based	Neuroactivity	Depression, Anxiety, Psychosis	Detection,Intervention	2019	[82]
Childhood Avatar of the Participant	Interact with the sad, happy, and fearful avatar	Immersive HMD based	No	Depression, Anxiety	Intervention	2020	[93]
Waiting room in the mental health clinic, Doctor avatars and boards	Perform the tasks as directed like completing questionnaires	Immersive HMD based	Gaze origin and direction, fixation point	Depression	Detection	2020	[83]
A Dark dissolute scene followed by fire in the midst of darkness and peaceful weather	Explore and progress by collecting supplies including medication	Immersive HMD based	No	Depression	Intervention	2021	[102]
Multiple Spherical balls changing colour in a Sphere and returning back to the original colour	Choose the ones that changed colour	Immersive HMD based	Neuroactivty	Depression, Anxiety	Detection, Intervention	2022	[84]
Google VR Earth	Place oneself anywhere in the world and experience the environment	Immersive HMD based	No	Depression	Intervention	2021	[90]
A Virtual Lunchroom	Move through the room while being laughed at by other guests	Immersive HMD based	Skin Conductance, Heart Rate, Gait	Depression	Intervention	2021	[85]

Chapter 3

Pressure Sensing Mats

In the introduction chapter, we have breifly discussed four methods for conducting gait analysis. Despite its advantages in terms of a wide range of motion, the Kinect system lacks the ability to provide foot pressure data and is also expensive. Furthermore, it is important to acknowledge that individuals may feel uncomfortable being recorded on video, which raises privacy concerns. On the other hand, accelerometers are more affordable than Kinect but cannot be utilized for measuring pressure distribution. While pressure sensitive heels are a cost-effective option, they pose challenges when it comes to customization for various foot sizes. In contrast, pressure sensitive mat (PSM) offers foot pressure distribution, have minimal privacy concerns, are cost-effective, and can be customized. This chapter focuses on the design of different types of pressure mats.

3.1 Types of Pressure Sensors

Pressure sensors operate based on the scientific principle of utilizing external force or pressure to alter the characteristics of a specific substance, subsequently translating it into pressure measurements. The following type of materials are mainly used for making pressure sensors

- **Capacitive**: The distance between the two plates of a parallel plate capacitor is inversely related to its capacitance. Capacitive pressure sensors take advantage of this characteristic by detecting changes in capacitance when pressure is applied, which in turn indicates a change in pressure. There are also MEMS-based Capacitive pressure sensors that consist of a movable mechanical element in the shape of a micrometer-sized diaphragm or a cantilever that deflects under the force of external pressure. The deflection of microstructures is measured by monitoring capacitance or resonance frequency variation in a capacitive structure [103].

- **Piezoelectric**: The phenomenon in which a substance can transform applied force or pressure into an electric charge is referred to as the Piezoelectric effect. Some of the materials that demonstrate this effect include lead Zirconium Titanate, which is commonly known as PZT, and Rochelle Salt [104].

Figure 3.1: Capacitive PSM using Captool[Ref 107]

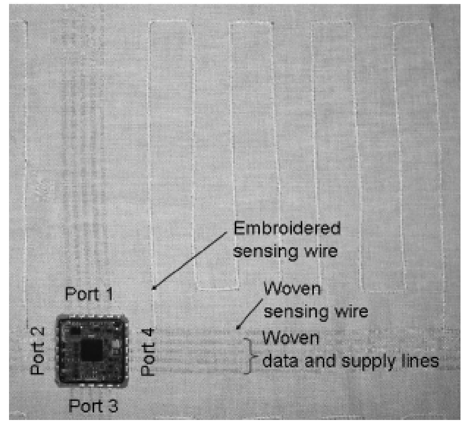

Figure 3.2: Capacitive PSM using embedded electronics[Ref 109]

- **Plastic Optical Fibre**: A plastic optical fiber refers to an optical fiber that is manufactured using polymers. It possesses flexibility and demonstrates the ability to bend. By being compatible with LEDs and Photodiodes, it enables the manipulation of light intensity entering the photodiode through the application of force or pressure on the fiber. Consequently, this change in intensity can be quantified and correlated to the applied pressure [105].
- **Piezoresistive**: Piezoresistive materials exhibit a modification in their electrical resistance when subjected to force or pressure. Materials such as silicon, polysilicon, and SiC, demonstrate the property of piezoresistivity [106].

There is prior work on PSMs i.e. designing the mat based on the type of materials used in the sensors mentioned above

3.1.1 Capacitive Sensor based Pressure mats

In the study conducted by the authors in paper [107], the development of indoor localization was facilitated through the utilization of a hardware called CapToolKit. This hardware consisted of a control unit that supported eight sensor elements specifically designed for capacitive sensing. To create a prototype, passive floor mats in a rectangular shape were employed, which were equipped with active sensor elements on two adjacent outer sides. The dimensions of these floor mats were adjustable, allowing for coverage of multiple square meters of floor space. For instance, the prototype implemented in the research covered an approximate area of $6m^2$, as illustrated in Figure 3.1.

The electrodes are applied in two layers that are insulated from each other using an insulated wire. Each electrode is connected to two wires, thereby expanding the spatial range of a single sensor. The resolution achieved is dependent on the quantity of sensors positioned on the mat's side. There are available systems that offer measurements within the sub-millimeter range. This particular setup was specifically designed for indoor localization. The mat covered an area of $6m^2$ and was equipped with only eight sensors. The selection of the number of sensors and the spacing between the wires is crucial to ensure that the average human foot always lands on a wire. Although the technology permits detection over a certain distance, this solution is preferred due to the significant signal-to-noise ratio resulting from the chosen wiring geometry.

In [108], researchers developed a pressure-sensitive mat that utilized the capacitive principle. This mat consisted of integrated, flexible electrodes that experienced a change in electric capacitance when compressed. The mat followed a sandwich configuration, with a thin elastomer film positioned between two flexible profiles. On both sides of the elastomer film, stretchable electrode layers were applied. When the film was stretched in one or both dimensions, the electrical capacitance between the electrodes increased. This increase occurred due to two factors: the expansion of the electrode surface and the simultaneous reduction in film thickness. As a result, the mat functioned as a stretch sensor. The researchers constructed a 100 x 100 mm mat with a dielectric thickness of 80 micrometers. One potential application proposed for this mat was to detect seat occupation in vehicles.

In [109], a textile-based mat is developed by incorporating electronics and interweaving them, as depicted in Figure 3.2. The embedded electronics sensor operates based on capacitance. The entire system functions as a network comprising numerous nodes, each possessing a distinct spatial coordinate and identification number. These attributes enable the identification and transmission of footstep data to the host PC. The dimensions of the mat were 240 x 200 cm, accommodating a total of 180 nodes. On average, the microcontroller required 1.5 ms to process the sensor data.

3.1.2 Optical Fibre Based

The utilization of plastic optical fibers is discussed in [105]. These fibers, made of plastic material, offer several advantages in terms of flexibility, cost-effectiveness, and ease of installation compared to traditional glass fibers. In [105], the plastic fibres are attached to a carpet layer orthogonally as shown in Fig. 3.3.

The plastic optical fiber is equipped with LEDs that are connected to two sides that are adjacent to each other. Photodiodes are connected opposite to the LEDs in order to measure the intensity of light when weight is applied on the mat. The mat contains a total of 9 horizontal and 6 vertical plastic optical fibers and measures 27 x 18 cm. To visualize the pressure applied on the mat, an 'I' shaped object is positioned on it, and a heat map is used to display the distribution of pressure.

In the study conducted by the author [110], a mat measuring 1 x 2 meters was specifically developed utilizing Plastic Optical Fiber (POF) technology. The mat consisted of 80 POFs, as illustrated in Figure 3.4. The primary purpose of this mat was to measure foot pressure by analyzing the bending of the POFs. Subsequently, the data obtained from the sensor head was utilized to generate a heat map, enabling the visualization of foot pressure distribution.

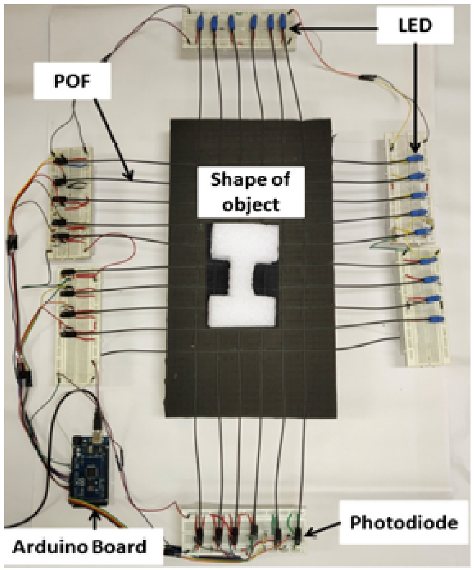

Figure 3.3: 16 x 7 cm optical fibre based PSM[Ref 105]

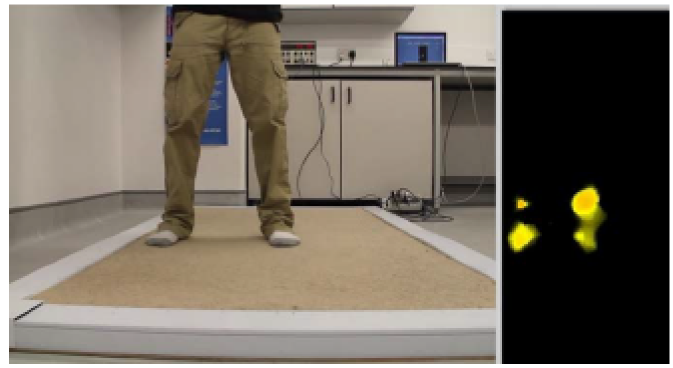

Figure 3.4: 1x2 metre optical fibre based PSM[Ref 110]

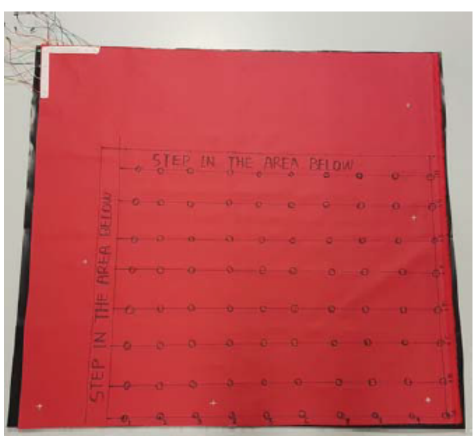

Figure 3.5: Velostat based PSM (8 x 10)[Ref 106]

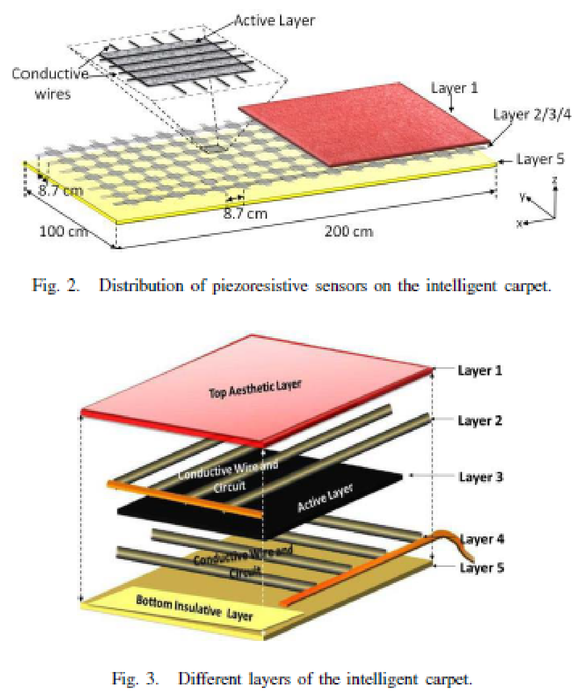

Figure 3.6: Velostat based PSM (16 x 7)[Ref 18]

Table 3.1: Different Materials used for making PSMs

S. No	Sensor	Size of the mat	Sensor Density	Application
1	Piezoresistive	90 x 60 cm	42 x 24	Plantar Pressure Distribution
2	Piezoresistive	200 x 100 cm	16 x 7	Gait Analysis
3	Piezoresistive	80 x 56 xm	8 x 10	Foot Position Mapping
4	Optical Fibre	200 x 100 cm	80 Plastic optical Fibres	Foot pressure Visualisation
5	Optical Fibre	27 x 18 cm	9 x 6	Pressure Visualisation of I shaped Object
6	Capacitive	240 x 200 cm	240	Tracing the walk of a person
7	Capacitive	100 x 100 mm		Seating pressure in Vehicles
8	Capacitive	6 m^2		Localisation of the person and fall detection

3.1.3 Piezoresistive Sensor Based

In this section, we will explore PSMs that rely on piezoresistive sensors, with Velostat being the most renowned and extensively utilized among them.

The pressure sensing mat described in [106] utilized velostat as shown in Figure 3.5. This design featured a sandwich structure, with copper tapes connecting two nonconductive layers in an orthogonal manner. As a result, the sensing array had dimensions of 8 x 10. The velostat material was positioned between the two sheets. Each sensor on the mat had a size of 1 cm^2. This mat served the purpose of detecting step pressure and also mapping the individual's position.

The study conducted by [18] involved the design of a pressure sensing mat using velostat material. The dimensions of the mat were 2 x 1 m, as depicted in Figure 3.6. The mat consisted of a sensor density of 16 x 7, with a spacing of 8.7 cm between each sensor. This mat was utilized for the calculation of various gait analysis parameters, including step length, step width, and the timing between feet, known as step time.

In a separate study by [111], a velostat based mat with dimensions of 90 x 60 cm was created. The sensor density of this mat was 42 x 24, with each sensel measuring 1cm^2. The mat was connected to a personal computer through bluetooth technology, enabling the collection of data at a frequency of 300 Hz. The primary applications of this mat were to measure instantaneous plantar pressure distribution, gait speed, and step count. A summarised view is given in the Table 3.1

3.2 Choosing the right material for a cost-effective PSM

Developing an ideal sensor is a challenging task due to its reliance on various factors, particularly the intended application. In order to assess the suitability of mats for our specific purpose, we will evaluate them based on several metrics including cost, customizability, amount of literature available, and circuit complexity. However, comparing these mats is not a straightforward process as their construction and data extraction methods differ significantly. Additionally, when creating a comprehensive pressure sensing system, the cost of external circuits must also be taken into account.

To simplify the comparison, let us consider a mat with dimensions of 30 x 30 cm, starting with the cost of the sensor material among the sensor materials Velostat is the least expensive with a 28 x 28 cm sized material costing about Rs.545[1] as compared to Plastic Optical Fibre cable 24 metres (approx length required for 30 x 30 cm mat) costing around Rs.2184 [2].

