Development of a Prototype for a Smart Bracelet that Detects Falls for Multiple Sclerosis Patients using SCRUM Framework



Katerina Kalcher

Supervisor: Prof. K. Petridis

Advisor: E. Lourakis

Department of Electronic Engineering
Hellenic Mediterranean University

This dissertation is submitted for the degree of
Master of Science

November 2023

Copyright © 2023 by Katerina Kalcher
All Rights Reserved
The approval of the thesis by the programme does not necessarily imply acceptance of the author's views by the Department

I would like to dedicate this thesis to my parents

Declaration

I, Katerina Kalcher, hereby declare that this thesis, entitled "Development of a Prototype for a Smart Bracelet that Detects Falls for Multiple Sclerosis Patients using SCRUM Framework", is a record of original work carried out by me under the supervision of E. Lourakis and K. Petridis. This thesis has not been submitted for any degree or examination at any other university.

I have thoroughly referenced all sources used in this thesis and have given due credit to the original authors. Any ideas or works that have been derived from other sources have been properly cited and referenced.

I understand that plagiarism is a serious academic offence and that, if found guilty, I may face severe penalties, including the cancellation of my degree.

I declare that the results presented in this thesis are accurate to the best of my knowledge and belief.

Katerina Kalcher
November 2023

Acknowledgements

The completion of this thesis would not have been possible without the support and guidance of several individuals. I would like to express my sincere gratitude to the following individuals who have made a significant impact on my academic journey:

Firstly, I would like to thank my thesis advisor Emmanuel Lourakis, for his unwavering support, guidance, and encouragement throughout my academic journey. His expertise and mentorship have been invaluable in shaping the direction of my study.

I would also like to extend my gratitude to the members of my thesis committee, Konstantinos Petridis and George Kakavelakis for their insights, suggestions, and feedback during the various stages of my research. Their valuable input helped me to improve the quality of my work.

I am also grateful to my colleagues and peers at Hellenic Mediterranean University, who have provided a supportive and enriching academic environment. I would like to thank them for their encouragement, camaraderie, and friendship.

Finally, I would like to express my deepest appreciation to my family and friends, who have provided love, support, and encouragement throughout my academic journey. Their unwavering belief in me has been a source of inspiration and motivation, even when I doubted myself.

Thank you all for your support and encouragement throughout my journey.

Abstract

This thesis presents the development of a smart bracelet prototype designed to detect falls in Multiple Sclerosis (MS) patients. The collaboration process was guided by the SCRUM framework, an Agile methodology that emphasizes collaboration and iterative improvement. The prototype integrates an accelerometer to monitor the patient's movements and employs a fall detection algorithm to distinguish between normal activity and falls. The prototype was designed to be comfortable and easy to use for both patients and caregivers. Results show that the prototype accurately detects falls in MS patients, providing a promising solution for improving patient safety and independence. The study highlights the utility of the SCRUM framework in guiding the creation of practical, user-centered medical technologies, and contributes to the growing body of research on wearable devices for fall detection in MS populations.

Keywords: Multiple Sclerosis, falls, smart bracelet, prototype, SCRUM framework, fall detection, patient safety, medical technology.

Table of contents

List of figures **xv**

List of tables **xvii**

Glossary **xix**

1 Introduction **1**
1.1 Technologies for MS treatment 2
1.2 Scrum Framework 4

2 Literature Review **7**
2.1 Existing Commercial Devices 7
2.2 Existing Research and Development 8
2.2.1 Wearable Sensors 9
2.2.2 Inertial Measurement Units (IMUs) 9
2.2.3 Machine Learning 10
2.2.4 Camera-based Systems 11
2.2.5 Pressure-sensitive Mats 13
2.2.6 Summary 13
2.3 Scrum Framework Prototyping 14

3 Statement of Problem and Methodology of Solution **15**

4 System Design Approach **17**
4.1 System Architecture 17
4.2 Hardware Design 23
4.2.1 Microcontroller 23
4.2.2 3-Axis Accelerometer 23
4.2.3 Ultra-wideband (UWB) 24

4.2.4 Peripherals . . . 25
4.2.4.1 Button . . . 25
4.2.4.2 Capacitor . . . 26
4.2.4.3 Light-emitting diodes . . . 27
4.2.4.4 Lithium-Polymer Battery . . . 28
4.2.4.5 Lithium-Polymer Battery Charger . . . 28
4.2.4.6 OLED Display . . . 30
4.2.4.7 Printed Circuit Board . . . 31
4.2.4.8 Resistor . . . 31
4.2.4.9 Voltage regulator . . . 31
4.2.5 Housing . . . 32
4.3 Software Design . . . 33
4.3.1 Code . . . 33
4.3.1.1 Fall detection Algorithm . . . 33
4.3.1.2 Post-Fall Process . . . 36
4.3.2 Application Programming Interface . . . 37

5 Implementation of the Project using SCRUM Framework 41
5.1 The Three Pillars of Empiricism . . . 41
5.2 Scrum Values . . . 42
5.3 Scrum Team . . . 43
5.3.1 Product Owner . . . 44
5.3.2 Scrum Master . . . 44
5.3.3 Developers . . . 44
5.4 Scrum Events . . . 44
5.4.1 The Sprint . . . 45
5.4.2 Sprint Planning . . . 45
5.4.3 Daily Scrum . . . 45
5.4.4 Sprint Review . . . 45
5.4.5 Sprint Retrospective . . . 45
5.5 Scrum Artifacts . . . 46
5.5.1 Product Backlog . . . 46
5.5.2 Sprint Backlog . . . 46
5.5.3 Increment . . . 46

6 Results and Discussion 47

7 Conclusions and Recommendations 49

References 51

Appendix A Technical specifications 57
A.1 ESP32WROOM32 . . . 57
A.2 Esp32 WeMos LOLIN32 . . . 58
A.3 ADXL335 . . . 58
A.4 DWM1000 . . . 60
A.4.1 Nominal Operating Conditions . . . 60
A.4.2 DC Characteristics . . . 60
A.4.3 Receiver AC Characteristics . . . 60
A.4.4 Receiver Sensitivity Characteristics . . . 61
A.4.5 Reference Clock AC Characteristics . . . 61
A.4.5.1 Reference Frequency . . . 61
A.4.5.2 Transmitter AC Characteristics . . . 62
A.4.5.3 Temperature and Voltage Monitor Characteristics . . . 62
A.5 Buttons . . . 62
A.5.1 Button 12x12x(7.3)mm . . . 62
A.5.2 Switch SMD 5.2x5.2x1.5mm . . . 63
A.6 Capacitors . . . 63
A.6.1 Tantalum capacitor smd 10uF 25V tolerance 10% . . . 63
A.6.2 Ceramic capacitor smd 100pF 50V tolerance 5% . . . 63
A.7 Light-emitting diode . . . 64
A.8 Lithium-Polymer Battery . . . 64
A.9 OLED Display . . . 64
A.10 Resistor . . . 65
A.11 Voltage regulator . . . 65
A.12 DOIT ESP32 DEVKIT V1 . . . 66
A.12.1 DOIT ESP32 DEVKIT V1 Specifications . . . 66
A.12.2 DOIT ESP32 DEVKIT V1 Pinout . . . 67

Appendix B Code 69

List of figures

4.1 Bracelet Operation Flowchart 18
4.2 Welcome message 18
4.3 Device loading 18
4.4 Time and battery level 18
4.5 Alarm button 19
4.6 Fall detected display 19
4.7 Send alarm display 19
4.8 Help sent display 19
4.9 Led alarm indocator blinking 20
4.10 Alarm received by nurse 20
4.11 Low battery display 20
4.12 History of patient data 21
4.13 Adding a patient 21
4.14 Editing or removing a nurse 22
4.15 Sample of patient information 22
4.16 System reset button 22
4.17 3-axis Analog Accelerometer (ADXL335) 24
4.18 DWM1000 module 24
4.19 Illustration of single- and double-sided Two-Way Ranging (TWR) methods 25
4.20 Button 12x12x(7.3)mm 26
4.21 Switch SMD 5.2x5.2x1.5mm 26
4.22 Different types of capacitors 27
4.23 Tantalum capacitor smd 10uF 25V tolerance 10% 27
4.24 Ceramic capacitor smd 100pF 50V tolerance 5% 28
4.25 LED SMD1206 650...850mcd 35° - red 28
4.26 Li-Po battery 550mAh 29
4.27 Charging Profile with Thermal Regulation 29

4.28 Oled Display 128x32 30
4.29 Custom PCB 31
4.30 1206 SMD Resistor 32
4.31 AMS1117 Module 32
4.32 First Hardware Assembly 34
4.33 Acceleration vector values in serial monitor 34
4.34 Graphical visualization of simulated fall 35
4.35 Graphical visualization of quick hand movements 35
4.36 Fall detection algorithm 36
4.37 Post-Fall algorithm 37
4.38 Database phpMyAdmin 38
4.39 API - communication schematics 39

5.1 The Three Pillars of Empiricism 42
5.2 Scrum Values 43

A.1 DOIT ESP32 DEVKIT V1 Pinout 67

List of tables

A.2 Esp32 WeMos LOLIN32 Specifications 58
A.3 ADXL335 Specifications 59
A.4 DWM1000 Operating Conditions 60
A.5 DWM1000 DC Characteristics 60
A.6 DWM1000 Receiver AC Characteristics 60
A.7 DWM1000 Typical Receiver Sensitivity Characteristics 61
A.8 DWM1000 Reference Clock AC Characteristics 61
A.9 WM1000 Transmitter AC Characteristics 62
A.10 DWM1000 Temperature and Voltage Monitor Characteristics 62
A.11 Button 12x12x(7.3)mm 62
A.12 Switch SMD 5.2x5.2x1.5mm 63
A.13 Tantalum capacitor smd 10uF 25V tolerance 10% Performance Characteristics 63
A.14 Ceramic capacitor smd 100pF 50V tolerance 5% Performance Characteristics 63
A.15 Light-emitting diode 64
A.16 3.7V Rechargeable Li Polymer Battery 550mAh 64
A.17 OLED Display 64
A.18 Resistor Technical Specifications 65
A.19 AMS1117 Electrical Characteristics 65
A.20 DOIT ESP32 DEVKIT V1 Specifications 67

Glossary

Acronyms / Abbreviations

ADL Activities of Daily Living

API Application Programming Interface

AR Augmented Reality

AutoML Automated Machine Learning

BIP Blended Intensive Mobility Programme

BLE Bluetooth Low Energy

CNN Convolutional Neural Network

CNS Central Nervous System

I^2C Inter-Integrated Circuit

IC Integrated Circuit

IMU Inertial Measurement Unit

LED Light-emitting diode

Li-Po Lithium-Polymer Battery

MCU Microcontroller Unit

ML Machine Learning

MPU Microprocessor Unit

MS Multiple Sclerosis

OLED Organic Light Emitting Diode

SMD Surface Mounted Device

SVM Support Vector Machines

TWR Two-Way Ranging

UWB Ultra-Wideband

VR Voltage Regulator

VR Virtual Reality

Chapter 1

Introduction

Multiple sclerosis (MS) is a chronic inflammatory disease characterized by lesions of the central nervous system (CNS) and can lead to severe physical or cognitive disabilities and neurological defects [1, 2].