When examining the conditioning circuits needed to retrieve information from the sensors, Velostat necessitates the use of Copper Tapes, Resistors, Multiplexers, and Microcontrollers. The approximate cost of these components, when combined, ranges from Rs 3000-5000, depending on the size of the mat. On the other hand, Optical fibre requires special LEDs, Photodiodes, resistors, and Microcontrollers, which collectively amount to around Rs 21000-24000. In the case of capacitive sensors, the cost of tranimpedance amplifiers and microcontrollers will vary depending on the specific capacitive sensors being utilized.

When it comes to customization, both the Velostat based mat and the Optical Fibre based mat provide a high level of flexibility. They allow us to create mats of any size and adjust the sensor density according to our needs. However, there are certain limitations to consider. In the case of both mats, the performance of the microcontroller can be a limiting factor. Additionally, the Velostat mat may be affected by crosstalk effects, while the optical fibre mat requires a significant amount of circuitry.

If we consider prior state of the art, Velostat emerges as the prominent material surpassing both capacitive and optical fiber sensors in terms of the consistent publication of research papers and the sheer quantity of papers. A simple search on IEEE Xplore using the keywords ”Velostat” and ”Mat” in the full text yields a greater number of papers compared to those focused on capacitive and plastic optical fiber sensors.

[1] https://shorturl.at/lBNRW

[2] https://www.digikey.in/en/products/detail/broadcom-limited/hfbr-rus100z/1990493

Chapter 4

VelGmat: Velostat based Gait Mat

In this chapter we discuss the iterative process and the design of the customized mat.

4.1 Why Velostat

Velostat is a composite polymer material composed of carbon-impregnated polyethylene, which effectively transforms the dielectric nature of polyethylene into an electrically conductive material through the inclusion of carbon powder. The selection of Velostat as a pressure-sensitive material was based on several key factors:

- The cost of the Velostat was less as compared to the other sensors
- Velostat is a flexible sensor that would allow for the mat to be flexible to a certain extent. It also follows that the mat would be easy to fold as well as transport to other places.
- Velostat offers decent scalability as compared to the others. As it is in the form of a sheet, we can get a customized sheet of the size we want and then the only thing that would limit us would be the electronics required to extract the data from the mat.
- The circuitry required to extract data from the velostat-based mat is very simple compared to the other sensing materials where some transducer is used to extract the data

To gain a basic understanding of how velostat functions, we employ a multimeter to gauge the resistance of the velostat. By applying pressure to the velostat with our hand, we observe how the resistance fluctuates. Subsequently, we remove our hand to observe any changes in resistance.

Expanding upon this concept, our objective is to create an interactive sheet that can identify the specific location on the sheet where interaction occurs. To achieve this, we must extract the resistance data from the mat, convert it into a format suitable for processing and storage, and ultimately visualize it on a laptop or desktop computer.

Initially, a straightforward approach involves cutting numerous pieces of velostat into 2 x 2 cm squares. Copper tapes are then affixed above and below each velostat piece. Wires are connected to both copper tapes, with a 5V voltage supplied to one wire. The other wire is connected to a biasing resistor and grounded, creating a voltage divider configuration as depicted in Figure 4.2.

Now, the resistance values at the junction of the velostat and the biasing resistor will vary depending on the amount of pressure applied to the velostat. These values can be processed and read by the microcontroller unit. However, this approach would not be suitable for a long mat, as we had initially planned to design a 10 feet mat. The reason for this is the large number of wires that would be required for each sensor (two wires per sensor) and the significant amount of manual labor involved in cutting numerous velostat pieces.

To overcome this challenge, we explored an alternative method inspired by the iPhone touch screen technology. In the iPhone touch screen, there are driving lines and sensing lines that form a matrix. When the screen is pressed, the circuit is completed, and the location and intensity of the applied force can be determined. Taking inspiration from this, we decided to use copper tapes to create both the driving and sensing lines, with the velostat placed in between.

For the driving lines, we connected a continuously moving 5V signal to the copper tapes attached to a sheet of chart paper. Additionally, resistors were connected to the copper tapes on a separate chart paper, similar to the first approach.

4.2 Velostat based Mats

Figure 4.1 illustrates the functioning of a mat based on Velostat. When pressure is exerted on the mat's surface, the Velostat converts it into resistance. In order to convert this resistance into an analog voltage, a conditioning circuit employs a biasing resistor. The resistors then transform the current from the columns into voltage. This voltage is subsequently transmitted to a microcontroller, where it is converted into its digital equivalent by the Analog to Digital Converter (ADC). Finally, the resulting digital values are displayed on the Integrated Development Environment (IDE) of the microcontroller.

Initially, a mat measuring 15 x 15 cm was created using chart paper, featuring a 4 x 4 matrix configuration consisting of 16 sensels. The primary objective was to ensure that the mat could accurately detect both the location and intensity of touch. The data obtained from the Arduino microcontroller was then transmitted to Processing for further analysis. The microcontroller used by the Arduino mega is ATMEGA 2560. It can be programmed using the Arduino IDE. Its specifications are shown in Table 4.1

The operational procedure is as follows. Initially, physical pressure or force is exerted on the mat. In this particular scenario, our fingers are being utilized (subsequently, our foot will be employed) to apply pressure on the mat. The Velostat, which is a piezoresistive material, undergoes compression, resulting in a decrease in its resistance. Consequently, the pressure is converted into resistance. Simultaneously, as the circuit is completed, the current flows through the biasing resistor. The voltage generated across the **biasing resistor**, as depicted in Figure 4.2 , is then transmitted to the Arduino, thereby transforming resistance into voltage. Within the Arduino, an Analog to Digital converter (ADC) module is present. The Arduino Mega is equipped with a 10-bit ADC module, which has a range of 0 to 1023. This module

Table 4.1: Arduino Mega Specifications

Operating Voltage	5 V
Power supply	7 V – 12 V
Current consumption	50 mA – 200 mA
Digital I/O Pins	54
Digital I/O Pins with PWM	15
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB
SRAM	8 KB
Clock Speed	16 MHz
EEPROM	4096 bytes
Length	102 mm
Width	53 mm
Power jack	yes
USB connection	yes

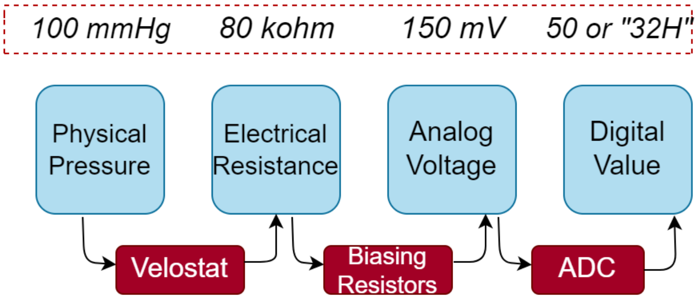

Figure 4.1: Internal Operation of the mat

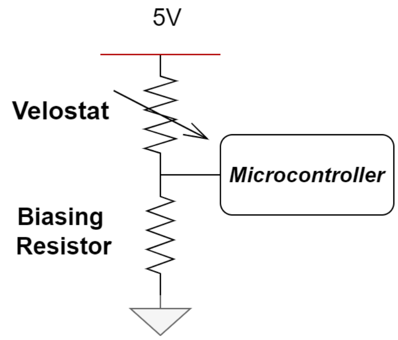

Figure 4.2: Biasing Resistor

converts the analog or continuous voltage into digital values ranging from 0 to 1023. Notably, a value of 0 corresponds to 0 Volt, while a value of 5 corresponds to 5V.

The code uploaded to the Arduino can be written using two different approaches. The first approach, known as the linear code, involves scanning the mat sensor by sensor. For example, if a sensor is located at the third row and fifth column and it is pressed, the data would be printed as 3,5@524, where 524 represents the digital value. When multiple sensors are pressed, the results are printed sequentially. However, this approach requires defining each sensor individually, resulting in an increase in the lines of code. Additionally, there is a hardware limitation as the rows of the mat need to be connected separately to digital pins on the microcontroller for providing Vcc. If the size of the mat increases, there may not be enough digital pins available on the microcontroller.

The second approach, called Mux code, involves creating a matrix of the same size as the mat. For example, for a 4x4 mat, a 4x4 matrix is created. Based on the pressed sensor, the digital value is updated at the corresponding location in the matrix. For instance, if the third row and fourth column are pressed, the value would be updated at the third row and fourth column of the matrix. In this approach, Vcc to the rows can be demultiplexed using demultiplexers, eliminating the need for individual connections as in the case of linear code. Similarly, the columns are multiplexed, and only one analog pin of the Arduino is used.

One important advantage of Mux code over linear code is that it simplifies the calculation of different metrics using the readings. With linear code, the results are printed in a linear fashion, making it complicated to perform calculations. On the other hand, Mux code allows for matrices to be printed and updated periodically, making it easier to calculate metrics and perform dynamic data visualization. Therefore, the Mux code proves to be a more effective tool in these scenarios compared to its counterpart, the linear code. The values are displayed on the serial monitor of the Arduino where lower values denote lower pressure and higher values denote higher pressure.

The Arduino's serial values were visualized using the Processing Development Environment. Within Processing, sketches were created to generate two-dimensional and three-dimensional graphics through

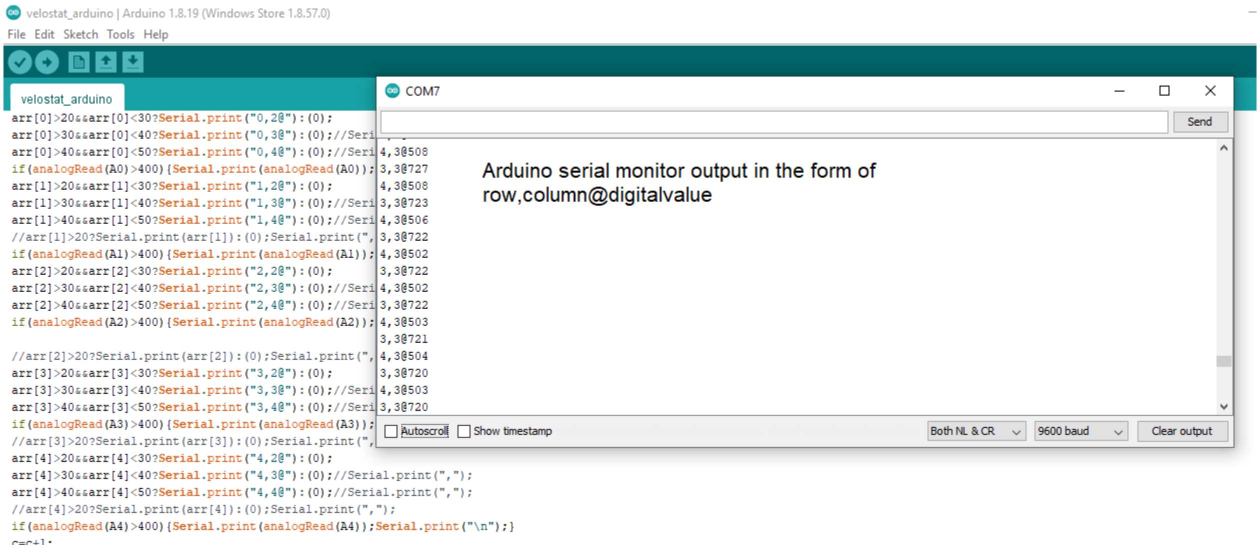

Figure 4.3: Arduino IDE output

code. A matrix was constructed, consisting of circular balls positioned at the sensels' locations. The colour intensity of each ball corresponded to the amount of pressure applied.

One of issues we noticed from this mat was Crosstalk.In this mat as we are using a matrix configuration such that individuals sensels are connected to other sensels because of continuous rows and columns so current finds others paths to flow causing activations from points on which pressure is not applied. This phenomenon is called crosstalk. Figure 4.7 illustrates that when any of the four sensels is pressed, a certain amount of current will flow in the neighboring sensels.

4.2.1 Crosstalk analysis

To reduce the crosstalk many techniques have been suggested but those are mostly hardware based techniques which increase the hardware complexity of the mat. Therefore we tried to think of other methods to reduce the crosstalk. We thought of using different configurations of Velostat as shown in Figure 4.6. We wanted to use a standard weight for all the three configurations so we chose a solid cylinder of radius 6 cm and weight of 750 grams and placed that on a fixed position on the mat as shown in the Figure 4.7. We wanted to see the digital values from the ADC in the Arduino corresponding to these weights. The following equation is used by converting a 10 bit ADC value into resistance

$R_{velostat}$ = Rbias (1023 - N)/ N

where $R_{velostat}$ is the resistance of the sensor, R_{bias} is the biasing resistor , 1023 is the maximum value of the ADC ,and N is the average value of the ADC obtained from the microcontroller. These vaues can also be converted into voltage using the following equation:

$$V_o = V_{in}(R_b/R_s + R_b)$$

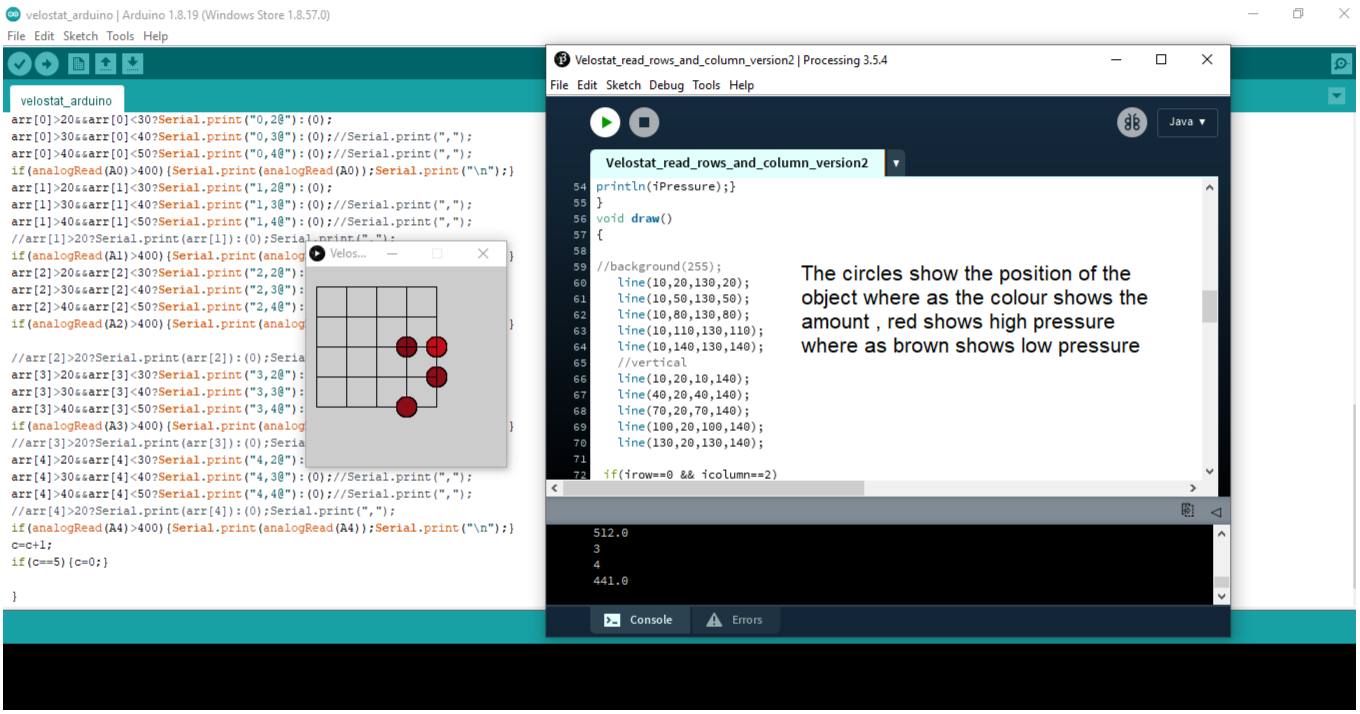

Figure 4.4: Output from Processing Software

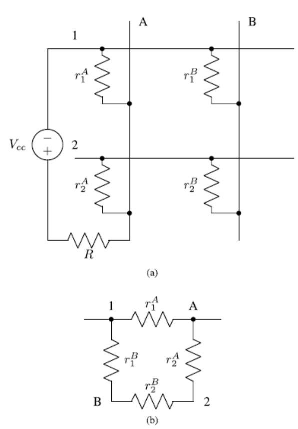

Figure 4.5: Circuit level example of Crosstalk

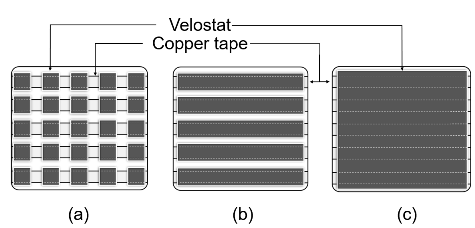

Figure 4.6: Different Configurations of Velostat

Figure 4.7: Circuit level example of Crosstalk

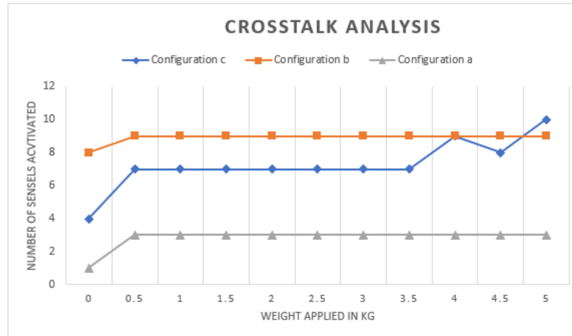

Figure 4.8: Different Configurations of Velostat

where V_o is the output voltage, V_{in} is the input voltage which is held constantly at 5V, R_b and R_s are the bias resistance and the Sensor resistance or velostat resistance respectively. 1023 here corresponds to 5 Volt and 0 corresponds to 0 Volt.

Configuration C

The threshold value was With only the cylinder placed on the mat was 50. With only the cylinder on the mat four sensels were activated and the maximum value was 127. Now using Force gauge we applied force on top of the cylinder as shown in Figure 4.7 starting from 0.5 Kg to 5 Kg with an increment of 0.5 Kg each time. Now when 0.5 Kg was applied 7 sensels were activated with a maximum value of 300. As we increase to 1Kg, 1.5 Kg upto 3.5 Kg 7 sensels are activated with the individual values increasing as the weight increases. At 5 Kg 9 sensels are activated with values greater than 200 in six of them and the maximum value being 484. At 4.5 Kg, 8 sensels were activated with the maximum value being 494. At 5 Kg 10 sensels were activated. The weight was applied for a minimum of 30 seconds so that the values would stabilize and after the removal of the weight, a waiting time of 10 seconds was chosen for the values to go back to the baseline.

Configuration B

In this configuration, as shown the velostat was only on copper strips and empty space was left in between. With only the cylinder placed on the mat 8 sensels were activated with a maximum value of 184. As we see in the Figure 4.8 as the weight increases, the values increase and the neighbouring values also increase non linearly. There is some improvement as compared to Configuration C as the number of sensels activated as same regardless of the weight increase.

Configuration A

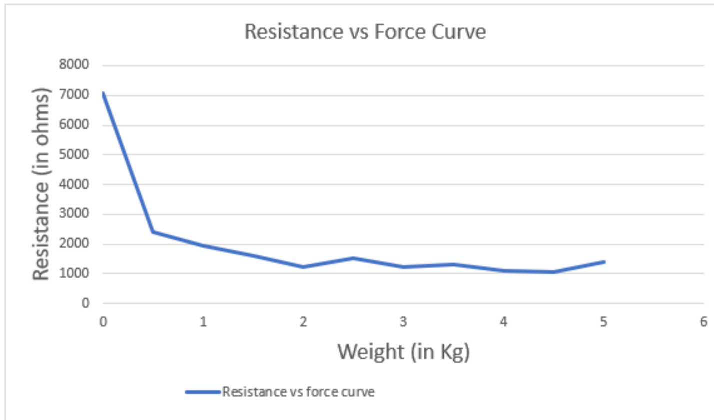

Figure 4.9: Resistance versus force applied for Velostat

In this configuration the velostat was cut to size a little bigger than the size of each sensel and was placed on each sensel. With only the cylinder placed on it , 1 sensel was activated with a value of 66. As we increased the weight to 0.5 Kg 3 sensels were activated with a maximum value of 286 and further as we went on increasing weights upto 5 Kg the number of sensels activated remained constant but the maximum value increased.

Overall the conclusion was that the best configuration for reduced crosstalk was Configuration A. For small mats this is a good solution but as the size increases and the number of sensels go into thousands, the process of cutting Velostat into small rectangular pieces beacomes very tiresome as well as consumes a lot of time. To reduce crosstalk and to save time by using configuration C, we decided to look for another solution by analysing the data from the mat.

Calibration: The curve for the resistance of the mat versus the force applied was drawn for the mat in Configuration C. The curve is shown in 4.9

Uniform Filtering: Filters are used to remove unwanted noise to give the desired result. Here we decided to reduce the crosstalk by using the Uniform filter. Uniform filters are implemented as 1-D uniform filters, and intermediate arrays are stored in the same data type as outputs The sizes of the uniform filter are given for each axis as a sequence of integers by the size parameter Depending on the number of dimensions of the input array, the filter can be centered over the pixel (the default), or shifted left or right. The uniform filter can be used for multidimensional image processing It applies the same weights to all pixels in the filter window, making it a type of spatially uniform filter Overall, the uniform

Figure 4.10: 15x15 mat

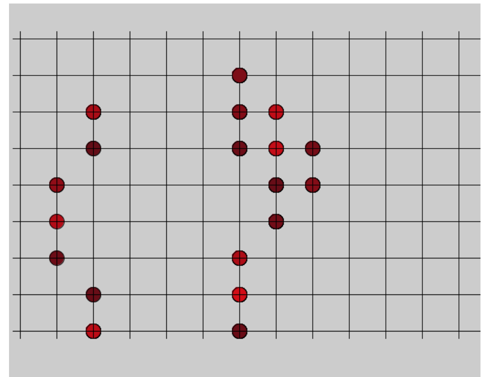

Figure 4.11: Foot Visualisation in Processing

filter is a simple and intuitive method of smoothing images, and it can be used in a variety of image processing applications.

4.2.2 1.8 x 1.8 feet mat

After all of this analysis the next target was to capture both feet using the VelGmat so we decided to increase the size of the mat. We chose a size where both feet can be comfortably placed on the mat. The size of the mat was chosen to 1.8 x 1.8 feet. Two mats of the same size were made but the sensel density of the two was kept different. One had a matric configuration of 15x15 where as the other had a configuration of 30x30. We used two 16:1 multiplexers for the analog output and two 16:1 demultiplexers to supply the Voltage(Vcc).

Mat 1: For this mat the sensel density was 15x15 as shown in Figure 4.8. The width of the copper tape was 2.5 cm, and the spacing between the copper tapes was kept at 0.5 cm. Now Processing software was used to see the visualisation of the feet as shown in Figure 4.9

The horizontal and vertical lines are the 15x15 matrix, and the coloured circles are the activated sensels. The light red colour in the visualisation represents less pressure applied, whereas the dark red colour represents high pressure applied by the foot.

Mat 2: For this mat the sensel density was 30x30 as shown in Figure 4.12 This was done by reducing the width of the copper tape to 1.25 cm and the spacing be 0.75 cm The higher sensel density was chosen in order to get a more accurate foot pressure visualisation. In this case we switched to visualisation using

Figure 4.12: 30x30 mat

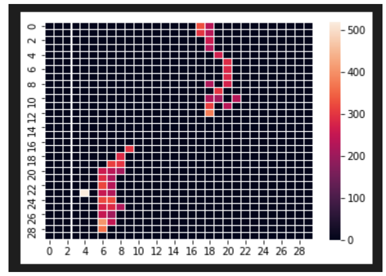

Figure 4.13: Static Data Visualisation

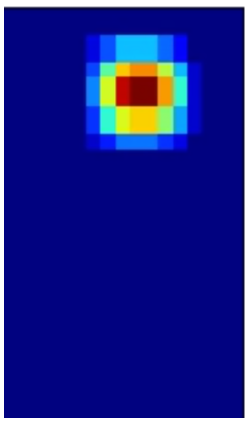

Figure 4.14: Heel Strike

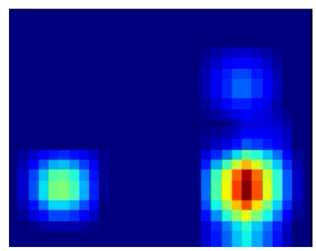

Figure 4.15: Both feet with one foot toe off

Python. First we used linear coding and used PLX DAQ extension to store the activation and the value of the pressure applied in a excel sheet and used that excel sheet to generate a heat map with code written in python. The heat map of the two feet is shown in Figure 4.13

For gait analysis, this type of visualisation would not suffice a dynamic visualisation that would give us the details of every sensel before the point of contact of the feet as well as after would be needed. For that the Mux code was used because it prints continously with a frequency depending on the microcontroller using a matrix of the same size as the matrix configuration of the mat, and then the persons steps on the mat the matrix is updated based on where the person stepped and the amount of pressure that was applied on the mat. The data from the mat was recorded and stored in the form of a text file using CoolTerm software. Also Uniform filtering was used to reduce the crosstalk. The data visualisation is as shown below in the sequence of the heel strike of the person, complete foot and then the toe-off.

Table 4.2: STM32 Specifications

Input Voltage	2 - 3.3 V
Flash Memory	128 KB
SRAM	20 KB
Clock Speed	72 MHz
Digital I/O Ports	37
Analog Pins	10
Timers	3
I2C Ports	2
SPI Ports	2
ADC	12 bit

Scanning Time: Moving forward the issue at hand was the scanning time of the mat. Scanning time refers to the time taken to scan all the sensels of the mat. Its importance was judged by the fact that if the scan time is more than the time taken by a foot to land and come off a ground then significant data from the foot would be lost so it is important to have less scan time for more reliable results. Keeping this in mind we also looked at alternatives to Arduino Mega as the specifications of the micrcontroller play a big role in the scanning time of the mats. Usually for Arduino Mega the clock is 16 MHz but it also has a prescaler which limits the amount of clock that can be used by the microcontroller(the clock frequency is divided by the prescaler), by default the prescaler is 128, also as we are reading analogue inputs one command to read the analogue values takes 13 clock cycles to execute, so the resultant frequency comes out to be 9600 Hz which means approximately 104 microseconds per reading.. Now we did some assembly-level programming to change the prescaler of the microcontroller, the optimum value for us was 16, so we choose it and the speed increased from 104 us per reading to 15 microsecond per reading but still as we decreased the Prescaler the reliability of the data from the arduino gets slightly decreased. So we looked at alternatives, after looking at the literature and datasheet we chose STM32F103C8 also called as the blue pill . The STM32F103C8 does not come with an inbuilt programmer as the arduino therefore an external USB to TTL serial adaptor is required to program it . The specifications of the microcontroller are shown in table 4.2. Also from the datasheet of the microcontroller states that the total conversion time of the microcontroller is 18 microseconds. Then in both Mat A and Mat B we calculated the scan time using arduino with once the default prescaler of 128 and the second time changed the prescaler to 16 . Along with that we also checked the time taken by the linear code as well as the mux code. The same thing was repeated using STM32 but using Mux code only. The details are in the table 4.3

Table 4.3: Full Scan Time Readings Of Mats

Array	**Lin. *P-128 (μ s)**	**Lin. *P-16 (μ s)**	**Mux *P-128 (μ s)**	**Mux *P-16 (μ s)**	**STM32 (μ s)**
15 x 15	4796	1928	164652	68552	48905
30 x 30	10780	5072	559568	305252	211223

*P - prescaler for the microcontroller

Sensitivty and Range: Sensitivity is how faint a touch can the mat reliably detect and range the maximum value it can give above which it saturates. Now Sensitivity and range are analysed from two aspects one is from the biasing resistor point of view and the second is the number of velostat sheets. In [112] it was found that for larger values of bias resistance, the sensitivity of the sensor is high but the range of pressure is low and vice versa so for an optimum value of 1k the sensitivity was relatively less but the range of pressure was high. Here kept the bias resistor constant at 1k but we changed the number of Velostat sheets that are in between the matrix configuration. For analysis on range we cut 5 sheets of Velostat of same size as the mat to place one by one on the mat. In the case of only one Velostat, we placed an object of cylindrical geometry of standard so that the base might be a circle and measured the analog values , similarly the number of Velostat sheets was increased from one to five and the analogue values were monitored as expected the values decreased indicating that the range increased as for a weight of 2kg for 1 sheet if the maximum value is 592 then if we increase the weight the value would saturate easily as the maximum value is 1023(for 10 bit ADC) but the same weight in case of 3 Velostat sheets the values is 419 then this value would not saturate as fast as the previous. Now for analysis on sensitivity we used the same setup as done for range, we used the linear code here because we wanted to see whether a particular sensor is activated or not, then an object of cylindrical geometry having a circular base was placed. First one sheet of Velostat was selected and the number of sensors activated was noted and then the number of sheets of Velostat were increased from one to five and the number of sensors getting activated were noted. It was seen that the number of sensors activated decrease on increasing the number of Velostat sheets. Readings are shown in the table 4.4.