MS is typically diagnosed in young adults with onset usually at the age of 20-50, although the disease may develop also in childhood and after the age of 60. Women are more likely to be affected than men [3]. It is clinically proven that MS becomes chronic and progressively worsens over time. Since MS is a disease that can affect multiple regions of the CNS, it can be the cause of cumulative motor disability (i.e., weakness, spasticity, and tremor), sensory disturbances (i.e., numbness, pain), visual dysfunctions (i.e., diplopia and optic neuritis), sphincter dysfunction, cognitive deficits (i.e., mainly in attention, procession speed, memory and learning), as well as neuropsychiatric and behavioral symptoms [2, 4].

Worldwide, more than 2.3 million people have a diagnosis of MS [3]. MS is the most prevalent cause of neurological disability in young adults [5]. Common symptoms of the disease include paresthesias or numbness, motor weakness, monocular visual disturbances, diplopia, incoordination, gait disturbances, dizziness and vertigo [3]. Research shows that falls are a commonplace occurrence in people with MS. More specifically, a rate of 56% is observed to fall at least once within a period of three months, with 37% of individuals characterised as frequent fallers [6].

Falls can have a major impact to the patients. The physical consequences of falls are a certainty. Except for that falls can have wider effects to the individuals. Motion impairment has a detrimental effect on daily life activities and quality of life. In addition, a fall can cause a person to worry about falling, which in turn can be responsible for activity curtailment [7]. Research shows that falls can also lead to significant social and psychological problems. These may include lack of social interaction, loss of confidence and independence and more generally difficulty in a person's daily life [8].

Consequently, it is essential to decrease falls or at least aim to minimise injury and discomfort caused by them. There are several studies upon fall prevention but there is definitely room for improvement on the research of fall detecting systems and devices.

The objective of this dissertation is to develop a system which is able to detect falls in an indoor environment, send falling alerts and provide the exact position of the individual. In order to achieve this goal a sensor-based wearable device was designed and implemented for the National MS Center in Melsbroek, Belgium.

1.1 Technologies for MS treatment

There is currently no cure for MS, but there are a number of technologies and treatments that can help to manage its symptoms and slow its progression.

One of the most commonly used treatments for MS is disease-modifying therapy (DMT). DMTs are drugs that can help to slow the progression of the disease and reduce the frequency of relapses. There are several types of DMTs available, including interferons, glatiramer acetate, and immunosuppressants [9].

Another promising technology for MS treatment is stem cell transplantation. This involves transplanting stem cells into the body, which can help to repair damaged tissues and improve symptoms. Stem cell transplantation is still an experimental treatment and is only available in clinical trials at this time [10].

Rehabilitation technologies, such as physical therapy, assistive devices, and adaptive equipment, can also be useful for people with MS. Physical therapy can help to improve strength, flexibility, and balance, and assistive devices, such as canes, walkers, and wheelchairs, can help with mobility and independence [11].

In addition, there are a number of technologies that are being developed specifically to help people with MS manage their symptoms. For example, wearable devices, such as activity monitors and sleep trackers, can help to monitor and manage fatigue, while virtual reality and augmented reality technologies can be used to improve mobility and reduce symptoms such as pain and spasticity [12, 13].

As previously mentioned, activity monitors are wearable devices that are designed to track physical activity, such as steps taken, calories burned, and sleep patterns. For people with MS, activity monitors can be especially useful in helping to manage symptoms, such as fatigue, and in promoting overall health and well-being. By tracking physical activity, people with MS can see how much they are moving and set goals for increasing their physical activity levels over time. In addition, activity monitors can be used to track sleep patterns and identify any potential sleep disruptions that may be contributing to fatigue. Activity

monitors are also a useful tool for people with MS who are working to improve their physical fitness. By tracking physical activity, people with MS can see how much they are moving and set goals for increasing their physical activity levels over time. This information can help to motivate people to be more active and to achieve their fitness goals. One study found that activity monitor use is common among persons with MS and may serve as a powerful strategy for promoting and sustaining physical activity behavior change in this population [14].

Moreover, innovative strategies for promoting and sustaining engagement in physical activity are critical given the evidence regarding benefits of physical activity in persons with MS. Results from the same study indicate that activity monitor use is associated with more total and health-promoting physical activity among persons with MS. Commercially available activity monitors in conjunction with evidence-based behavioral strategies may be a worthwhile and economical approach for promoting naturally-occurring physical activity in MS. Overall, the use of activity monitors warrants further research investigating how devices may be used as a behavioral intervention tool for people with MS [14].

Virtual reality (VR) and augmented reality (AR) technologies are digital platforms that allow users to experience and interact with computer-generated environments and objects. These technologies have the potential to be especially beneficial for people with MS, as they can help to manage symptoms, improve mobility, and enhance quality of life [15].

One of the symptoms that can be particularly debilitating for people with MS is pain, which can be caused by spasticity and other factors. One study states that VR has been used to deliver intensive individual muscle training in patients undergoing neurorehabilitation for spinal cord injuries, which resulted in subjective and objective physical function improvements [16]. While this study discusses the potential of virtual and augmented reality technologies for pain management in general, it does not specifically mention their use for treating patients with MS. However, it suggests that virtual and augmented reality technologies can be used to help manage pain by providing immersive, interactive environments that can distract the user from their pain. While further research is needed to determine the effectiveness of these technologies for managing pain specifically in people with MS, it is possible that they could be used to help manage pain caused by spasticity and other factors.

In addition to managing pain, VR and AR technologies can also be used to improve mobility for people with MS. Another study investigated the feasibility of using AR-enhanced systems in MS patients' telerehabilitation and found that remote rehabilitation carried out with the help of an AR system had a positive effect on the strength and efficiency of the upper limbs of patients diagnosed with MS [15]. Additionally, the study mentions that remote

telerehabilitation enhanced with an immersive AR interface is one of the most promising methods for improving functional performance and quality of life for MS patients.

VR and AR technologies can also be used to help people with MS manage anxiety and depression, which can be common symptoms of the disease. According to a study, VR and AR technologies have the potential to aid in the management of anxiety and depression [17]. By utilizing immersive and interactive environments, these technologies allow individuals to escape from their daily challenges and engage in evidence-based psychological treatments. The study highlights that VR exposure-based treatments have shown promise in reducing anxiety disorders. With the ability to simulate reality and create new realities, VR and AR have the potential to significantly contribute to the assessment, understanding, and treatment of mental health problems, thereby improving overall mental health and well-being.

Ultimately, VR and AR technologies offer a range of benefits for people with MS. Whether it's managing pain, improving mobility, or enhancing quality of life, these technologies have the potential to make a significant difference in the lives of people with MS. As VR and AR technologies continue to evolve and improve, they offer hope for people with MS and provide a way to manage symptoms and improve their overall well-being.

In summary, there are a number of technologies and treatments available for MS that can help to manage its symptoms and slow its progression. While there is no cure for MS, these technologies offer hope for people with the disease and provide a way to improve their quality of life.

1.2 Scrum Framework

Over the past few years, Agile approach has become the most popular development concept. This is due to many development and production teams, particularly those trying to form a culture of constant delivery. In the past, production teams (particularly those in the software, aerospace, manufacturing, and defense industries) designed projects based on the Waterfall concept. Using this approach, teams define first the project requirements and scope of work, and then design a product based on these specifications. If any problems are discovered during testing, they are corrected before the final product is launched. While this approach seems reasonable, the developer teams were still required to adhere to the scope of work and requirements initially defined. There were no modifications or alterations allowed along the way. It could take years for the teams to complete the project they were assigned under this approach. Over the years, the nature of the situation of the project changed (but the requirements did not), making the planned solution out-of-date when it was finally deployed.

The main reason for the change in the problem situation was that the traditional Waterfall approach did not allow for modifications or alterations along the way. Another reason for the change in the problem situation was the increasing complexity of software development projects. As technology advanced, the projects became more complex, requiring more collaboration and communication among team members. The Waterfall approach, with its emphasis on strict requirements and limited communication, became less effective in this new environment. The Agile approach, on the other hand, promotes constant communication, collaboration, and feedback, allowing for greater flexibility and adaptability in complex projects. Agile methods also emphasize the importance of continuous improvement and learning, which helps teams stay up-to-date with the latest technology and market trends. This approach enables development teams to deliver products that are better suited to the current market needs, improving customer satisfaction and business outcomes.

As a result of this problem, a number of development teams adopted new approaches to planning and delivering new products during the 1990s, including Scrum, Rapid Application Development, Extreme Programming, Feature-Driven Development, and Pragmatic Programming. In the history of Agile, these approaches to software development are the earliest methods that eventually lead to the Agile Manifesto. A fundamental value of Agile is prioritizing individuals and interactions over processes and tools. Similarly, working software is prioritized over comprehensive documentation. Meanwhile, customer collaboration takes precedence over contract negotiations, and the ability to adapt to change overrides following a plan [18].

Agile Subway Map depicts Scrum as one of several Agile frameworks outlined in the Manifesto for Agile Software Development, which was created by the Agile Alliance, a non-profit membership organization. This framework provides adaptive solutions for complex problems that help people, teams, and organizations create value. By following an iterative, incremental approach, Scrum maximizes predictability and minimizes unnecessary risks.

Firstly, by breaking the project down into smaller, more manageable iterations or sprints, Scrum enables the team to focus on a specific set of goals or objectives within a fixed timeframe. This approach helps to reduce the uncertainty and unpredictability often associated with longer development cycles, making it easier to predict the outcome of each iteration and the overall project progress.

Secondly, Scrum's iterative approach enables the team to get feedback on the work done during each sprint, which can be used to adapt the subsequent iterations to better meet the evolving needs of the project. This feedback loop helps to identify and address issues early on, reducing the likelihood of major problems arising later in the project.

Thirdly, by prioritizing the most valuable features and delivering them incrementally, Scrum enables the team to validate assumptions and test hypotheses, reducing the risk of developing features that may not be used or valued by the end-user.

Finally, Scrum emphasizes transparency and collaboration, which further promotes predictability and reduces risks. Daily Scrum meetings, sprint reviews, and retrospectives provide opportunities for the team to communicate progress, discuss any issues, and identify opportunities for improvement.

Compared to other Agile methodologies, Scrum's iterative and incremental approach provides a structured and predictable framework for delivering value while minimizing risks [19, 20]. With its empiricism and lean approach, it allows applicants to do their work their way while adhering to the framework's values [18].

Using Agile methodologies as teaching/learning practices has proven to be successful in higher education (HE). Even when applied in HE, the Scrum framework facilitates a sufficiently high level of engagement in group projects, mainly because it promotes active learning and self-management. A key concept of active learning is that learners are responsible for their own learning. The Agile manifesto supports this principle by valuing student-driven inquiry and continuous improvement among other values. As its core structure aims to maximize a team's performance over time, Scrum also enhances collaborative learning between the members when a learning product is desired. Cooperative learning has been shown to be beneficial to undergraduates in both face-to-face and distance education studies [18].

Chapter 2

Literature Review

The purpose of this literature review is to explore the existing research and knowledge on the development of a prototype for a smart bracelet that detects falls for MS patients using scrum methodology. The aim of this review is to set up the borderline between the known and unknown in this field and highlight the contribution of this MSc thesis towards building new knowledge.

As MS is a chronic and disabling autoimmune disease that affects the central nervous system, leading to various symptoms such as fatigue, weakness, and loss of coordination, one of the most significant challenges that MS patients face is the risk of falls. Falls can result in serious injuries and long-term disability, thereby impacting the quality of life of MS patients.

To address this issue, wearable devices, such as smart bracelets, have been developed for fall detection. The use of scrum methodology, an Agile approach to software and hardware development that emphasizes collaboration, flexibility, and iterative development, has also gained increasing attention in recent years. However, there is still a research gap in the development of a prototype for a smart bracelet that detects falls for MS patients using scrum methodology.

Thus, this literature review will examine the current state of knowledge on MS and falls, smart bracelets and fall detection, scrum methodology, and existing solutions for fall detection in MS patients. Through the synthesis and analysis of the existing literature, this chapter will provide the foundation for the development of new knowledge and contribute to the improvement of the quality of life of MS patients.

2.1 Existing Commercial Devices

Fall detection devices are wearable or standalone technology devices that are designed to detect when a person has fallen and alert a designated caregiver or responder. For people

with MS, fall detection devices can be a valuable tool in improving safety and reducing the risk of injury. Falls are a common occurrence in people with MS and can have negative consequences. Accurate measures of fall frequency are needed to prevent falls and improve safety for people with MS. One compares different methods of detecting falls, including wearable electronic devices and real-time self-reporting [21]. The study suggests that fall detection devices can be a valuable tool in fall detection and prevention.

Automated fall detection systems consist of sensors and a machine learning algorithm trained on simulated or real-world falls. Most automated fall detection systems use a body-worn inertial monitoring unit (IMU) with an accelerometer, and optionally a gyroscope, as the sensor. The same study highlights the development of such devices and their increasing interest. A fully automated body-worn fall detection device that can detect falls without relying on self-report could be more accurate and convenient.

Wearable electronic devices can be used for fall detection and alerting designated caregivers or responders. The previous study discusses the use of real-time body-worn self-reporting and an automated body-worn detector to detect falls in individuals with MS. By using fall detection devices, people with MS can feel confident and secure, knowing that they are being monitored for falls. Their families can also have peace of mind knowing that their loved ones are being taken care of.

Fall detection devices are an important tool for people with MS in improving safety and reducing the risk of injury. Whether worn as a pendant or placed in the home, these devices provide a valuable service by detecting falls and alerting designated caregivers or responders who can then provide assistance. By using these devices, people with MS can maintain their independence while also receiving necessary support when needed. Overall, fall detection devices offer an effective solution to prevent falls among individuals with MS while providing peace of mind to both patients and their families [21].

2.2 Existing Research and Development

Various technologies have been developed to address the issue of fall detection for individuals with MS. The most common technologies are as follows:

- Wearable Sensors [21]
- Inertial Measurement Units (IMUs) [21]
- Machine Learning [22]
- Camera-based Systems [23]

- Pressure-sensitive Mats [24]

2.2.1 Wearable Sensors

Wearable devices such as accelerometers and gyroscopes are one of the most commonly used technologies for fall detection due to their ability to provide continuous monitoring of body movements in a non-intrusive manner. These sensors can be integrated into various wearable devices such as smartwatches, bracelets, and belts, making them a convenient option for fall detection in different populations. For instance, smart bracelets, such as Fitbit, Garmin, and Apple Watch, have been widely adopted due to their portability and convenience.

One study found that a wearable device with tri-axial accelerometers had a high accuracy rate of 93.5% for detecting falls in elderly populations [25]. Another study utilized a smartwatch with a custom algorithm for fall detection, which achieved an accuracy rate of 86% in real-world tests [26]. Furthermore, some smart bracelets also have additional features such as heart rate monitoring and GPS tracking, which can provide useful information for emergency response in the event of a fall.

Wearable sensors have also been used in combination with machine learning algorithms to improve the accuracy of fall detection. One study used a tri-axial accelerometer to collect acceleration data, which were then processed using machine learning algorithms to detect falls. The proposed system achieved an accuracy of up to 99% [27].

Wearable sensors have several advantages for fall detection, including their ease of use, convenience, and non-intrusiveness. However, their use can be limited by their cost, need for calibration, and potential for false alarms.

Incorporating wearable sensors within the framework of scrum methodology for the creation of a prototype smart bracelet designed to detect falls among Multiple Sclerosis patients holds the potential to offer a novel and innovative solution, effectively catering to the distinctive requirements of this demographic.

2.2.2 Inertial Measurement Units (IMUs)

IMUs are widely used for fall detection due to their ability to accurately measure acceleration, orientation, and angular velocity of the body. IMUs consist of accelerometers, gyroscopes, and magnetometers, which can provide a comprehensive understanding of the movement of the body in three dimensions.

IMUs have been used in several studies for fall detection in different populations, including elderly individuals and other patients. One study found that a custom-made IMU had an accuracy rate of 100% in detecting simulated falls and activities of daily living [28].

The smartphone-based fall detection system developed by Panagiotis G. Tsinganos uses the accelerometer and gyroscope sensors to collect data from the user's movements. The collected data is then processed using signal processing methods such as filtering, feature extraction, and classification algorithms. Additionally, machine learning techniques such as support vector machines (SVM) and decision trees are used to classify the data as a fall or non-fall event. This system provides a promising solution for prompt health care provision to prevent and restore any harm caused by falls, especially to frail populations [29].

IMUs have also been used in wearable devices such as smartwatches and bracelets for fall detection. One study used a combined smartphone and smartwatch fall detection system that aims to address the limitations of existing fall detection systems regarding usability and efficiency. The system combined threshold-based and pattern recognition techniques in both devices, with the intent of having the watch contribute to the specificity of the fall detection strategy. The paper reports that the accuracy of the system as a whole was below the ones reported in other research works, who managed to reach an accuracy of around 90% [30].

IMUs have several advantages over other technologies for fall detection, including their accuracy, portability, and low power consumption. However, their use can be limited by their cost and the need for accurate calibration.

The use of IMUs in the development of a prototype for a smart bracelet that detects falls for MS patients using scrum methodology could provide a new and innovative solution to address the unique needs of this population.

2.2.3 Machine Learning

Machine learning (ML) is an emerging technology that has shown promising results in fall detection. It involves training a model on a large dataset of sensor data to identify patterns that correspond to falls. This model can then be used to detect falls in real-time using sensor data from wearable devices.

One study presents a wearable sensor device-based strategy to identify and distinguish fall activities from activities of daily living (ADL) in older individuals. The study applies conventional machine learning methods and non-coding Automated Machine Learning (AutoML) methods to categorize acceleration signals as falling or regular activity. The results indicate that AutoML predicts exceptionally accurate results in binary classifications with 99.9% accuracy on three out of four machine learning techniques. Overall, the research provides insight into the feasibility of using AutoML for fall detection in older populations, which could be an essential tool for managing health in the elderly [31].

Another study presents a machine learning framework for automated fall detection in elderly people with neurodegenerative disorders, such as Parkinson's disease. The framework

consists of data collection, preprocessing, feature extraction, and machine learning classifiers, including C4.5, Random Forest, RepTree, and LMT. Using a dataset collected from 3-axis accelerometer sensors mounted on a person's waist, the study compared the performance of the classifiers and found that C4.5 achieved the highest accuracy of 97.36%. The authors suggest that the proposed fall detection system can be effectively used to monitor elderly people with neurodegenerative diseases, and future work could involve collecting more data, using deep artificial neural networks, and implementing a knowledge-driven approach to remove uncertainty. The study highlights the potential of motion-sensor technologies and machine learning for improving the care of elderly people and reducing medical care costs[22].

Machine learning algorithms have also been used to identify features that are most important for fall detection, which can help to improve the accuracy of fall detection systems. One study used a machine learning algorithm to identify the most important features for fall detection. A study addresses the issue of falls among the elderly and proposes a wearable device to collect data for fall and near-fall analysis. The device is able to detect and classify different types of falls and normal movements and posture, including near-fall situations. A Naive Bayesian classifier is used for fall analysis, which has been proven to be efficient in classifying different movements and postures accurately and detecting fall and near-fall situations in real time. The device is also adaptable to an individual's particular gait, posture, and lifestyle, and can continuously update its classification process. The paper also introduces an optimum feature selection algorithm that selects only the most relevant features necessary for accurate movement classification. The proposed device prototype is promising, but there is still room for improvement, particularly in addressing false alarms and hardware capability for tracking and sending correct data for updates[32].

Machine learning has several advantages for fall detection, including its ability to handle complex sensor data and its potential for high accuracy. However, its use can be limited by the need for large amounts of labeled data for training, which can be time-consuming and costly.

The employment of machine learning in crafting a prototype for an intelligent wristband, designed to identify instances of falls among Multiple Sclerosis (MS) patients through the application of the Scrum methodology, has the potential to furnish a novel and inventive solution for attending to the distinct requirements of this population.

2.2.4 Camera-based Systems

Ambient sensors, such as cameras and pressure sensors, have also been used for fall detection in recent years. These systems rely on computer vision techniques to analyze the video feed

captured by cameras in order to detect and classify falls. One of the main advantages of camera-based systems is their ability to provide rich visual information, which can be useful for understanding the context of a fall event.