Table 4.4: Sensitivity And Range Of Mats

Velostat Sheets in series	**Active Sensors area (cm^2)**	**Sensors activated**	**Maximum value from ADC**
1	3.75	3	592
2	2.5	2	510
3	1.25	1	419
4	1.25	1	342
5	0	0	-

*Threshold value for ADC scaling - 300 with max. value - 1023

Thus, more layers of Velostat extended the detected pressure range but also overall the capacity of the sensor to detect small pressure changes decreases so we have to choose an optimum value for our application. Based on the readings the optimum value we have chosen is 2.

4.2.3 Sensing Tex Mat

For validation of our mat, we purchased a commercial 3.3 x 3.3 feet pressure sensing mat as shown in Figure 4.16. Sensing Mat Development Kits (Sensing Mat Dev Kits) enables the usage of the Sensing Mat Platform and related Technologies in multiple applications including health monitoring, wellness, sports and human interface with software, among other applications. They also provided software with the mat. This software includes basic features like pressure map representation with configurable pressure-colour scale, and pressure map data export into .JSON files. But also advanced tools for analysis of pressure maps such as recording of pressure map sessions, and pressure map session player in order to enable the record and analysis of pressure map sessions. Our main aim was to use sensing Tex for gait analysis, so we purchased three mats to get an overall size of 10 x 3 feet mat.

4.2.3.1 Stance Phase Calculation

Gait analysis has been used extensively in sports, surveillance and healthcare. Gait cycle has two phases, one phase is called the stance phase and the second phase is called swing phase. The stance phase begins with heel strike of the participant and ends with the toe off which is when the toe is completely lifted off the ground. It is the 60 % of the gait cycle. The swing phase begins with the toe

Figure 4.16: Sensing Tex mat

Figure 4.17: Heel Strike(t1)

Figure 4.18: Toe off(t2)

off i.e. When the foot is in the air and ends with the heel strike i.e. when the foot just starts to touch the ground [113]. Here as we have a 1.8x1.8 feet mat we will only be able to calculate stance phase for different participants. Now for this study we have Mat 2 i.e 30x30 mat with mux code and compared it with the Sensing Tex mat. The time of the heel strike of person t1 was noted as well as t2 time was noted as shown in 4.17 and 4.18 and stance phase was calculated by subtracting t1 from t2. Each participant performed three walks and the stance phase value was the average of the three values.

4.2.3.2 Participants and Results

Ten participants with range of age from 22 - 30 years volunteered to participate in the stance phase experiment. These participants have no known health ailments and have normal body posture. These participants are asked to take a natural walk on both mats (VelGmat and commercial mat). The Figure

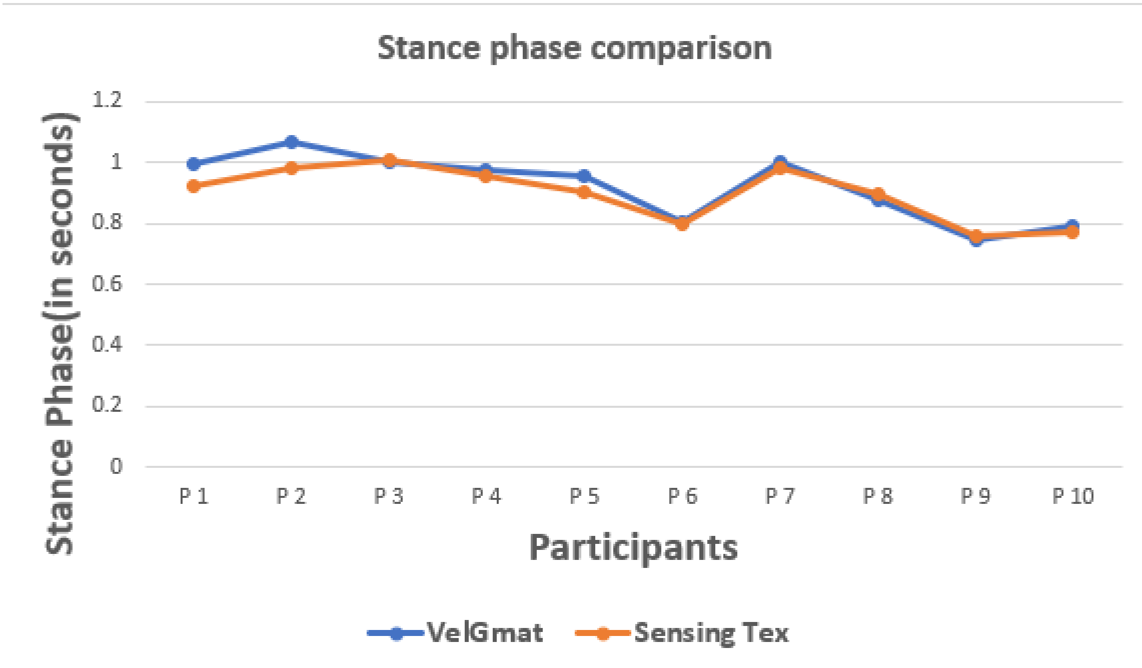

Figure 4.19: Comparison between Sensing Tex and VelGmat

4.19illustrates the comparison of stance phase calculation for both mats. The stance phase accuracy of our customized VelGmat was observed to be 95% of the stance phase values of the commercial mat.

4.2.4 3.5 x 2 feet mat

After the success of the 1.8 x 1.8 feet mat the next challenge was to increse the length of the mat so that we would be able to calculate other Gait analysis parameters such as

1. **Stride Length**: It is the distance between the first placement of the foot and the second placement of the same foot
2. **Stride velocity**: It measures how fast or slow a person is while completing the stride
3. **Cadence**: It is the number of steps per minute
4. **Gait Cycle**: It includes the stance as well as the swing phase.Stance is the term used to designate the entire period during which the foot is on the ground. Stance begins with initial contact. The word swing applies to the time the foot is in the air for limb advancement. Swing begins as the foot is lifted from the floor (toe-off).

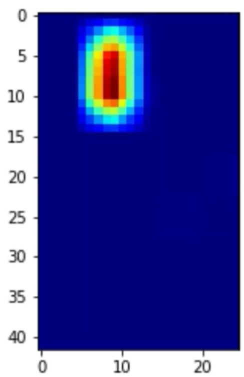

Figure 4.20: First foot

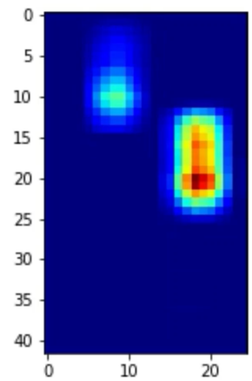

Figure 4.21: First foot coming off and Second foot

The main issues with the increasing size were the increasing scan time, sensitivity and range and also the sensel density and how that would impact the foot pressure visualisation.We started out with a 5x2 feet mat and started to analyse it with respect to all those parameters mentioned above. The crosstalk was there even after the unifrom filtering, the scan time was high more than 1s for the 5x2 feet mat using arduino Mega. Then we kept on reducing size and experimening until we reached the size in which all factor be it scan time, sensitivty and range and foot pressure visualisation were satified and that was 3.5 x 2 feet mat with a matrix configuration of 42x25.

4.2.4.1 Results of data Visualisation

The microcontroller used was STM32F103C8; mux code was used which uses raster scan method to search every sensel of the mat. One sheet of continuous velostat was used. The scan time of one mat was 222 mili seconds. The data from the mat was recorded and visualised. The results of that visualisation of data are shown in 4.20, 4.21, 4.22 and 4.23 respectively.

As the 3.5 x 2 feet mat was working correctly we replicated the design process and two other mats of the same size were made and then combined to form a 10.5 x 2 feet mat. The data from the mat could be recorded and gait metrics like stride length, stride velocity, cadence and gait cycle could be calculated from them.

4.2.5 10.5 x 2 feet mat

The complete setup was placed so that the three mats are placed in front of one another, as shown in Fig. 4.24. The data was recorded simultaneously from all three mats. As in Fig 4.25 in the first module,

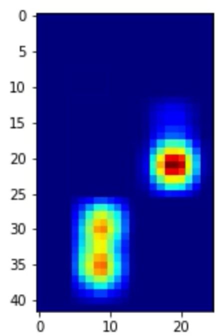

Figure 4.22: Second foot coming off and third foot

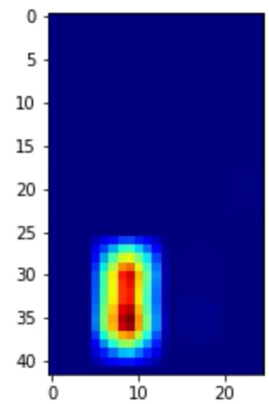

Figure 4.23: Third foot

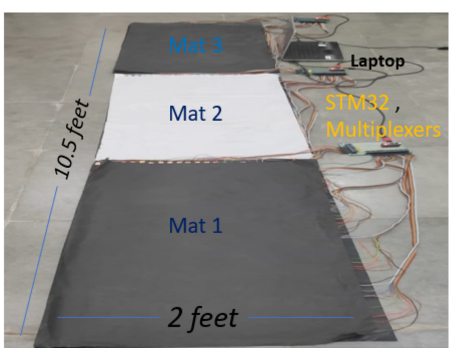

Figure 4.24: 10.5 x 2 feet mat

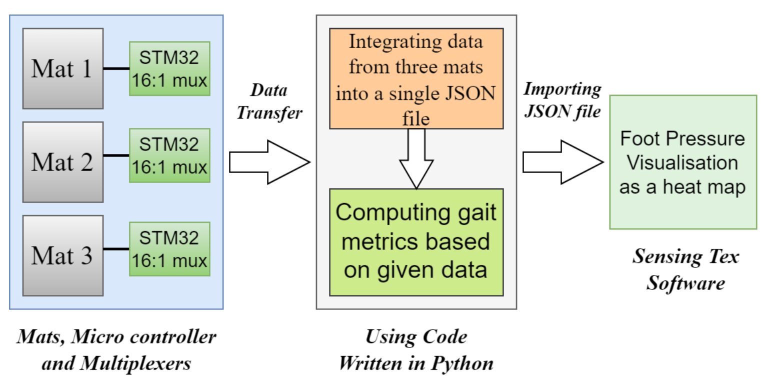

Figure 4.25: Modular Design

the mats along with the Multiplexers and Microcontrollers are responsible for the data collection. The data is Transferred and stored by the PC. Now the data is converted into a JSON file by a Python Script. The JSON file is fed to another python script for calculation of gait parameters. The same file is feed to back Sensing Tex software for foot pressure visualisation.

4.2.5.1 Data Visualisation

A brief background on sensel density is necessary before discussing data visualisation. Agrawal, Tarun Kumar, et al. designed a Velostat-based mat of dimensions 6.56 x 3.28 feet [114]. The sensel density was 16x7 and the spacing between the conducting materials was 8.7 cm leading to less sensel density as compared to Kim, Young, et al. The mat in case of Kim, Young, et al was 2.95 x 1 feet in dimensions but had a sensel density of 42 x 24 [115]. In case of Kim, Young, et al foot pressure can be visualised with ease as compared to Agrawal, Tarun Kumar, et al. Our VelGmat is 3.5 x 2 feet and three combined makes it 10.5 x 2 feet and has a sensel density of 42 x 25. Thus, both calculation gait parameters and visualisation of foot pressure can easily be done.

The data was transmitted to the PC at a sampling rate of 5 Hz. Matrix size was 42x25 for one mat and 126x25 for three mats. The issue of crosstalk was addressed through the implementation of a Python script. The script processed data extracted from the mat by applying uniform filtering. Uniform filtering is a computational technique wherein each pixel's value within an image is substituted with the arithmetic mean of the surrounding pixel values, with equal weighting. Additionally, unwanted or spurious data points were eliminated by enforcing a constraint that confined the range of these spurious data values to zero. This constraint effectively nullified or removed the undesired data points, ensuring that they did not contribute to the final processed data. The heat map of the data from one mat is shown in Fig. 4.26.

To enhance data visualisation efficacy, the data from the three mats was converted into a JSON file compatible with the Sensing Tex software[1] and data visualisation was performed. The visualisation is shown in Fig 4.27.

4.2.5.2 Cost Effective VelGmat

VelGmat is a low cost attempt to calculate gait parameters.The three mats combined were around 150-180 USD. This is very economical as compared to the sensing Tex which is around 1500 USD.

[1]https://sensingtex.com/sensing-mat/

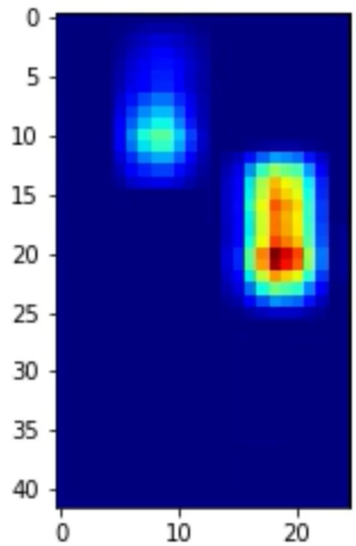

Figure 4.26: Heat map of right foot taking off and left foot on the mat

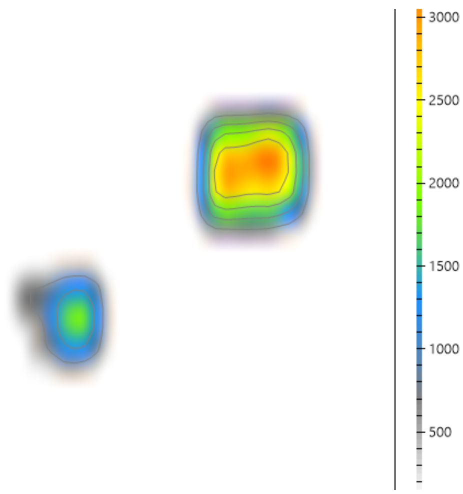

Figure 4.27: Heat map of right foot taking off and left foot on the mat on Sensing Tex Software

For a fair comparison Sensing Tex is better in terms of full mat scan time and response from the mat is very fast compared to VelGmat, Sensing Tex has various other software tools for data analysis. The VelGmat's size was kept at 3.5x2 feet to get a full scan time which is less than minimum time for which the foot is on the ground i.e. 60% of the gait cycle (around 0.6 seconds) [113] [116] . With lengths beyond 3.5 feet, the full scan time would increase, and data loss would occur.A single layer of Velostat sheet was used. Also, the foot pressure data was analysed, with plots such as the maximum pressure versus time and mean pressure versus time. After looking at the graph of mean pressure versus time it was observed that in most of the participants, the mean pressure in the Negative environment was more than the mean pressure in the positive environment. It can be interpreted as follows in a negative environment as there is darkness the walk was more careful as compared to a relatively free walk in the positive environment.