The automatic detection of falls is crucial in providing immediate aid to elderly people and preventing injuries. Vision-based fall monitoring is gaining attention for its diverse features, but it faces challenges such as robustness and efficiency in performing generalization to invisible regions. These sensors can be installed in homes or care facilities and can detect falls by analyzing the changes in the environment. In a study, the authors propose a deep learning-based fall detection system that uses RGB images from a single camera and ensures privacy. The system achieves high accuracy and recall scores for fall recognition, even with synthetic pose data under different camera viewpoints. The authors also present a human fall dataset that can be used to identify other events and improve the system's scope for identifying general human activity. The proposed system has the potential to advance privacy and improve the identification of falls in health information technology [33].

Another study proposed a new approach for fall detection in outdoor environments using a combination of 2D and 3D features from depth images generated by a supervised learning method from a single RGB image. The proposed method uses human detection and tracking using the particle swarm optimization method, which solves the initialization problem encountered in previous tracking studies. Unlike other studies, this approach does not require a special camera such as the Kinect sensor, a depth sensor, or a multiple camera system. The proposed method also avoids using the background reference image feature for image segmentation due to its vulnerability towards dynamic outdoor changes. The experimental results show reliable and robust performance, suggesting the possibility of effective application to pre-existing surveillance systems. This study is a promising development in fall detection research, and the authors plan to further their research by detecting multiple people and falls in a single scene[34].

Although camera-based systems have the potential to be highly accurate, they also face several challenges. One of the main challenges is the need for a clear line of sight between the camera and the person being monitored. This can be problematic in situations where the camera view is obstructed, or when the person is out of range of the camera. Additionally, privacy concerns may arise when using ambient sensors such as camera-based systems, as they involve capturing and processing visual information about individuals.

Despite these challenges, camera-based fall detection systems hold promise for improving the accuracy and reliability of fall detection in real-world settings. The development of these systems is an active area of research and is expected to have a significant impact on the field of fall detection.

2.2.5 Pressure-sensitive Mats

Pressure-sensitive mats are another type of sensing technology that have been explored for fall detection. These mats are designed to detect changes in pressure caused by a person stepping or falling on them.

Several studies have investigated the use of pressure-sensitive mats for fall detection, and have reported promising results. For example, one study investigates the use of barometric pressure measurement as an augmentation to wearable accelerometry and gyroscope-based falls detection devices to reduce false positive rates. The study involves simulated falls and daily living activities in a cohort of 20 healthy volunteers. The proposed system demonstrated improvements in accuracy, sensitivity, and specificity compared to existing accelerometry-based techniques. The inclusion of barometric pressure measurement significantly reduces false positives and enables the detection of less severe impact falls. The use of such a system may lead to early detection of falls among the elderly, improving outcomes and reducing healthcare expenditure [35].

Similarly, another study proposed a fall detection system that uses a pressure-sensitive mat made out of a piezoelectric material combined with a machine learning algorithm to classify falls based on the characteristics of the pressure signals [36].

One advantage of pressure-sensitive mats is their ability to detect falls in a non-intrusive manner, without requiring the person to wear any additional sensors or devices. Additionally, pressure-sensitive mats are relatively inexpensive and can be easily integrated into existing environments, such as homes or healthcare facilities.

However, pressure-sensitive mats also face certain limitations. For example, they may not be suitable for detecting falls that do not involve impact with the ground, such as falls from a standing position. Additionally, pressure-sensitive mats may be less accurate in environments with high levels of ambient noise, which can interfere with the pressure signals.

Despite these limitations, pressure-sensitive mats show promise as a viable technology for fall detection, particularly in settings where other sensing technologies may not be feasible or practical. Ongoing research in this area is expected to further refine and improve the accuracy and reliability of pressure-sensitive mat-based fall detection systems.

2.2.6 Summary

While these technologies have shown promising results for fall detection, they may not be suitable for all populations, especially those with chronic conditions such as MS. Therefore, the development of a prototype for a smart bracelet that specifically targets fall detection for

MS patients using scrum methodology could provide a new solution to address the unique needs of this population.

2.3 Scrum Framework Prototyping

Scrum framework prototyping is an iterative and incremental approach to software development that is based on the principles of the Scrum framework. The Scrum framework is a widely adopted methodology for managing complex projects and delivering high-quality software products [37].

In Scrum framework prototyping, the development team works in sprints to create prototypes of the product. The sprints are time-boxed, typically lasting two to four weeks, and during each sprint, the team focuses on creating a working prototype of the product. The prototypes created during each sprint are used to gather feedback and make adjustments to the product, allowing the team to iterate on the design and improve the product with each sprint [38].

The Scrum framework prototyping approach is ideal for projects where the requirements are uncertain or subject to change. By creating prototypes during each sprint, the team can quickly adapt to changes in requirements and ensure that the product is aligned with the needs of the stakeholders. The prototypes also serve as a tangible representation of the product, allowing stakeholders to see and experience the product, and provide feedback to the development team [39].

Scrum framework prototyping also promotes collaboration between the development team and stakeholders. The team regularly engages with stakeholders during the sprint review and retrospective, where they present the prototype and gather feedback. This allows the team to work closely with stakeholders and ensure that the product meets their needs and expectations.

In conclusion, Scrum framework prototyping is an effective approach for managing complex software development projects. By creating prototypes during each sprint, the team can iterate on the design, respond to changing requirements, and engage with stakeholders to deliver a high-quality product that meets their needs and expectations [40].

Chapter 3

Statement of Problem and Methodology of Solution

The objective of this project was to design and create a Fall Detection System for the patients of the MS Center. The system had to be wearable and capable of wireless communication, so that data could be collected and edited. The device had to detect falls of the patients. In the event of a fall, the device had to alert the staff of the MS Center via SMS.

To be able to detect falls, the device first has to be able to sense motion and the different measurable qualities involved with motion. Sensing in the device is implemented with a tri-axis accelerometer, which measures acceleration along the three coordinate axes. To use this sensor to detect falls, the sensor readings have to be outputted to a microcontroller for processing and application to algorithms. For this to occur, first the sensor readings are converted from an analog voltage signal to a discretized bit value for the microcontroller to be able to use them. This is accomplished by passing the sensor outputs through an Analog to Digital Converter (ADC) before entering the microcontroller.

The microcontroller has to take the discretized bit data from the ADC and apply different formulas and conversion factors to calculate the necessary factors (acceleration magnitude). Using these factors, the microcontroller feeds them into an algorithm, comparing the inputs with various threshold values, initiating triggers when certain thresholds are met or exceeded.

Upon identifying a fall, the device initiates a continuous audible, tactile, and visual warning. The user is then given the option to cancel the alert in the instance that the fall is mistaken or not serious and the user is able to regain their composure on their own. If left uncancelled, the fall is considered serious and an alert is sent out to the MS Center staff.

Throughout the process of sensor readings, algorithm triggers, fall detection, etc. the device is continuously synched to the server. This is done using a UWB module. The server and consequently a computer constantly monitors the status of the device; it receives and

stores all sensor data onto its hard drive and is updated with any algorithm trigger changes or fall detections. The computer is also needed to use the API of the system. Via the API the administrator can add or remove bracelets and the patients wearing them, or add or remove MS Center staff to be alerted in case of a fall.

The above problem was tackled by a group of students from three different European universities. Two students from the Hellenic Mediterranean University in Chania, Crete, four students from the Instituto Superior Politécnico Gaya in Vila Nova de Gaia, Portugal and two students from the AP Hogeschool in Antwerp, Belgium. This project was assigned to the students in the framework of a Blended Intensive Mobility Programme (BIP) supported by Erasmus+. The students originated from different departments, more specifically, two students were studying management, two students were studying electronic engineering and the remaining four students were studying IT.

Initially, the collaboration between the students started remotely, with the intention of completing it in person at the AP Hogeschool, during a week-long project presentation. The project was to be implemented using the SCRUM framework. An initial online team meeting was held with the SCRUM master and roles were assigned to each team member. The team members then met again online and agreed on how the rest of the meetings would be held, how the tasks would be divided, how the team would work, etc. The product backlog was created, sprints were launched in the sprint calendar, as well as daily scrums. Weekly online meetings were thus established to monitor all stages of the work in order to make it more effective and efficient.

Chapter 4

System Design Approach

This chapter will elaborate on the system architecture including the hardware and the software design of the prototype.

4.1 System Architecture

The smart bracelet is a smart electronic device that is exclusively designed for use by the patients of the MS Center. The device works only within the facilities of the MS Center in Melsbroek, Belgium.

Most of the patients suffer from MS or related neurological disorders. Due to the nature of these diseases, a fall incidence can be very dangerous to the patient. The bracelet is designed for detecting falls of the patients and alerting the MS Center staff, so that a quick reaction time is achieved.

As previously mentioned, the main function of the bracelet is to detect falls. Despite that, there are also other important features which are listed below:

- Sends an alarm to the nurses mobile phones
- Possibility of sending an alarm manually
- Obtain the patient's position at the moment the alarm is triggered
- Display the history of the patient's information

The Figure 4.1 depicts the function of the bracelet.

The wristband has a display which when powered, should initialise with a "Welcome" message and should load as it prepares for use (Figure 4.2 and Figure 4.3). When the loading completes, the time and battery level then become visible (Figure 4.4).

Fig. 4.1 Bracelet Operation Flowchart

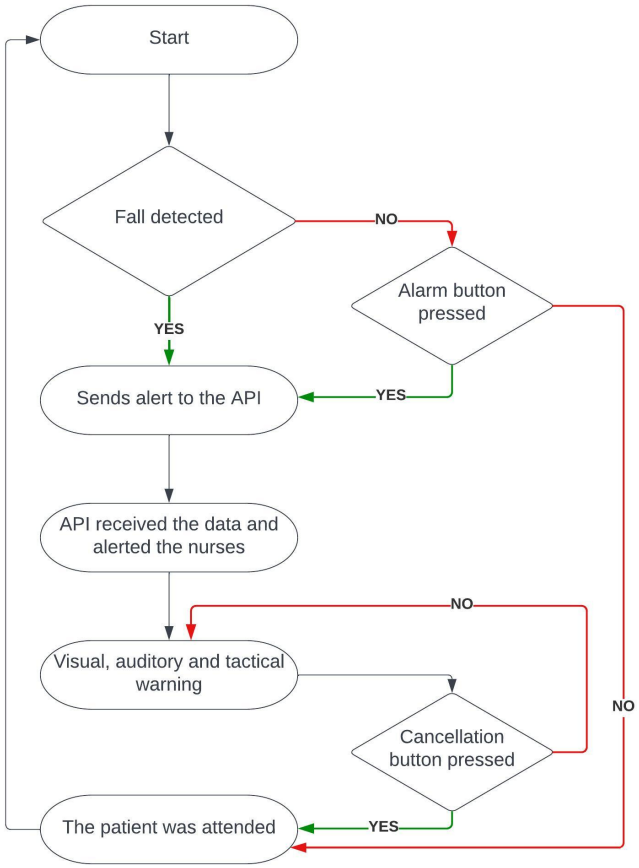


Fig. 4.2 Welcome message

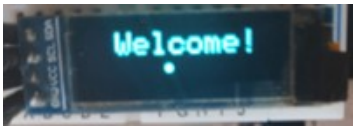


Fig. 4.3 Device loading

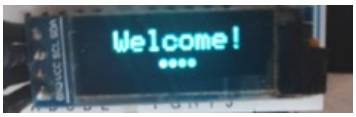


Fig. 4.4 Time and battery level



In case of a fall detection or if the alarm button is pressed, the message "Fall Detected" will appear on the display (Figures 4.5 & 4.6).

Fig. 4.5 Alarm button

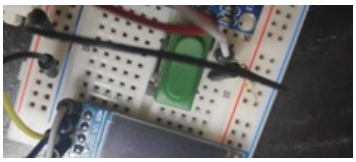
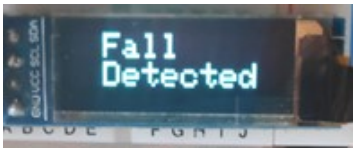
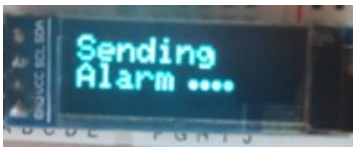


Fig. 4.6 Fall detected display



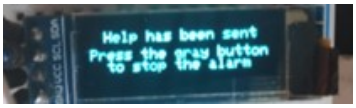
At this point the wristband is communicating with the antenna in order to receive the distance between them. This process that can last between 1 to 5 seconds maximum if the distance between them is large. When the distance is obtained, there is a notion of the position of the patient depending on where the antenna is placed. Next the wristband sends to the API the address of itself, the antenna's address, and the obtained distance between patient and antenna.The display then shows that the alarm is been sent (Figure 4.7).

Fig. 4.7 Send alarm display



At the time the API receives this data, the display shows that the information has been sent and the led starts blinking (Figures 4.8 & 4.9)

Fig. 4.8 Help sent display



At that moment the API sends the alarm for help to the nurses' mobile phones (Figure 4.10). Should the patient press the cancellation button, the LED will stop blinking and the wristband will "reset" itself and return to its normal operation, which displays the time and

Fig. 4.9 Led alarm indocator blinking

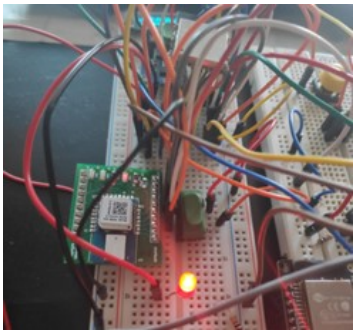


Fig. 4.10 Alarm received by nurse



battery level. When the wristband runs out of battery power, it will display a "Low Bat" message and shut down (Figure 4.11).

Fig. 4.11 Low battery display



By pressing the same button used to reset the alarm (cancellation button), when the wristband is out of battery, it will restart and after passing the loading screen it will switch off again if it is not charged.

All the patient information is stored in a web application that has a friendly user interface for nurses to use and see the patient's history. Figure 34 shows some examples of the stored information that is accessible by the nurses.

The web application has some functionalities, such as adding or removing patients and nurses to the system, editing information, viewing each patient's information, logging in, logging out, etc. (Figures 4.13, 4.14 & 4.15).

The wristband also features a button that is not visible from the outside and serves to reset the wristband and return to the "Welcome" message in case of malfunctions (Figure 4.16).