Chapter 5

Virtual Reality and detection of depression

In this chapter, we will discuss the role of Virtual Reality in the detection of depression

5.1 Virtual Reality

Reality is known to people as things that can be seen or feelings that can be felt. Imagination and dreams are somethings which are close to reality.Everyone is unable imagine the same and dreams can't be tapped into as of yet. Television, cinema, animations are things that are meant to mimic reality and show people something that they forget the 'reality' for a short period of time. Nevertheless, people merged the real world with an imaginary world, making the difference seem very bleak. Virtual Reality is one of the steps in this direction.The word virtual reality is an oxymoron but also some people prefer to call it a neoplasm. Ivan Sutherland in the 1960s developed the first VR system.The idea is to simulate a virtual environment so that the user perceives it as real. The more disconnected from actual reality one becomes in other words the more realism virtual reality produces the more successful a virtual reality environment. It has been in the limelight for the past 2-3 decades. As explained in the second chapter there are immersive and non immersive forms of VR. Immersive forms which use a Head Mounted Device(HMD) are more popular.

It has the potential to revolutionalise many industries such as gaming, healthcare, education and entertainment. As of now, it is very popular in the gaming community VR has applications in Gaming, Healthcare. Now in the case of mental health specially VR is a gamechanger beacuse of its ability of immersiveness and customisability of scenes. As already mentioned in the introduction the issues with the conventional methods of detecting depression mainly being with the subjective assessment are addressed using VR by creating an environment that is capable of evoking emotions.

5.2 Virtual Reality scenes

As discussed in Chapter 2 the different virtual environments used for the detection or intervention of depression were shown. For our experiment, we also designed novel VR environments. We referred to them based on the emotions that they evoke and named them the positive, negative and the neutral scene. They are shown in Fig. 5.1, Fig. 5.2 and Fig. 5.3.

5.2.1 Virtual Reality Head Mounted Devices

Initially the VR Head Mounted Device(HMD) used was the Occulus Quest 2 from Meta which is equipped with an Octa-core Kryo 585 CPU (1 x 2.84 GHz, 3 x 2.42 GHz, 4 x 1.8 GHz) and an Adreno 650 GPU. It has 6 GB of RAM and 128 GB or 256 GB of storage. The display resolution is 1832 x 1920 per eye and it supports a refresh rate of 60 Hz, 72 Hz, or 90 Hz [1].As the graphics of the scenes enhanced the quest 2 processing capabilities were not enough for the scene.
As a result we switched to HTC Vive Pro 2.The headset has a dual RGB low persistence LCD screen with a resolution of 2448 × 2448 pixels per eye (4896 x 2448 pixels combined) and a refresh rate of 90/120 Hz. It has a field of view of 120 degrees and requires two compatible base stations and two compatible motion controllers to fully work. We used a PC with RAM 16GB and graphics Card 970 [2].

5.3 Experimental Setup

5.3.1 Background

The VelGmat being a low cost option of a pressure sensing mat was developed as an alternative to the commercially obtained Wellness mat from Sensing Tex[3]. Three such mats were placed in such a way that the second mat was placed at the end of the first one thus forming a 10.5 x 2 feet mat as shown in Fig. 4.24. The VR scenes designed in Unity were loaded into the HTC Vive Pro.

[1] https://www.meta.com/gb/quest/products/quest-2/tech-specs/
[2] https://www.vive.com/uk/product/vive-pro2/specs/
[3] https://sensingtex.com/sensing-mat/

5.3.2 Method

5.3.2.1 Participants

We collected data from 5 participants. The participants were all college students with a mean age of 22 years. The participants had no history of depression. They had no to minimal exposure to VR. The PHQ scores [117] as well as the gait analysis values were recorded. The PHQ-9 range from 0-4 indicates no depression, 5-9 indicates mild depression, 10-14 indicates moderate depression and 15-19 indicates moderately severe depression. The participants reported no(n=2) to mild depression(n=3) and the gait values corresponding to that are mentioned in [118][4]. . The screening was done on the basis of the following:

Inclusion criteria: The target population is college-going young adults aged 18 to 30.

Exclusion criteria: Individuals that report having been diagnosed with or having a history of Major Depressive Disorder(MDD) or other mental disorders for more than 1 year. Individuals reportedly undergoing pharmacological interventions or taking prescription drugs. Individuals reporting having epilepsy, visual impairments, or spine and leg injuries that could affect the VR experience or the Gait mat parameters.

5.3.2.2 VR Environments

We developed three VR environments to evoke positive, negative, and neutral affective experiences, while they locomotively explore the environment to record their gate behavior. All three environments have a 10 x 2 feet aisle with 6 feet high shelves on both sides 2 feet apart. There are two similar aisles on the right and left that allow the players to circle the right and left shelves in a clockwise and anticlockwise manner, respectively. The walking area is separated from the forest by a glass wall. The right aisle has an opaque wall with images on it in positive and negative environments. Both shelves are stacked with four objects on three different levels. The aisles on the sides have crates in the corners. The tree assets used in the forest were imported from the Unity Demo URP terrain.

Positive environment: The environment is designed to elicit happiness in the participant. This is done by using bright warm lighting and saturated colours. The objects to be picked up are coloured light blue and light pink and thus easy to differentiate [119] [120]. The images on the display wall are selected from the IAPS database with high valance ratings (above 50) [121].

[4]https://doi.org/10.5281/zenodo.10020931

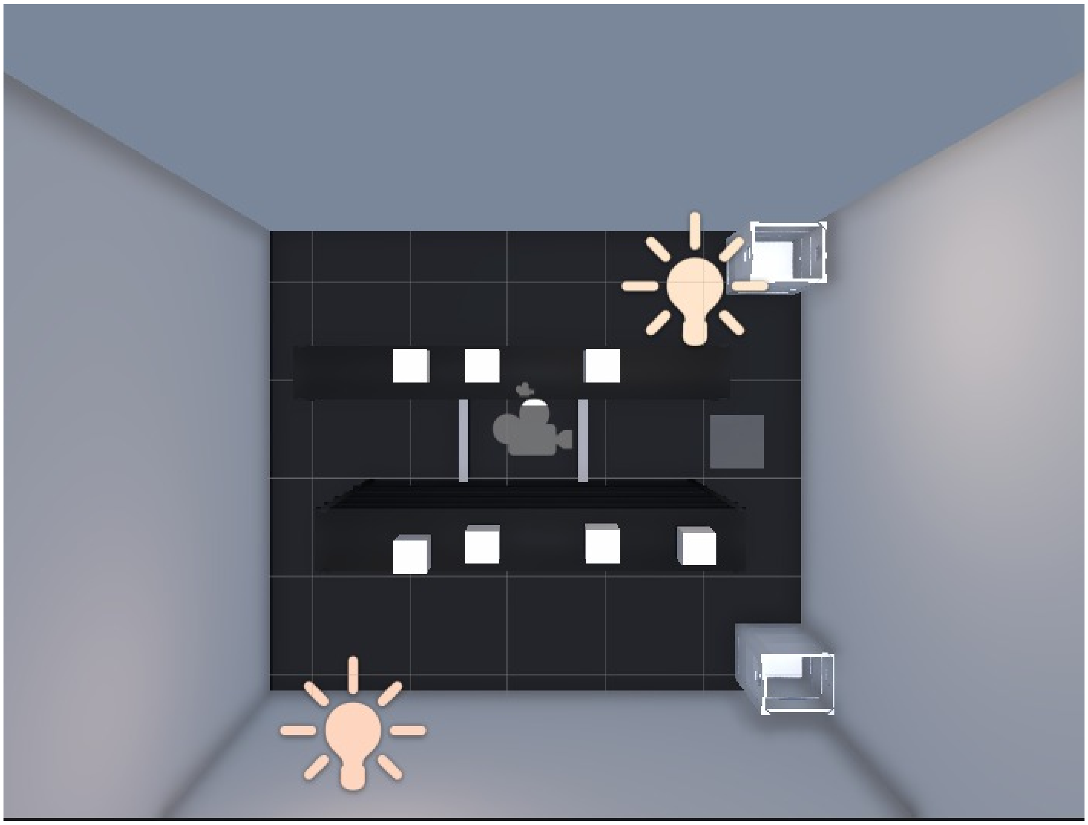

Figure 5.1: Neutral Environment

Negative environment: The environment is designed to elicit sad emotions in a participant. This is achieved using a dark setting with low-intensity light and dull colours. The shelves are bulkier and thus make the space feel more congested. The objects to be picked up are coloured dark brown and dark green making them tougher to differentiate. [119] [120]. The images on the wall depict decay and suffering. These were also selected based on the IAPS database ratings below 50 [121].

Neutral environment: It is the control environment designed to collect participants' gait data without emotional elicitation in the VR. The Scene contains black and white colours on all the objects, with no Images on the wall and no music. The images of the environments are shown in Fig. 5.1, Fig. 5.2 and Fig. 5.3[5].

The session began with participants' requirement to fill out a consent form in which they were informed about their rights to withdraw from the study, and the anonymity of their data. Further, they were informed about the procedure and the material used in the study. Participants who agreed to con-

[5]Credit to this section goes to Dr Priyanka Srivastava and Rohan Lahane

Figure 5.2: Positive Environment

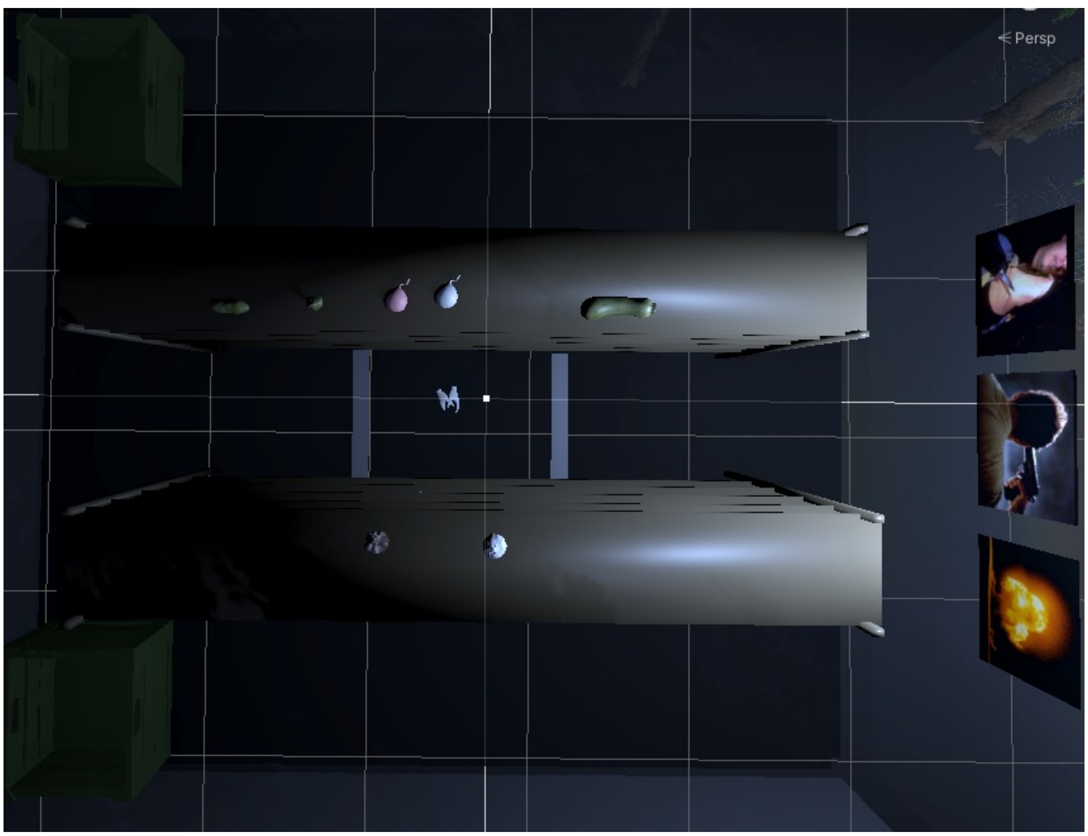

Figure 5.3: Negative Environment

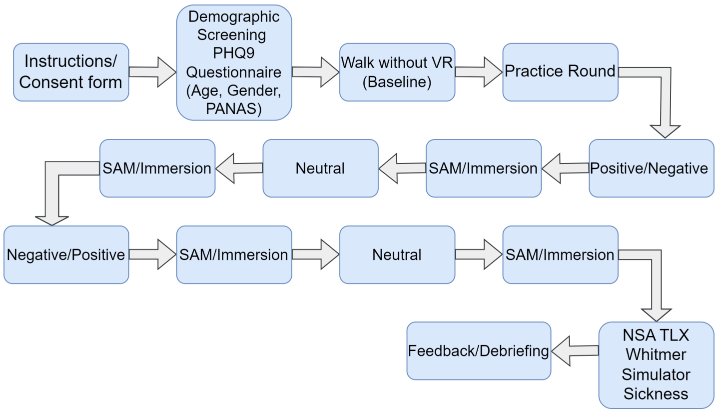

Figure 5.4: Flow of the experiment

Figure 5.5: Subject walking on the mat wearing VR headset

tinue and cleared the screening form were asked to fill out the Positive and Negative Affect Schedule (PANAS) to assess their mood before the experiment, followed by walking on the gait mat as they normally would. Their gait was recorded in the non-VR condition to set a baseline for the other readings. They were then made familiar with the controls of the VR headset and controllers. A chance to practice the task of this study was given to make sure difficulty in using the device would not be an issue while collecting data. A Visual example is shown in Fig. 5.5

The immediate mood was recorded using the PANAS after every walk, PHQ-9 [117] was used to record their self-reported depressive mood state after completing the VR environment exploration.