Fig. 4.12 History of patient data

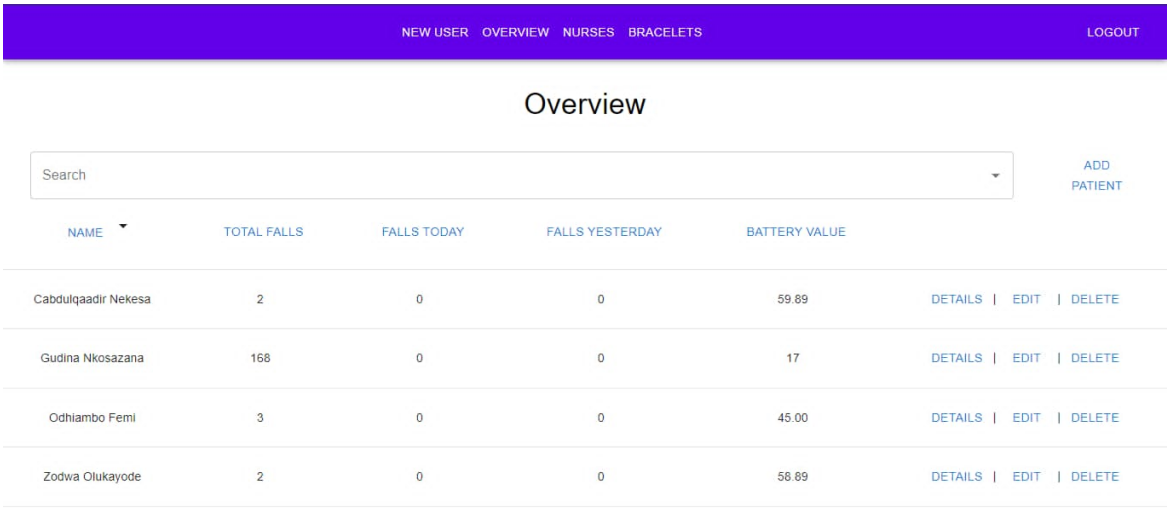


Fig. 4.13 Adding a patient

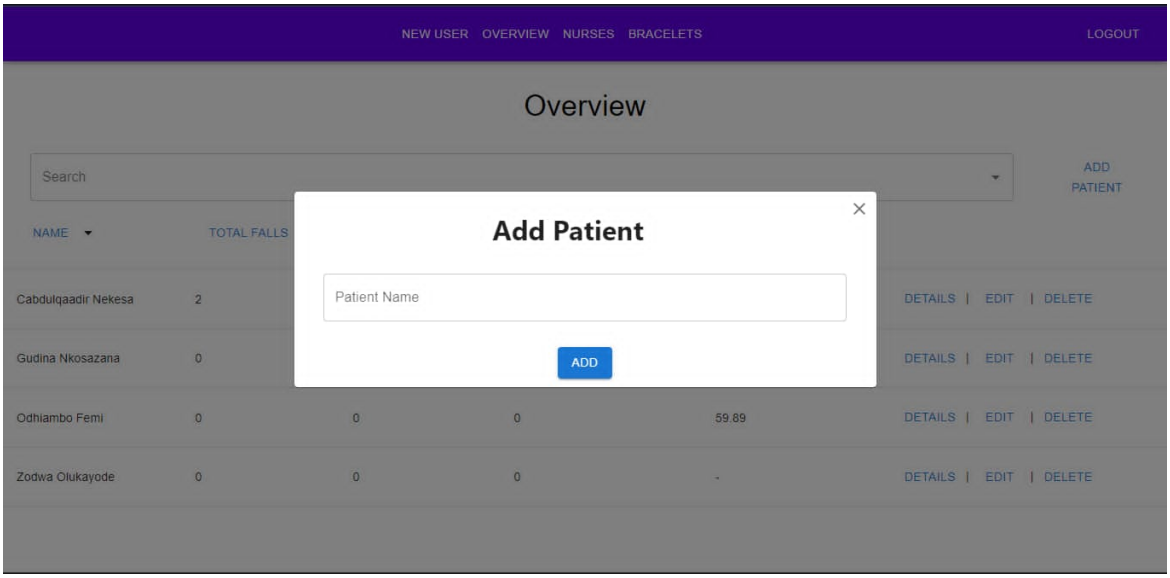


Fig. 4.14 Editing or removing a nurse

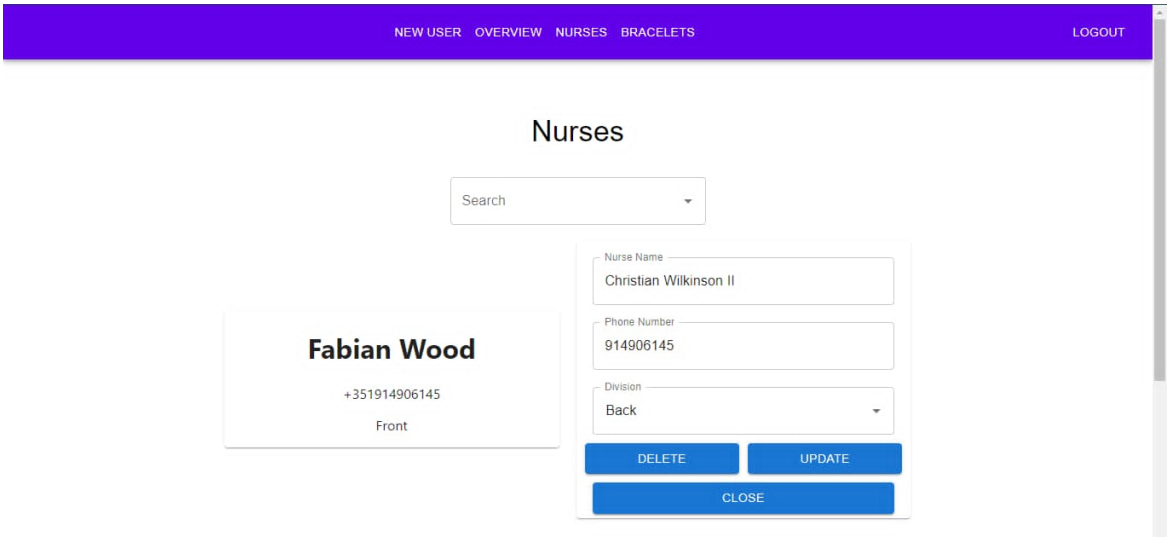


Fig. 4.15 Sample of patient information

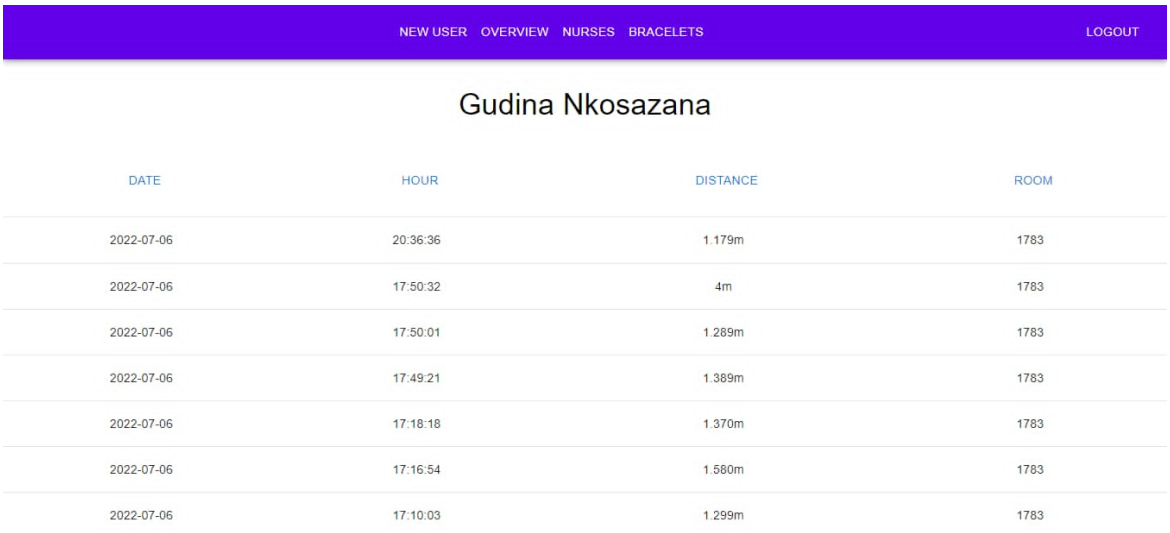
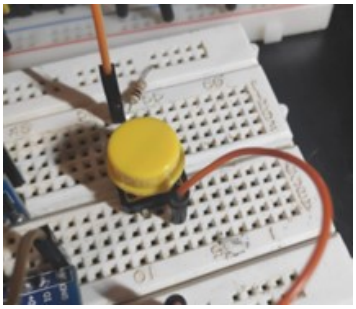


Fig. 4.16 System reset button



4.2 Hardware Design

This section includes the selection of electronics equipment and the integration of all components.

4.2.1 Microcontroller

First and foremost for the falling detection system to work properly, a microcontroller which will perform all the internal calculations is necessary. A microcontroller (MCU) is an integrated circuit (IC) device used for controlling other portions of an electronic system, usually through a microprocessor unit (MPU), memory, and some peripherals.

The falling detection system of this study is implemented using the Microcontroller ESP32-WROOM-32 programmed in Arduino language. The main reasons for selecting this particular module are the following:

- It is small in size
- It can be easily programmed
- It is energy efficient
- It supports Wi-Fi protocols
- It has Bluetooth Low Energy (BLE) technology

As stated above, the MCU was chosen for a number of reasons including BLE technology. Nevertheless, as the project developed, the BLE turned out to be redundant.

Except for the ESP32-WROOM-32, a WeMos LOLIN32 ESP-32 based board was also used. The function of this second board is to be a component of the antenna. Since its core is identical to the the ESP32-WROOM-32, both boards have the same characteristics. The main difference of these two boards is the supply voltage

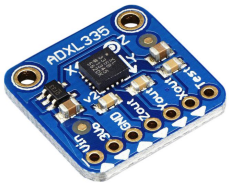
The full list of specifications can be found in the appendix A.1.

4.2.2 3-Axis Accelerometer

In order to detect a fall, a falling sensor is necessary. This kind of sensor works by detecting the abrupt changes of body movements. The most appropriate sensor for this goal is an accelerometer. An accelerometer measures the rate of change of velocity of a body considering its own rest frame. Hence accelerometers can be powerful components and have many applications [41].

For this project a triaxial accelerometer was implemented. This sensor allows analysis of all of the vibrations being experienced by a structure . Each unit incorporates three separate sensing elements that are oriented at right angles with respect to each other. The particular sensor that was used is the ADXL335.

Fig. 4.17 3-axis Analog Accelerometer (ADXL335)



4.2.3 Ultra-wideband (UWB)

UWB technology is a short-range wireless communication protocol, like WiFi or Bluetooth. It creates a radio spectrum that is spread over a very wide band width. The main difference is that UWB is spread over a very wide band width in comparison to other short-range wireless communication protocols [42].

The DWM1000 module was used in this project as it is the first UWB-based transceiver chip and is responsible for obtaining the distance between the patient and a reference point, i.e. between the bracelet and the antenna. This particular module integrates antenna, all RF circuitry, power management and clock circuitry all in one.

Fig. 4.18 DWM1000 module



The module has 4 channels with frequencies between 3.5GHz and 6.5GHz working at 500MHz, data transmission up to 8Mbps and programmable signal strength. It also has an SPI interface to communicate with a microcontroller.

These devices start communicating with each other as soon as they are within range and calculate their distance knowing that:

$$Distance = Speed\ of\ light \times Propagation\ time$$

Fig. 4.19 Illustration of single- and double-sided Two-Way Ranging (TWR) methods [43]

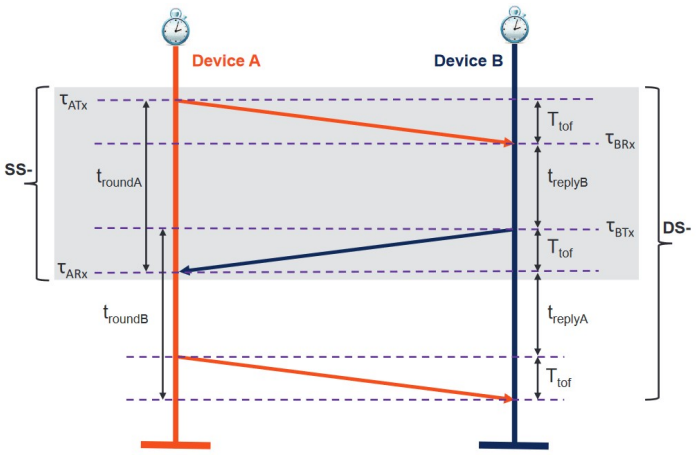


Figure 4.19 illustrates the calculation of the distance between the modules. Firstly, device A sends the message (T_{AT_X}) and records the time mark. Device B then receives the message, and has the record of time mark. After a delay (T_{replyB}), device B sends the message (T_{BT_X}) and has a record of the time mark, and finally device A receives the message, and has the record of time mark. This process occurs twice. It is possible to calculate the signal propagation time from this round trip, where the result according to [44] would be:

$$T_{prop} = \frac{(T_{round1} \times T_{round2} - T_{reply1} \times T_{reply2})}{(T_{round1} + T_{round2} + T_{reply1} + T_{reply2})}$$

The specifications of the DWM1000 can be found in the appendix A.5.

4.2.4 Peripherals

4.2.4.1 Button

Buttons are simple and essential components for any project that has a user interface. These components possess two or more contacts and their function is to control an electrical circuit in which the operator manually presses a button to actuate an internal switching mechanism.

A push button is a button where when pressed opens or closes the current passage according to its type of operation – whether it is normally open (NO) or normally closed (NC) – and once it is not pressed it returns to its normal state.

In this project two (NO) 12x12mm push buttons were used to activate or cancel fall alarms (Figure 4.20).

Fig. 4.20 Button 12x12x(7.3)mm



There is also another button installed in the device which serves to reset the wristband if there are working problems (Figure 4.21).

Fig. 4.21 Switch SMD 5.2x5.2x1.5mm



4.2.4.2 Capacitor

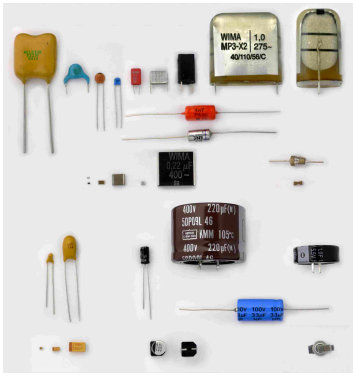
A capacitor is a device for storing electrical energy in an electric field by virtue of accumulating electric charges on two close surfaces (conductors) insulated from each other [45]. It is a passive electronic component with two terminals.

The insulating layer between a capacitors plates is commonly called the Dielectric. A conductor may be a foil, thin film, sintered bead of metal, or an electrolyte. The nonconducting dielectric medium acts to increase the capacitor's charge capacity. The most common dielectrics materials include glass, ceramic, plastic film, paper, mica, air, and oxide layers.

Because of their ability to store electrical charge and then deliver it by discharging it to a circuit (thus acting as a current source), capacitors are essential elements of any modern electronic circuit. Some of their uses are in voltage smoothing circuits, in modulating the frequency of radio transmitters, in the inputs and outputs of transistors, etc [46].

Capacitors can be divided into various types and categories depending upon the type of dielectric and electrodes used and their function and use (Figure 4.22). For example, there are electrostatic, electrolytic and electrohemical capacitors [47].

Fig. 4.22 Different types of capacitors



In this project two different capacitors for each antenna were used. The capacitors were placed parallel at the input.

- Tantalum capacitor smd 10uF 25V tolerance 10% (Figure 4.23)
- Ceramic capacitor smd 100pF 50V tolerance 5% (Figure 4.24)

Fig. 4.23 Tantalum capacitor smd 10uF 25V tolerance 10%



4.2.4.3 Light-emitting diodes

Light-emitting diodes (LED) are semiconductor devices that emit noncoherent, narrow-spectrum light when forward voltage is applied. Similar to a diode, current flows from the

Fig. 4.24 Ceramic capacitor smd 100pF 50V tolerance 5%



p-side to the n-side of the semiconductor, but not in the reverse direction. The electrons in the semiconductor recombine with electron holes, releasing energy in the form of photons [48]. The emitted light can be of various colors depending on the material of the semiconductor. There is a wide variety of LED types, e.g., Miniature, High-power, AC-driven, Flashing, Bi-color [49].

A red LED light is included and programmed to blink in case of a fall (Figure 4.25).

Fig. 4.25 LED SMD1206 650...850mcd 35° - red



4.2.4.4 Lithium-Polymer Battery

A lithium polymer battery (Li-Po) is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte making it adaptable to different formats and allowing high discharge rates [50].