The participants were instructed about the specifics of the task they were expected to perform. For example: “Walk around in the environment once clockwise around the right shelf and once anticlockwise around the left shelf, and in each round, while returning, pick up the specified object and place it into the respective crate”. After completing the tasks within one environment, participants were given a break outside the VR and asked to fill out the SAM questionnaire to share their affective experience of the environment [122]. Upon completion of all three environments, the participants were asked to evaluate the environment in terms of cognitive and physical load using NASA TLX, presence and involvement in the environment using Whitmer’s presence questionnaire, and virtual reality induced symptoms and effects using Kennedy’s simulator sickness questionnaire (SSQ). Further participants were asked for verbal feedback on how they felt. It took 40-45 minutes for one participant to complete the whole

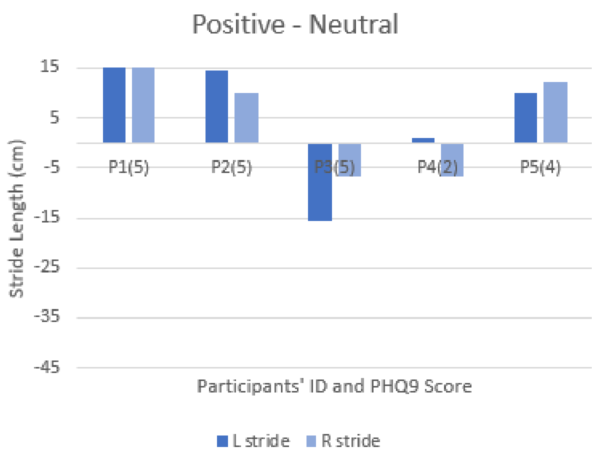

Figure 5.6: Stride length in positive as compared to neutral

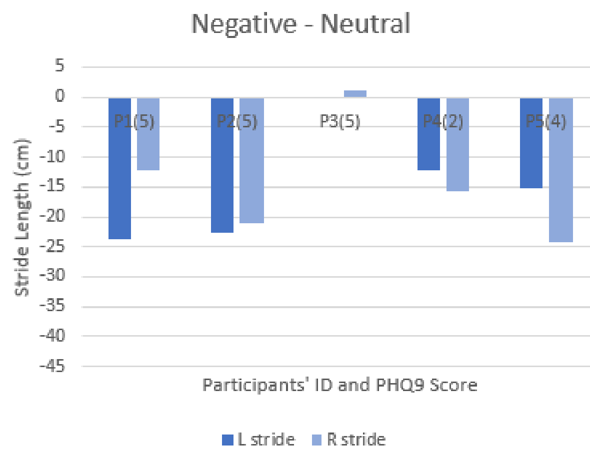

Figure 5.7: Stride length in negative as compared to neutral

process. The flow of the experiment is shown in 5.4. The positive and negative environments were randomised for each participant in order to minimise the order effect.

5.3.2.3 Results

The study investigated the relationship between PHQ (Patient Health Questionnaire) scores and gait patterns across different conditions, such as the absence of virtual reality (no VR), as well neutral, negative and positive VR conditions. The resultant gait values and graphs are shown in [118][6]. In the no VR condition, no significant correlation was found with gait velocity , while there was a noteworthy negative correlation between PHQ scores and right stride length (Rr = -0.6). A weak positive correlation was observed between PHQ scores and cadence (r = 0.13) in this condition. Under VR neutral condition 1, there were negative correlations for stride length (Lr = -0.17, Rr = -0.15), velocity (Lr = -0.57, Rr = -0.58), and cadence (r = -0.46). In VR neutral condition 2, negative correlations were found for stride length (Lr = -0.15, Rr = -0.51) and cadence (r = -0.33), and there was a strong negative correlation with right velocity (Rr = -0.75).

In the VR positive affective conditions, there were positive correlations between PHQ scores and gait parameters, including stride length (Lr = 0.06, Rr = 0.4), velocity (Lr = 0.07, Rr = 0.42), and cadence (r = 0.19). However, in VR negative conditions, PHQ scores were negatively correlated with stride length (Lr = -0.19, Rr = -0.16) and positively correlated with cadence (r = 0.61). In VR positive-neutral1

[6]https://doi.org/10.5281/zenodo.10020931

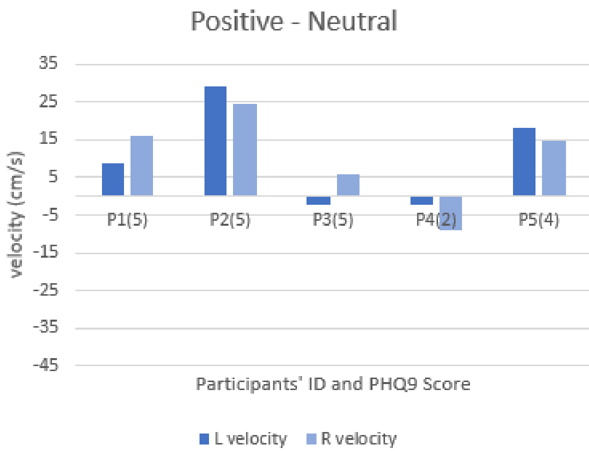

Figure 5.8: Stride velocity in positive as compared to neutral

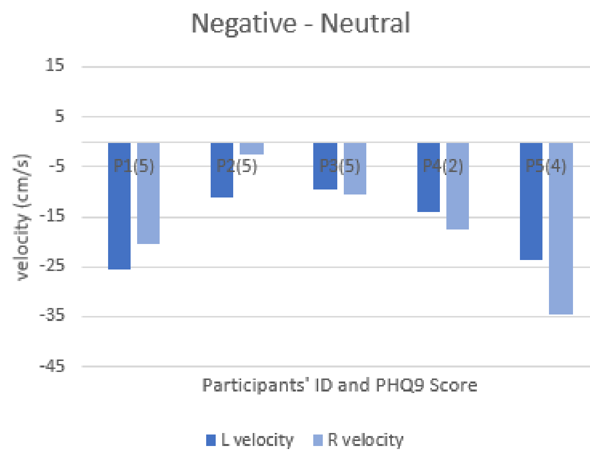

Figure 5.9: Stride velocity in negative as compared to neutral

conditions, PHQ scores showed positive correlations with stride length (Lr = 0.20, Rr = 0.48), stride velocity (Lr = 0.41, Rr = 0.80), and cadence (r = 0.35). In VR negative-neutral2 conditions, right stride (Rr = 0.25), right velocity (Rr = 0.30), and cadence (r =0.67) exhibited positive correlations, whereas left stride (Lr = -0.15) and left velocity (Lr = -0.04) had weak negative correlations. The stride length was longer, and stride velocity was faster in the positive environment with respect to the neutral as shown in 5.6 and 5.8 and shorter and slower with respect to the neutral in the case of the negative environment as shown in 5.7 and 5.9.

When comparing depressed and non-depressed groups based on median PHQ values (5 versus 2 and 4), using descriptive statistics differences in stride length, velocity, and cadence were observed in the Positive-neutral1 and Negative-neutral2 conditions. However, due to the limited sample size, inferential statistics were not conducted.

5.3.2.4 Impact of VR scene on Participants:

The scenes were designed to have higher valence for positive and lower values for negative, but the results using questionnaires showed higher valence for negative as shown in Fig. 5.10, but the effect was observable in gait, as described previously. The results of the Simulator sickness questionnaire showed that one participant experienced a bit of sweating, another participant experienced slight eye strain, difficulty focusing and dizziness. The other participants did not report any such experience.

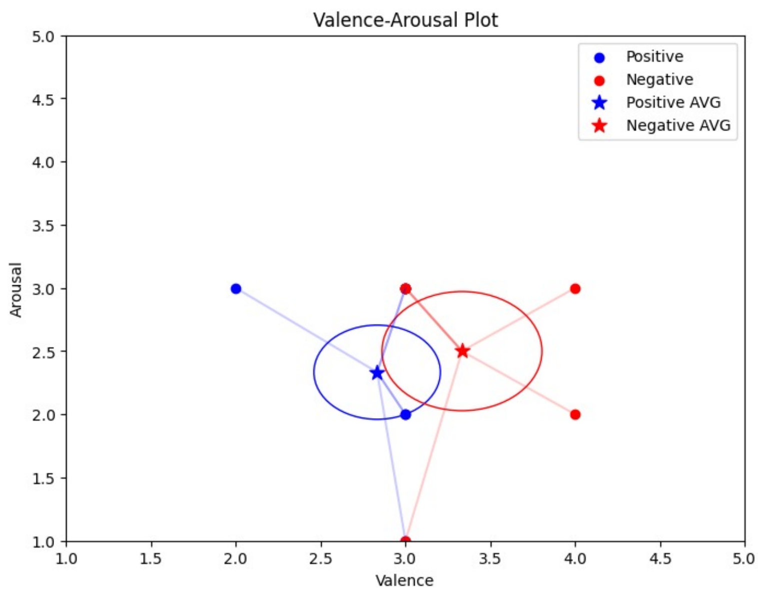

Figure 5.10: Valence Arousal graph for VR scenes

Chapter 6

Conclusion and Future Work

In this section, the results and inferences from the use of VR and gait mat, as well as other hardware in the field of Healthcare, would be summarised. Making more quantitative, free from bias assessments for disorders, especially mental health disorders, is something every medical professional strives for. The use of VR and a gait mat for the detection of depression is a small step in this direction. For this process to move forward smoothly, challenges on both the VR front and the Gait detection front need to be addressed. This thesis identified the obstacles with the mechanism for the gait analysis, proposed a solution and tested it using empirical studies.

6.1 Contributions

The contributions from the thesis can be illustrated in the following-

- **Design**
  - The rates of depression are skyrocketing in different parts of the world. The conventional methods of detection are very costly, require more manpower and are prone to bias. As part of the thesis, we developed a 10.5 x 2 feet VelGmat, which is a mat for performing gait analysis. Gait behaviour has been found to be closely related to depression.
  - To prime the participant to feel in a certain situation we used Virtual Reality and designed various environments like positive, negative and neutral scenes which would evoke emotions in the participant.The scenes were designed keeping the dimensions of the VelGmat in mind

- The mat and the VR setup provide a fertile base to test the gait parameters of participants in different environments. The gait data along with the data from the PHQ questionnaires can be sent to health care professionals for further analysis.

- **Application**
  - We validated the VelGmat against the Sensing Tex which is a commercial mat for gait parameters like the stance phase of the gait cycle and got 95% accuracy.
  - We converted the data from the VelGmat into a JSON file compatible with the commercial Sensing Tex software. This enabled us to analyse the data using the tools of the commercial software.
  - A user study was conducted where the gait of the participants was recorded in response to different VR environments like positive,negative and neutral. The PHQ9 data was also taken from the participants.

- **Literature**
  - We conducted two systematic literature reviews: The first on the application of VR in healthcare in general and the second one on the application of VR in depression
  - We constructed tables having the different VR Scenes for different disorders along with the sensors used to measure other parameters related to the disorder. A similar table was created where different VR scenes for detection and intervention in depression were shown along with the sensors to measure other physiological and behavioural signals related to depression
  - We outlined the different physiological and behavioral responses related to depression and the relevant hardware used to monitor them and finally summarized them in a figure
  - We Proposed a bare minimum checklist to create a novel scene in VR for depression studies. The checklist included Measures selection, Content impact and Baseline value.

6.2 Limitations

One of the biggest limitation we faced was regarding the size of the mat being dependent on the capacity of the microcontroller. Different microcontroller and their capabilities can be explored for a larger mat along with taking care of the crosstalk. The insulating material used for the mat can be optimised so as to make the mat more flexible and easy to carry and store. The sample size of the user studies was less and more extensive, focused group studies can be used for better and more reliable results.

6.3 Future Work

As part of the future work, we would like to expand the scope of our research with following points. The idea of a room where the person in the room is localised and that data is known to the VR HMD is possible if we increase the size of the mat to a 10x10 feet mat and place it a room under the carpet. The data can be sent to VR headset whereby we can use infinite walking algorithm as a starting point to do many activities such as exploring museum walking and jumping around barriers.

An application can be developed which takes the data from the mat as input and gives us the foot pressure visualisation, gait metrics, and analysis tools like centre of pressure, maximum pressure, etc. The app as well as the mat can be a low cost alternative to the commercial sensing tex. The specs of a microcontroller can worked on for a high sampling rate in proportion to a large enough size with minimal crosstalk.

Related Publications

6.4 Relevent Publications

6.4.1 Journal Publications

Mohammad Waqas; Vivek R, Rohan Lahane, Y. Raghu Reddy, Priyanka Srivastava, Syed Azeemuddin ***"A Virtual reality and pressure sensing based approach for correlation of gait with depression"***, *Journal for Translational Engineering in Health and Medicine* , April 2024 **[In Proceedings]**

6.4.2 Conference Publications

1. **Mohammad Waqas Wani**, Pawankumar Gururaj Yendigeri; Vivek Pareek, Sai Anirudh Karre Y. Raghu Reddy, Syed Azeemuddin ***"VelGmat : Low Cost Gait Mat for Stance Phase Calculation"***, *The 20th International Conference on IEEE Sensors* , Oct 2022 **[Published]**

2. **Mohammad Waqas Wani**, Pawankumar Gururaj Yendigeri; Dhiraj Shanmukh Mitra, Sai Anirudh Karre Y. Raghu Reddy, Syed Azeemuddin ***"Using Virtual Reality for Detection and Intervention of Depression - A Systematic Literature Review"***, *arXiv:2403.01882v1*

Bibliography

[1] S. Lilienfeld, S. J. Lynn, L. Namy, N. Woolf, G. Jamieson, A. Marks, and V. Slaughter, *Psychology: From inquiry to understanding*, vol. 2. Pearson Higher Education AU, 2014.

[2] R. Tadayon, C. Gupta, D. Crews, and T. McDaniel, "Do trait anxiety scores reveal information about our response to anxious situations? a psycho-physiological vr study," in *Proceedings of the 4th International Workshop on Multimedia for Personal Health & Health Care*, pp. 16–23, 2019.

[3] L. Mason, S. Scrimin, S. Zaccoletti, M. C. Tornatora, and T. Goetz, "Webpage reading: Psychophysiological correlates of emotional arousal and regulation predict multiple-text comprehension," *Computers in Human Behavior*, vol. 87, pp. 317–326, 2018.

[4] L. Ciabattoni, F. Ferracuti, S. Longhi, L. Pepa, L. Romeo, and F. Verdini, "Real-time mental stress detection based on smartwatch," in *2017 IEEE International Conference on Consumer Electronics (ICCE)*, pp. 110–111, IEEE, 2017.

[5] M. M. Bradley, L. Miccoli, M. A. Escrig, and P. J. Lang, "The pupil as a measure of emotional arousal and autonomic activation," *Psychophysiology*, vol. 45, no. 4, pp. 602–607, 2008.

[6] M. Li, W. Zhang, B. Hu, J. Kang, Y. Wang, and S. Lu, "Automatic assessment of depression and anxiety through encoding pupil-wave from hci in vr scenes," *ACM Transactions on Multimidia Computing Communications and Applications*.

[7] Y. Wang, J. Wang, X. Liu, and T. Zhu, "Detecting depression through gait data: examining the contribution of gait features in recognizing depression," *Frontiers in psychiatry*, vol. 12, p. 661213, 2021.

[8] V. Decker, M. Valenti, V. Montoya, A. Sikorskii, C. W. Given, and B. A. Given, "Maximizing new technologies to treat depression," *Issues in Mental Health Nursing*, vol. 40, no. 3, pp. 200–207, 2019.

[9] T. Wang, C. Li, C. Wu, C. Zhao, J. Sun, H. Peng, X. Hu, and B. Hu, "A gait assessment framework for depression detection using kinect sensors," *IEEE Sensors Journal*, vol. 21, no. 3, pp. 3260–3270, 2020.

[10] M. W. Whittle, *Gait analysis: an introduction*. Butterworth-Heinemann, 2014.

[11] Y. Wahab and N. A. Bakar, "Gait analysis measurement for sport application based on ultrasonic system," in *2011 IEEE 15th international symposium on consumer electronics (ISCE)*, pp. 20–24, IEEE, 2011.

[12] N. Shibuya, B. T. Nukala, A. I. Rodriguez, J. Tsay, T. Q. Nguyen, S. Zupancic, and D. Y. Lie, "A real-time fall detection system using a wearable gait analysis sensor and a support vector machine (svm) classifier," in *2015 Eighth International Conference on Mobile Computing and Ubiquitous Networking (ICMU)*, pp. 66–67, IEEE, 2015.

[13] E. Ochsmann, U. Noll, R. Ellegast, I. Hermanns, and T. Kraus, "Influence of different safety shoes on gait and plantar pressure: a standardized examination of workers in the automotive industry," *Journal of occupational health*, vol. 58, no. 5, pp. 404–412, 2016.

[14] G. Baldewijns, G. Verheyden, B. Vanrumste, and T. Croonenborghs, "Validation of the kinect for gait analysis using the gaitrite walkway," in *2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, pp. 5920–5923, IEEE, 2014.

[15] K. Yagi, Y. Sugiura, K. Hasegawa, and H. Saito, "Gait measurement at home using a single rgb camera," *Gait & posture*, vol. 76, pp. 136–140, 2020.

[16] H. M. Thang, V. Q. Viet, N. D. Thuc, and D. Choi, "Gait identification using accelerometer on mobile phone," in *2012 International Conference on Control, Automation and Information Sciences (ICCAIS)*, pp. 344–348, IEEE, 2012.

[17] R. de Fazio, E. Perrone, R. Velázquez, M. De Vittorio, and P. Visconti, "Development of a self-powered piezo-resistive smart insole equipped with low-power ble connectivity for remote gait monitoring," *Sensors*, vol. 21, no. 13, p. 4539, 2021.

[18] T. K. Agrawal, S. Thomassey, C. Cochrane, G. Lemort, and V. Koncar, "Low-cost intelligent carpet system for footstep detection," *IEEE Sensors Journal*, vol. 17, no. 13, pp. 4239–4247, 2017.

[19] A. Basu, "A brief chronology of virtual reality," *arXiv preprint arXiv:1911.09605*, 2019.

[20] M. Rus-Calafell, P. Garety, E. Sason, T. J. Craig, and L. R. Valmaggia, "Virtual reality in the assessment and treatment of psychosis: a systematic review of its utility, acceptability and effectiveness," *Psychological medicine*, vol. 48, no. 3, pp. 362–391, 2018.

[21] G. Lugo, M. Ibarra-Manzano, F. Ba, and I. Cheng, "Virtual reality and hand tracking system as a medical tool to evaluate patients with parkinson's," in *Proceedings of the 11th EAI International Conference on Pervasive Computing Technologies for Healthcare*, pp. 405–408, 2017.

[22] K. Seo and H. Ryu, "Nothing is more revealing than body movement: Measuring the movement kinematics in vr to screen dementia," in *Proceedings of the Asian HCI Symposium'18 on Emerging Research Collection*, pp. 21–24, 2018.

[23] N. Baghaei, L. Stemmet, I. Khaliq, A. Ahmadi, I. Halim, H.-N. Liang, W. Xu, M. Billinghurst, and R. Porter, "Designing individualised virtual reality applications for supporting depression: A feasibility study," in *Companion of the 2021 ACM SIGCHI Symposium on Engineering Interactive Computing Systems*, pp. 6–11, 2021.

[24] B. Niederriter, A. Rong, F. Aqlan, and H. Yang, "Sensor-based virtual reality for clinical decision support in the assessment of mental disorders," in *2020 IEEE Conference on Games (CoG)*, pp. 666–669, IEEE, 2020.

[25] A. M. Amin, X. Tong, D. Gromala, and C. D. Shaw, "Cardboard mobile virtual reality as an approach for pain distraction in clinical settings: comparison, exploration and evaluation with oculus rift," in *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, pp. 2345–2351, 2017.

[26] I. Phelan, M. Arden, M. Matsangidou, A. Carrion-Plaza, and S. Lindley, "Designing a virtual reality myoelectric prosthesis training system for amputees," in *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, pp. 1–7, 2021.

[27] I.-A. Bratosin, I.-B. Păvăloiu, A. Vasilăţeanu, D. Gavajiuc, G. Drăgoi, and N. Goga, "Pain relief using virtual reality," in *2019 11th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, pp. 1–4, 2019.

[28] M. R. Desselle, L. R. Holland, A. McKittrick, G. Kennedy, P. Yates, and J. Brown, """a wanderer's tale": The development of a virtual reality application for pain and quality of life in australian burns and oncology patients," *Palliative & Supportive Care*, pp. 1–7, 2022.

[29] A. K. Bourke, A. Barré, B. Mariani, C. M. el Achkar, A. Paraschiv-Ionescu, K. Aminian, B. Vereijken, N. Skjæret, and J. Helbostad, "Design and development of an inertial sensor based exergame for recovery-step training," in *2014 11th International Conference on Wearable and Implantable Body Sensor Networks Workshops*, pp. 27–32, IEEE, 2014.

[30] M. Ma and K. Bechkoum, "Serious games for movement therapy after stroke," in *2008 IEEE international conference on systems, man and cybernetics*, pp. 1872–1877, IEEE, 2008.

[31] I. Afyouni, A. Einea, and A. Murad, "Rehabot: Gamified virtual assistants towards adaptive telerehabilitation," in *Adjunct Publication of the 27th Conference on User Modeling, Adaptation and Personalization*, pp. 21–26, 2019.

[32] A. Elor, S. Lessard, M. Teodorescu, and S. Kurniawan, "Project butterfly: Synergizing immersive virtual reality with actuated soft exosuit for upper-extremity rehabilitation," in *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 1448–1456, IEEE, 2019.

[33] J. d. F. O. Araújo, E. H. Ribeiro, M. de Paiva Guimarães, J. R. F. Brega, A. F. Brandão, and D. R. C. Dias, "Immersive brain puzzle: a virtual reality application aimed at the rehabilitation of post-stroke patients," in *2021 16th Iberian Conference on Information Systems and Technologies (CISTI)*, pp. 1–6, IEEE, 2021.

[34] P. Mohammadi, M. Malekzadeh, J. Kodl, A. Mukovskiy, D. L. Wigand, M. Giese, and J. J. Steil, "Real-time control of whole-body robot motion and trajectory generation for physiotherapeutic juggling in vr," in *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pp. 270–277, IEEE, 2018.

[35] M. Matsangidou, E. Schiza, M. Hadjiaros, K. C. Neokleous, M. Avraamides, E. Papayianni, F. Frangoudes, and C. S. Pattichis, "Dementia: I am physically fading. can virtual reality help?

physical training for people with dementia in confined mental health units," in *International Conference on human-computer interaction*, pp. 366–382, Springer, 2020.

[36] A. Naro and R. S. Calabro, "What do we know about the use of virtual reality in the rehabilitation field? a brief overview," *Electronics*, vol. 10, no. 9, p. 1042, 2021.

[37] P. Langhorne, J. Bernhardt, and G. Kwakkel, "Stroke rehabilitation," *The Lancet*, vol. 377, no. 9778, pp. 1693–1702, 2011.

[38] Y. Lai, S. Sutjipto, M. D. Clout, M. G. Carmichael, and G. Paul, "Gavre 2: towards data-driven upper-limb rehabilitation with adaptive-feedback gamification," in *2018 IEEE international conference on robotics and biomimetics (ROBIO)*, pp. 164–169, IEEE, 2018.

[39] N. Rohrbach, E. Chicklis, and D. E. Levac, "What is the impact of user affect on motor learning in virtual environments after stroke? a scoping review," *Journal of neuroengineering and rehabilitation*, vol. 16, no. 1, pp. 1–14, 2019.

[40] N. Rohrbach, E. Chicklis, and D. E. Levac, "What is the impact of user affect on motor learning in virtual environments after stroke? a scoping review," *Journal of neuroengineering and rehabilitation*, vol. 16, no. 1, pp. 1–14, 2019.

[41] M. A. Ahmad, D. K. A. Singh, N. A. Mohd Nordin, K. Hooi Nee, and N. Ibrahim, "Virtual reality games as an adjunct in improving upper limb function and general health among stroke survivors," *International journal of environmental research and public health*, vol. 16, no. 24, p. 5144, 2019.

[42] K. S. Gurusamy, R. Aggarwal, L. Palanivelu, and B. R. Davidson, "Virtual reality training for surgical trainees in laparoscopic surgery," *Cochrane database of systematic reviews*, no. 1, 2009.

[43] S. Li, J. Cui, A. Hao, S. Zhang, and Q. Zhao, "Design and evaluation of personalized percutaneous coronary intervention surgery simulation system," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, no. 11, pp. 4150–4160, 2021.

[44] S. Maria, S. Lambert, and I. Avellino, "From déjà vu to déjà vécu: Reliving surgery in post-operative debriefing," in *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 462–465, IEEE, 2022.

[45] M. P. Fried, R. Satava, S. Weghorst, A. Gallagher, C. Sasaki, D. Ross, M. Sinanan, J. Uribe, M. Zeltsan, H. Arora, *et al.*, "Identifying and reducing errors with surgical simulation," *BMJ Quality & Safety*, vol. 13, no. suppl 1, pp. i19–i26, 2004.

[46] A. Gupta, J. Cecil, and M. Pirela-Cruz, "A cyber-human based integrated assessment approach for orthopedic surgical training," in *2020 IEEE 8th International Conference on Serious Games and Applications for Health (SeGAH)*, pp. 1–8, IEEE, 2020.

[47] J. S. Abelson, E. Silverman, J. Banfelder, A. Naides, R. Costa, and G. Dakin, "Virtual operating room for team training in surgery," *The American Journal of Surgery*, vol. 210, no. 3, pp. 585–590, 2015.

[48] M. Buscarini and J. P. Stein, "Training the urologic oncologist of the future: where are the challenges?," in *Urologic Oncology: Seminars and Original Investigations*, vol. 27, pp. 193–198, Elsevier, 2009.

[49] K.-C. Siu, B. J. Best, J. W. Kim, D. Oleynikov, and F. E. Ritter, "Adaptive virtual reality training to optimize military medical skills acquisition and retention," *Military medicine*, vol. 181, no. suppl_5, pp. 214–220, 2016.

[50] W. Zhong and P. Mancuso, "Utilization and surgical skill transferability of the simulator robot to the clinical robot for urology surgery," *Urologia Internationalis*, vol. 98, no. 1, pp. 1–6, 2017.

[51] K. D. Agyeman, S. H. Summers, D. H. Massel, J. Mouhanna, A. Aiyer, and S. D. Dodds, "Innovation in orthopaedic surgery education: novel tools for modern times," *JAAOS-Journal of the American Academy of Orthopaedic Surgeons*, vol. 28, no. 18, pp. e782–e792, 2020.

[52] J. S. Abelson, E. Silverman, J. Banfelder, A. Naides, R. Costa, and G. Dakin, "Virtual operating room for team training in surgery," *The American Journal of Surgery*, vol. 210, no. 3, pp. 585–590, 2015.

[53] C. Zheng, J. Li, G. Zeng, W. Ye, J. Sun, J. Hong, and C. Li, "Development of a virtual reality preoperative planning system for postlateral endoscopic lumbar discectomy surgery and its clinical application," *World Neurosurgery*, vol. 123, pp. e1–e8, 2019.

[54] B. Harrison, R. Oehmen, A. Robertson, B. Robertson, P. De Cruz, R. Khan, and D. Fick, "Through the eye of the master: The use of virtual reality in the teaching of surgical hand preparation," in *2017 IEEE 5th International Conference on Serious Games and Applications for Health (SeGAH)*, pp. 1–6, IEEE, 2017.

[55] Z. Haji, A. Arif, S. Jamal, and R. Ghafoor, "Augmented reality in clinical dental training and education," *JPMA. The Journal of the Pakistan Medical Association*, vol. 71, no. 1 (Suppl 1), p. S42, 2021.

[56] Y. M. Mekki, M. M. Mekki, M. A. Hammami, and S. M. Zughaier, "Virtual reality module depicting catheter-associated urinary tract infection as educational tool to reduce antibiotic resistant hospital-acquired bacterial infections," in *2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT)*, pp. 544–548, IEEE, 2020.

[57] T. Everson, M. Joordens, H. Forbes, and B. Horan, "Virtual reality and haptic cardiopulmonary resuscitation training approaches: A review," *IEEE Systems Journal*, 2021.

[58] C.-H. Yang, S.-F. Liu, C.-Y. Lin, and C.-F. Liu, "Immersive virtual reality-based cardiopulmonary resuscitation interactive learning support system," *IEEE Access*, vol. 8, pp. 120870–120880, 2020.

[59] Z. Hussain, D. M. Ng, N. Alnafisee, Z. Sheikh, N. Ng, A. Khan, A. Hussain, D. Aitken, and A. Sheikh, "Effectiveness of virtual and augmented reality for improving knowledge and skills in medical students: protocol for a systematic review," *BMJ open*, vol. 11, no. 8, p. e047004, 2021.

[60] T. Ryall, B. K. Judd, and C. J. Gordon, "Simulation-based assessments in health professional education: a systematic review," *Journal of multidisciplinary healthcare*, vol. 9, p. 69, 2016.

[61] J. Labovitz and C. Hubbard, "The use of virtual reality in podiatric medical education," *Clinics in Podiatric Medicine and Surgery*, vol. 37, no. 2, pp. 409–420, 2020.

[62] S. Sukumar, A. Zakaria, C. J. Lai, M. Sakumoto, R. Khanna, and N. Choi, "Designing and implementing a novel virtual rounds curriculum for medical students' internal medicine clerkship during the covid-19 pandemic," *MedEdPORTAL*, vol. 17, p. 11106, 2021.

[63] T. Baniasadi, S. M. Ayyoubzadeh, and N. Mohammadzadeh, “Challenges and practical considerations in applying virtual reality in medical education and treatment,” *Oman medical journal*, vol. 35, no. 3, p. e125, 2020.

[64] S. G. Izard, J. A. J. Méndez, P. Ruisoto, and F. J. García-Peñalvo, “Nextmed: How to enhance 3d radiological images with augmented and virtual reality,” in *Proceedings of the Sixth International Conference on Technological Ecosystems for Enhancing Multiculturality*, pp. 397–404, 2018.

[65] C. Moreira, I. B. Nobre, S. C. Sousa, J. M. Pereira, and J. Jorge, “Improving x-ray diagnostics through eye-tracking and xr,” in *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 450–453, IEEE, 2022.

[66] J. Klonig and M. Herrlich, “Integrating 3d and 2d views of medical image data in virtual reality for efficient navigation,” in *2020 IEEE International Conference on Healthcare Informatics (ICHI)*, pp. 1–7, IEEE, 2020.

[67] F. Pires, C. Costa, and P. Dias, “On the use of virtual reality for medical imaging visualization,” *Journal of Digital Imaging*, vol. 34, no. 4, pp. 1034–1048, 2021.