The bracelet futures two 550mAh lithium polymer batteries for both the wristband and the antenna that communicates with it. The batteries include an internal PCB with overcharge, over-discharge, and short-circuit protection (Figure 4.26).

4.2.4.5 Lithium-Polymer Battery Charger

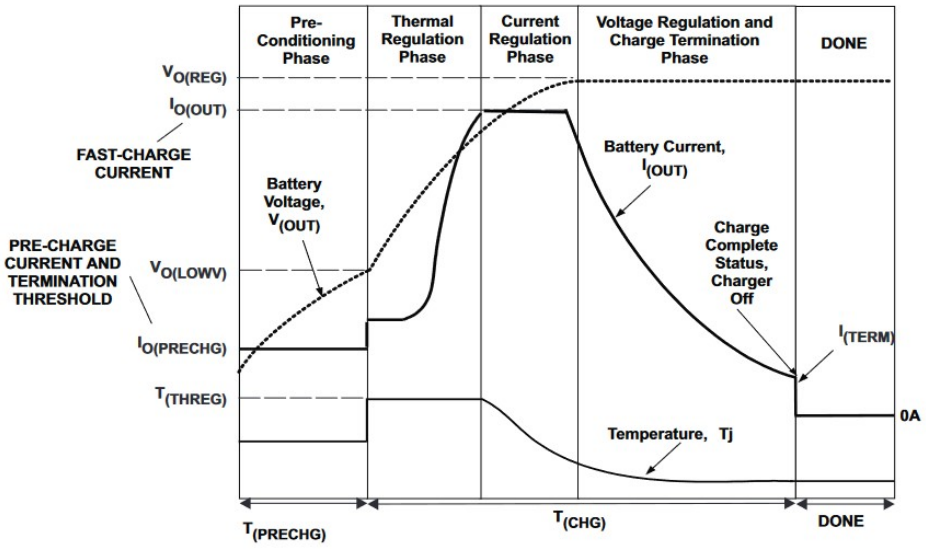
Since batteries discharge over time according to the load they are feeding, it is necessary to charge them every certain time. There is a wide variety of ICs that can be used to charge

Fig. 4.26 Li-Po battery 550mAh



batteries. However each one is quite specific in its characteristics and can be more or less complex depending on whether they are linear chargers or switch type chargers. As with voltage regulators, linear chargers are simpler but less efficient than switch type chargers.

Fig. 4.27 Charging Profile with Thermal Regulation [51]



Pre-charging stage. In the first stage of charging, the charger injects only a small percentage of the value of the max. charging current into the battery. The charger enters this mode if the battery is heavily discharged and the voltage is below a certain level. In this stage of charging there is a threshold value for the battery voltage, which when reached, enters the fast charge stage.

Fast charging stage. This stage, also called constant current stage, regulates the current entering the battery. This current is normally determined by the value of a resistor placed on one of the IC pins - the lower the resistor, the higher the charging current. The value of the pre-charging current mentioned above, therefore also depends on the value of this

resistor. Once the voltage in the battery reaches a certain value also indicated in the datasheet (Vo(Reg)), which normally corresponds to 4.2V, it means that the battery is almost charged and enters the last stage of charging.

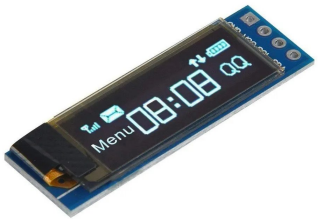
End of charge stage. Here the charger stops regulating the current going to the battery and starts regulating the voltage. However it continues to monitor the current flowing to the battery and once it reaches the I (term), the charger knows that the battery is charged and ends the charging process. However if the voltage in the battery drops below a certain level the charging process starts again. There is another stage referred to in the picture as the "Thermal Regulation Phase". This is a phase that occurs if the IC reaches a certain temperature, where the current will gradually increase to lower the power dissipated and decrease the temperature of the IC. However this is a phase that does not occur in switch chargers due to their high efficiency. All of the above is depicted in Figure 4.27.

4.2.4.6 OLED Display

A display is an OLED device, which allows to visualize data graphically. OLED stands for Organic Light Emitting Diode. In short, an OLED display works by emitting blue-green and red lights when the material that composes it is subjected to an electromagnetic field. It is currently the most advanced technology for manufacturing screens and has low power consumption compared to others (LCD, Plasma, etc.) [52].

The bracelet includes a 128x32 pixel resolution OLED display which allows viewing messages, time and battery, according to the operating situation. The display interacts with the microcontroller via an Inter-Integrated Circuit (I^2C). The screen is auto-illuminated and the energy consumption is low.

Fig. 4.28 Oled Display 128x32

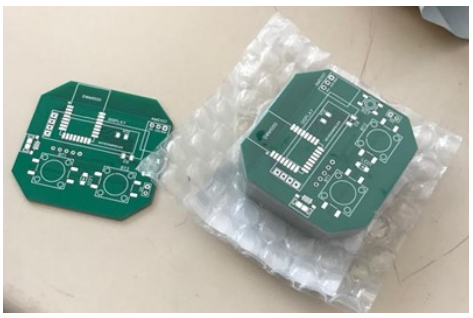


4.2.4.7 Printed Circuit Board

Printed Circuit Boards (PCBs; also known as Printed Wiring Boards, PWB) are a tool used in electrical and electronic engineering to connect electronic components to one another in a controlled manner [53].

For this project it was necessary to built a customized PCB. However, it was not possible to receive the PCB in time in order to solder the components and test its operation. Hence at the time of the on-site project, a prototype on a breadboard was used.

Fig. 4.29 Custom PCB



4.2.4.8 Resistor

A resistor is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to limit or regulate current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses [54].

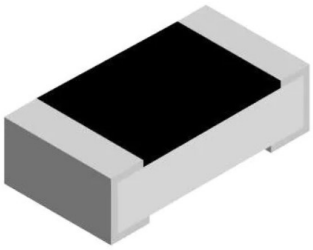
For this project following SMD resistors with case code 1206 mm have been used in order to save space in the PCB:

- 10 kOhm resistor
- 1 kOhm resistor
- 150 Ohm resistor
- 220 Ohm resistor

4.2.4.9 Voltage regulator

Voltage regulators (VRs) are systems designed to automatically maintain the voltage of a power source within acceptable limits. There are two main types of voltage regulators: linear

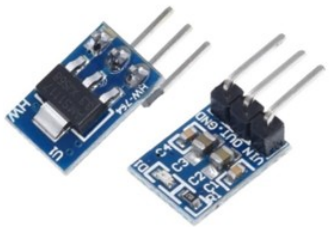
Fig. 4.30 1206 SMD Resistor



and switching. The difference between the two types is that the latter operates with higher efficiency compared to the other [55].

A VR comes along with the two MCUs the ESP32-WROOM-32 and the WeMos LOLIN32 ESP-32. The AMS1117 module (Figure), which was used in the current study,is based on the AMS1117 linear voltage regulator and converts a 5V input voltage into a 3V output voltage. It also has an operation indicator LED.

Fig. 4.31 AMS1117 Module



4.2.5 Housing

The housing of a fall-detection wristband is a crucial component that determines its durability, comfort, and functionality. The wristband must be designed to withstand daily wear and tear while also being comfortable enough to wear all day.

The housing is usually made of durable, lightweight materials such as plastic, silicone, or TPU (thermoplastic polyurethane). The material must be flexible enough to allow the wristband to move with the user's wrist, but also sturdy enough to protect the internal components from damage. The wristband should also have a water-resistant coating to protect it from accidental splashes or exposure to moisture.

In terms of design, the housing of a fall-detection wristband should be compact and streamlined, with no sharp edges or protrusions that could cause discomfort. The wristband

should be adjustable to fit a variety of wrist sizes and be easily removable for charging or maintenance.

The wristband should also have a secure fastening mechanism to ensure that it stays securely on the user's wrist. This is particularly important for fall-detection wristbands, as the sensors need to be in contact with the skin to accurately detect movements and falls.

In conclusion, the housing of a fall-detection wristband is an important aspect to consider when developing this type of wearable device. The housing must be durable, comfortable, and functional to ensure that the wristband is effective in detecting falls and promoting patient safety.

4.3 Software Design

This section will discuss the software building process of the smart bracelet, so that it adresses all of the tasks mentioned in the section 4.1.

The microcontroller programming was done in the Arduino programming language and enviroment (Arduino IDE).

4.3.1 Code

For the first attempt of writing a code, the DOIT ESP32 DEVKIT V1 board (A.12) was used. This development board is created to utilize the ESP-WROOM-32 module.

The following Figure 4.32 shows the breadboard which was used to place the components for testing. The sensory pins of the accelerometer connect to three analog pins of the board. Specifically pin X to pin 13, Y to pin 14 and pin Z to pin 34. The fall indicator led has a series resistance of 1 Kohm and is connected to pin 18.

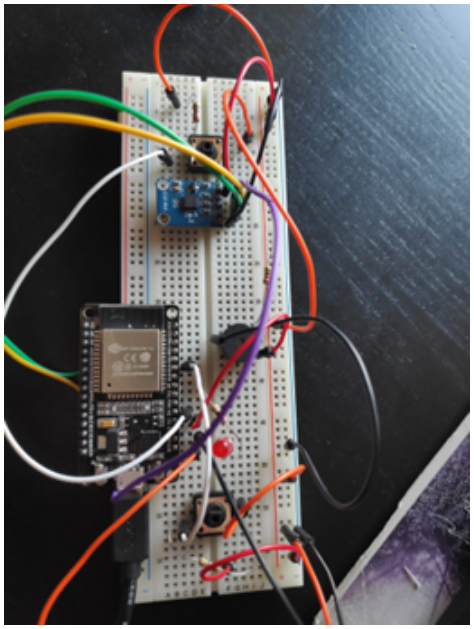
Finally, both the alarm and cancellation buttons were designed to be both activated at positive voltage as shown in the Figure 4.32, so the connections are also not faithful to the final scheme. In this case, the alarm button was connected to pin 4 and the cancel button to pin 19. Both have pulldown resistors so that there is no short circuit when a button is pressed.

A buzzer is also mounted on the breadboard but as of that point it was not used.