[68] K. Sato, S. Fukumori, T. Matsusaki, T. Maruo, S. Ishikawa, H. Nishie, K. Takata, H. Mizuhara, S. Mizobuchi, H. Nakatsuka, *et al.*, “Nonimmersive virtual reality mirror visual feedback therapy and its application for the treatment of complex regional pain syndrome: an open-label pilot study,” *Pain medicine*, vol. 11, no. 4, pp. 622–629, 2010.

[69] F. Rousseaux, A. Bicego, D. Ledoux, P. Massion, A.-S. Nyssen, M.-E. Faymonville, S. Laureys, and A. Vanhaudenhuyse, “Hypnosis associated with 3d immersive virtual reality technology in the management of pain: a review of the literature,” *Journal of Pain Research*, vol. 13, p. 1129, 2020.

[70] S. Grassini, “Virtual reality assisted non-pharmacological treatments in chronic pain management: A systematic review and quantitative meta-analysis,” *International Journal of Environmental Research and Public Health*, vol. 19, no. 7, p. 4071, 2022.

[71] M. M. Ahern, L. V. Dean, C. C. Stoddard, A. Agrawal, K. Kim, C. E. Cook, and A. Narciso Garcia, “The effectiveness of virtual reality in patients with spinal pain: A systematic review and meta-analysis,” *Pain Practice*, vol. 20, no. 6, pp. 656–675, 2020.

[72] O. Giotakos, K. Tsirgogianni, and I. Tarnanas, "A virtual reality exposure therapy (vret) scenario for the reduction of fear of falling and balance rehabilitation training of elder adults with hip fracture history," in *2007 Virtual Rehabilitation*, pp. 155–158, IEEE, 2007.

[73] M. Rus-Calafell, P. Garety, E. Sason, T. J. Craig, and L. R. Valmaggia, "Virtual reality in the assessment and treatment of psychosis: a systematic review of its utility, acceptability and effectiveness," *Psychological medicine*, vol. 48, no. 3, pp. 362–391, 2018.

[74] R. M. Baños, V. Guillen, S. Quero, A. Garcia-Palacios, M. Alcañiz, and C. Botella, "A virtual reality system for the treatment of stress-related disorders: A preliminary analysis of efficacy compared to a standard cognitive behavioral program," *International Journal of Human-Computer Studies*, vol. 69, no. 9, pp. 602–613, 2011.

[75] R. Uthayasangar and P. Wimalaratne, "Towards virtual therapy for alcoholic depression," in *2013 4th International Conference on Intelligent Systems, Modelling and Simulation*, pp. 397–403, IEEE, 2013.

[76] R. M. Baños, V. Guillen, S. Quero, A. Garcia-Palacios, M. Alcañiz, and C. Botella, "A virtual reality system for the treatment of stress-related disorders: A preliminary analysis of efficacy compared to a standard cognitive behavioral program," *International Journal of Human-Computer Studies*, vol. 69, no. 9, pp. 602–613, 2011.

[77] H. Cai, X. Sha, X. Han, S. Wei, and B. Hu, "Pervasive eeg diagnosis of depression using deep belief network with three-electrodes eeg collector," in *2016 IEEE international conference on bioinformatics and biomedicine (BIBM)*, pp. 1239–1246, IEEE, 2016.

[78] H. Cai, Z. Wang, Y. Zhang, Y. Chen, and B. Hu, "A virtual-reality based neurofeedback game framework for depression rehabilitation using pervasive three-electrode eeg collector," in *Proceedings of the 12th Chinese Conference on Computer Supported Cooperative Work and Social Computing*, pp. 173–176, 2017.

[79] K. M. R. De Asis, E. J. P. Guillem, F. A. M. Reyes, and M. J. C. Samonte, "Serenity: A stress-relieving virtual reality application based on philippine environmental variables," in *Proceedings of the 6th International Conference on Frontiers of Educational Technologies*, pp. 155–159, 2020.

[80] H.-G. Kim, E.-J. Cheon, D.-S. Bai, Y. H. Lee, and B.-H. Koo, "Stress and heart rate variability: a meta-analysis and review of the literature," *Psychiatry investigation*, vol. 15, no. 3, p. 235, 2018.

[81] D. Ayata, Y. Yaslan, and M. Kamaşak, "Emotion recognition via galvanic skin response: Comparison of machine learning algorithms and feature extraction methods," *IU-Journal of Electrical & Electronics Engineering*, vol. 17, no. 1, pp. 3147–3156, 2017.

[82] P. Bilgin, K. Agres, N. Robinson, A. A. P. Wai, and C. Guan, "A comparative study of mental states in 2d and 3d virtual environments using eeg," in *2019 IEEE International Conference on Systems, Man and Cybernetics (SMC)*, pp. 2833–2838, IEEE, 2019.

[83] B. Niederriter, A. Rong, F. Aqlan, and H. Yang, "Sensor-based virtual reality for clinical decision support in the assessment of mental disorders," in *2020 IEEE Conference on Games (CoG)*, pp. 666–669, IEEE, 2020.

[84] K. Lu, K. Yueh, H. Hu, M. Guo, and Y. Liu, "A novel neurofeedback attentional enhancement approach based on virtual reality," in *2022 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, pp. 5140–5143, IEEE, 2022.

[85] F. Bolinski, A. Etzelmüller, N. A. De Witte, C. van Beurden, G. Debard, B. Bonroy, P. Cuijpers, H. Riper, and A. Kleiboer, "Physiological and self-reported arousal in virtual reality versus face-to-face emotional activation and cognitive restructuring in university students: A crossover experimental study using wearable monitoring," *Behaviour Research and Therapy*, vol. 142, p. 103877, 2021.

[86] Y. Kim, J. Moon, N.-J. Sung, and M. Hong, "Correlation between selected gait variables and emotion using virtual reality," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1–8, 2019.

[87] G. Liang, Y. Li, D. Liao, H. Hu, Y. Zhang, and X. Xu, "The relationship between eeg and depression under induced emotions using vr scenes," in *2019 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, vol. 1, pp. 1–4, IEEE, 2019.

[88] G. Stamou, A. Garcia-Palacios, and C. Botella, "The combination of cognitive-behavioural therapy with virtual reality for the treatment of post-natal depression," in *Proceedings of the 31st Australian Conference on Human-Computer-Interaction*, pp. 599–603, 2019.

[89] A. J. Lin, F. Cheng, and C. B. Chen, “Use of virtual reality games in people with depression and anxiety,” in *Proceedings of the 5th International Conference on Multimedia and Image Processing*, pp. 169–174, 2020.

[90] J. Fernandez-Alvarez, D. Colombo, C. Suso-Ribera, A. Chirico, S. Serino, D. Di Lernia, A. G. Palacios, G. Riva, and C. Botella, “Using virtual reality to target positive autobiographical memory in individuals with moderate-to-moderately severe depressive symptoms: A single case experimental design,” *Internet Interventions*, vol. 25, p. 100407, 2021.

[91] M. Goel, P. Srivastava, M. Agrawal, R. Singhal, R. Chand, and A. R. Baijesh, “Head-movement analysis of 360° affective experience,” in *2021 IEEE 7th International Conference on Virtual Reality (ICVR)*, pp. 231–239, IEEE, 2021.

[92] D. Barsasella, M. F. Liu, S. Malwade, C. J. Galvin, E. Dhar, C.-C. Chang, Y.-C. J. Li, and S. Syed-Abdul, “Effects of virtual reality sessions on the quality of life, happiness, and functional fitness among the older people: a randomized controlled trial from taiwan,” *Computer Methods and Programs in Biomedicine*, vol. 200, p. 105892, 2021.

[93] I. Ghaznavi, D. Gillies, D. Nicholls, and A. Edalat, “Photorealistic avatars to enhance the efficacy of selfattachment psychotherapy,” in *2020 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, pp. 60–67, IEEE, 2020.

[94] J. Wu, Y. Sun, G. Zhang, Z. Zhou, and Z. Ren, “Virtual reality-assisted cognitive behavioral therapy for anxiety disorders: a systematic review and meta-analysis,” *Frontiers in Psychiatry*, vol. 12, p. 575094, 2021.

[95] H.-Y. Yen and H.-L. Chiu, “Virtual reality exergames for improving older adults’ cognition and depression: a systematic review and meta-analysis of randomized control trials,” *Journal of the American Medical Directors Association*, vol. 22, no. 5, pp. 995–1002, 2021.

[96] Y. Kim, S. Hong, and M. Choi, “Effects of serious games on depression in older adults: Systematic review and meta-analysis of randomized controlled trials,” *Journal of Medical Internet Research*, vol. 24, no. 9, p. e37753, 2022.

[97] V. Gava, H. R. F. Fialho, L. B. Calixtre, G. M. Barbosa, and D. H. Kamonseki, “Effects of gaming on pain-related fear, pain catastrophizing, anxiety, and depression in patients with chronic

musculoskeletal pain: A systematic review and meta-analysis," *Games for health journal*, vol. 11, no. 6, pp. 369–384, 2022.

[98] K. D. Thoondee and A. Oikonomou, "Using virtual reality to reduce stress at work," in *2017 computing conference*, pp. 492–499, IEEE, 2017.

[99] A. Suwanjatuporn and T. Chintakovid, "Using a virtual reality system to improve quality of life of the elderly people with depression," in *2019 IEEE International Conference on Consumer Electronics-Asia (ICCE-Asia)*, pp. 153–156, IEEE, 2019.

[100] F. Grieger, H. Klapperich, and M. Hassenzahl, "Trash it, punch it, burn it–using virtual reality to support coping with negative thoughts," in *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, pp. 1–6, 2021.

[101] N. Baghaei, L. Stemmet, I. Khaliq, A. Ahmadi, I. Halim, H.-N. Liang, W. Xu, M. Billinghurst, and R. Porter, "Designing individualised virtual reality applications for supporting depression: A feasibility study," in *Companion of the 2021 ACM SIGCHI Symposium on Engineering Interactive Computing Systems*, pp. 6–11, 2021.

[102] Y. J. Li and H. I. Luo, "Depression prevention by mutual empathy training: Using virtual reality as a tool," in *2021 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, pp. 60–63, IEEE, 2021.

[103] S. M. Khan, R. Mishra, N. Qaiser, A. M. Hussain, and M. M. Hussain, "Diaphragm shape effect on the performance of foil-based capacitive pressure sensors," *AIP advances*, vol. 10, no. 1, 2020.

[104] E. Lemaire, R. Moser, C. Borsa, and D. Briand, "Green paper-based piezoelectronics for sensors and actuators," *Sensors and Actuators A: Physical*, vol. 244, pp. 285–291, 2016.

[105] V. Arute, A. Syed, and A. Khandelwal, "Time–space–weight calibrated plastic optical fiber-based pressure sensing carpet," *Optical Engineering*, vol. 60, no. 9, pp. 094106–094106, 2021.

[106] E. Li, X. Lin, B.-C. Seet, F. Joseph, and J. Neville, "Low profile and low cost textile smart mat for step pressure sensing and position mapping," in *2019 IEEE International Instrumentation and Measurement Technology Conference (I2MTC)*, pp. 1–5, IEEE, 2019.

[107] A. Braun, H. Heggen, and R. Wichert, "Capfloor–a flexible capacitive indoor localization system," in *Evaluating AAL Systems Through Competitive Benchmarking. Indoor Localization and Tracking: International Competition, EvAAL 2011, Competition in Valencia, Spain, July 25-29, 2011, and Final Workshop in Lecce, Italy, September 26, 2011. Revised Selected Papers 1*, pp. 26–35, Springer, 2012.

[108] H. Böse, E. Fuß, and J. Ehrlich, "A2. 2-capacitive sensor mats for pressure detection with high sensitivity," *Proceedings SENSOR 2015*, pp. 55–60, 2015.

[109] D. Savio and T. Ludwig, "Smart carpet: A footstep tracking interface," in *21st International Conference on Advanced Information Networking and Applications Workshops (AINAW'07)*, vol. 2, pp. 754–760, IEEE, 2007.

[110] J. A. Cantoral-Ceballos, N. Nurgiyatna, P. Wright, J. Vaughan, C. Brown-Wilson, P. J. Scully, and K. B. Ozanyan, "Intelligent carpet system, based on photonic guided-path tomography, for gait and balance monitoring in home environments," *IEEE sensors Journal*, vol. 15, no. 1, pp. 279–289, 2014.

[111] Y. Kim, J. Moon, N.-J. Sung, and M. Hong, "Correlation between selected gait variables and emotion using virtual reality," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1–8, 2019.

[112] A. Fatema, S. Poondla, R. B. Mishra, and A. M. Hussain, "A low-cost pressure sensor matrix for activity monitoring in stroke patients using artificial intelligence," *IEEE Sensors Journal*, vol. 21, no. 7, pp. 9546–9552, 2021.

[113] A. Kharb, V. Saini, Y. Jain, and S. Dhiman, "A review of gait cycle and its parameters," *IJCEM International Journal of Computational Engineering & Management*, vol. 13, pp. 78–83, 2011.

[114] T. K. Agrawal, S. Thomassey, C. Cochrane, G. Lemort, and V. Koncar, "Low-cost intelligent carpet system for footstep detection," *IEEE Sensors Journal*, vol. 17, no. 13, pp. 4239–4247, 2017.

[115] Y. Kim, J. Moon, N.-J. Sung, and M. Hong, "Correlation between selected gait variables and emotion using virtual reality," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1–8, 2019.

[116] M. P. Murray, A. B. Drought, and R. C. Kory, "Walking patterns of normal men," *JBJS*, vol. 46, no. 2, pp. 335–360, 1964.

[117] K. Kroenke, R. L. Spitzer, and J. B. Williams, "The phq-9: validity of a brief depression severity measure," *Journal of general internal medicine*, vol. 16, no. 9, pp. 606–613, 2001.

[118] M. Waqas, "Gait data," Oct. 2023.

[119] G. Riva, F. Mantovani, C. S. Capideville, A. Preziosa, F. Morganti, D. Villani, A. Gaggioli, C. Botella, and M. Alcañiz, "Affective interactions using virtual reality: the link between presence and emotions," *Cyberpsychology & behavior*, vol. 10, no. 1, pp. 45–56, 2007.

[120] A. Naz, R. Kopper, R. P. McMahan, and M. Nadin, "Emotional qualities of vr space," in *2017 IEEE virtual reality (VR)*, pp. 3–11, IEEE, 2017.

[121] P. J. Lang, M. M. Bradley, and B. N. Cuthbert, "International affective picture system," 1988.

[122] M. M. Bradley and P. J. Lang, "Measuring emotion: the self-assessment manikin and the semantic differential," *Journal of behavior therapy and experimental psychiatry*, vol. 25, no. 1, pp. 49–59, 1994.