4.3.1.1 Fall detection Algorithm

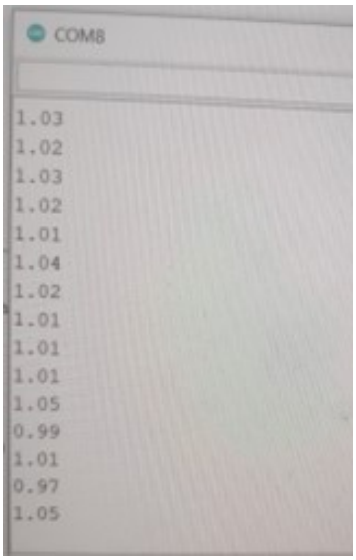
The fall detection algorithm is based off the concept that during a fall, a person experiences a large spike in acceleration. This means that when the sensor is stationary it should only read acceleration equal to 1g, which corresponds to the gravitational force in one of the axes or summed over the three axes as shown in Figure 4.33. Note that the calculated values

Fig. 4.32 First Hardware Assembly



have a small error because of the precision of the analog inputs of the microcontroller. The flowchart of the algorithm can be seen in Figure 4.36.

Fig. 4.33 Acceleration vector values in serial monitor



Excessive testing has been done using the acceleration values on the serial monitor, in order to graphically see the particularities in the acceleration vector that occur when there is a fall. The tests included several simulations of falling and rapid impacts of the sensor

on objects in an attempt to distinguish between the two. The following Figures (4.34, 4.35) show some graphical examples of some of the tests.

Fig. 4.34 Graphical visualization of simulated fall

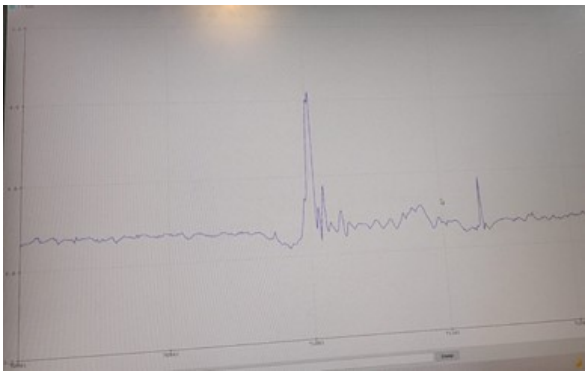


Fig. 4.35 Graphical visualization of quick hand movements

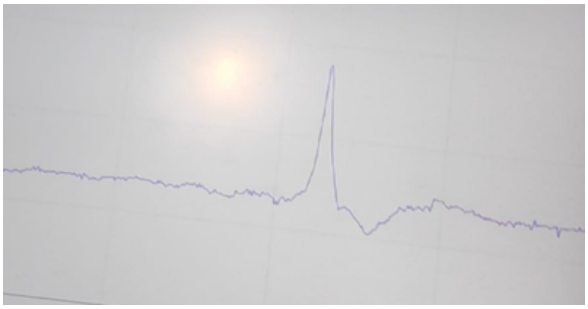
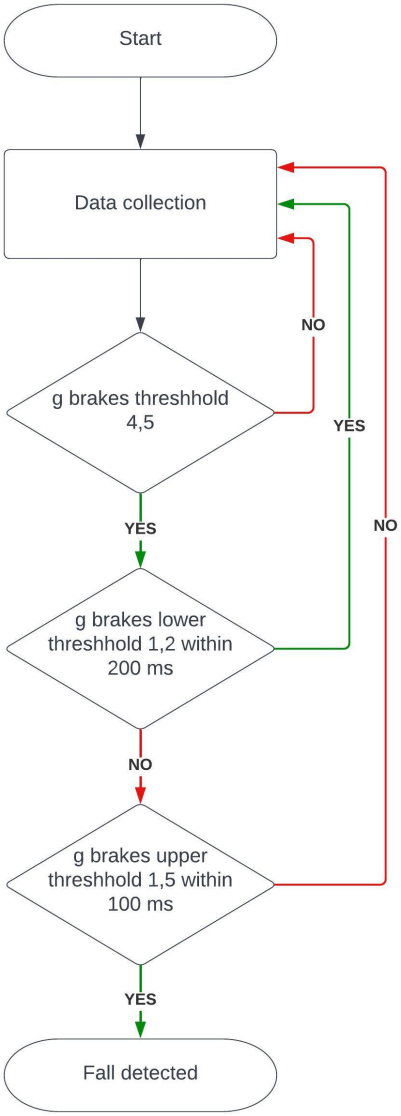


Figure 4.34 shows the results obtained in a fall simulation, while Figure 4.35 corresponds to accelerated hand movement.

As for the fall detection algorithm, it starts with the calculation of the acceleration vector every 10 ms. If at any time there is an acceleration peak like the ones seen in the above Figures and that value exceeds 4.5, the loop starts. The algorithm checks if in a time span of 200 ms the acceleration breaks a set lower threshold of 1.2g. If so, the loop starts over. If this condition is not met, the algorithm then checks if the acceleration breaks a set upper threshold of 1.5g within 100 ms. If this upper threshold is broken, this indicates a person has fallen. This part of the code allows to distinguish between possible falls or physical activities, since as Figure 4.34 shows, the deceleration is sudden in case of a fall as opposed to simple abrupt hand movements (Figure 4.35). The full Arduino program for the algorithm can be seen in Appendix B.

Fig. 4.36 Fall detection algorithm

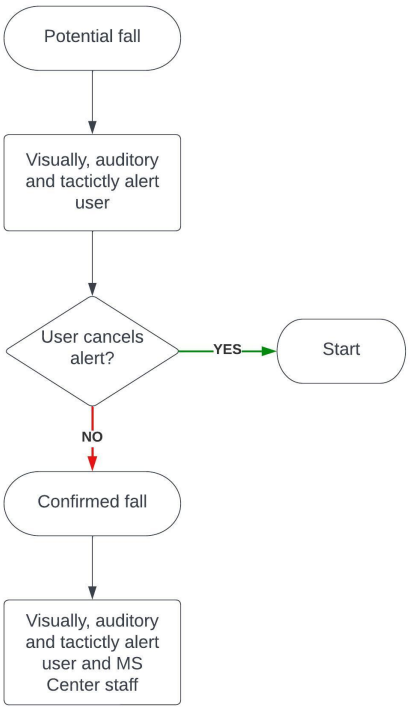


4.3.1.2 Post-Fall Process

Following the detection of a fall by the algorithm, the fall detection program then progresses to what is called a post-fall process. The flowchart for the process can be seen in Figure 4.37. In this process, all falls detected by the algorithm are considered ‘potential falls’. The user is then alerted and given the opportunity to cancel the alert if it was falsely triggered or they were able to regain their composure. If the alert is not cancelled, the program changes into confirmed fall mode, where the user and the MS Center staff are alerted of a confirmed fall

incident. In the Appendix B the final prototype Arduino program, that fully implements the sensor, buttons, buzzer and the LED, can be found.

Fig. 4.37 Post-Fall algorithm



4.3.2 Application Programming Interface

The Application Programming Interface (API) is an interactive web application that can be accessed via web by the patients caregivers. This application stores information about each patients falls and a brief history of his medical condition. As previously mentioned in section 4.1, the application can be also used to add, remove or edit bracelets and nurses within the facilities of the MS Center. Last but not least the application ensures data security. Below is a list of all the feautures of the API:

- Handles user accounts:
  - Logging in
  - Creating accounts
- Can receive data from bracelets

- Can give patient's recorded data
- Maintain data related to nurses
- Send alerts to registered nurses

In order to create the API, Node.js was used. Node.js is an opensource, asynchronous event-driven JavaScript runtime, which is designed to build scalable network applications [56]. The web application interface was created using the React library. This tool allows to interact with the API and allows nurses to enter and retrieve data, as seen in section 4.1.

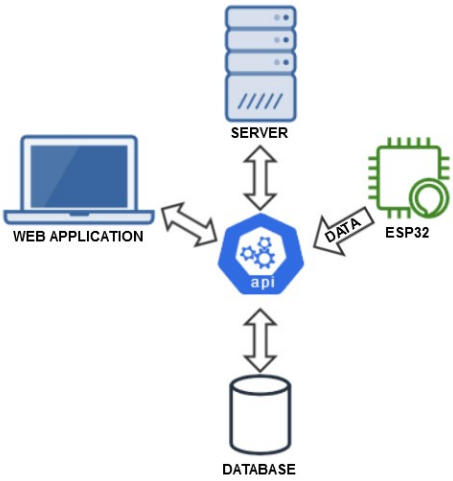
In case a fall incident occurs, the data sent by the wristband passes through the API and is placed in a database (Figure 4.38). This database, created in MySQL and managed in phpMyAdmin, has its data collected by the API and sent to the web interface, thus allowing the interface to be updated.

Fig. 4.38 Database phpMyAdmin



This data is also transmitted to the server. The web application is constantly communicating with the server through the API, so all of the data (fall detection alarms etc.) are visible in the web application. Following Figure 4.39 shows the communication schema.

Fig. 4.39 API - communication schematics



Chapter 5

Implementation of the Project using SCRUM Framework

According to the Scrum guide, Scrum is a lightweight framework that helps people, teams and organizations to create value through adaptive solutions to complex problems [37]. Scrum incorporates teams of people who, taken as a whole, possess all the knowledge and abilities necessary to complete the work and may share or gain more skills as needed [18]. The core of scrum theory is based on empiricism and lean thinking. To practice Scrum effectively, it is essential to learn the Scrum values and principles, which are reflected in the three empiricism pillars. All Scrum roles, events, and artifacts rely on them. They are of utmost importance to product development. The three pillars of Scrum empiricism are inextricably linked to each other, as there can be no Scrum if one of the pillars is not implemented [37].

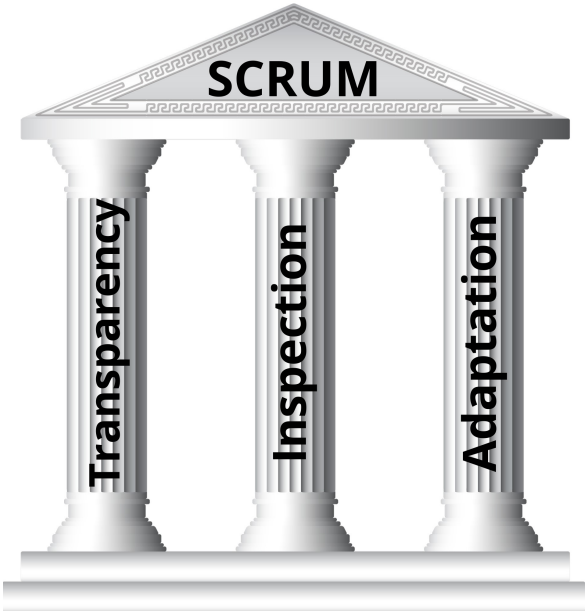
5.1 The Three Pillars of Empiricism

The first pillar of empiricism is transparency. Transparency requires that both the recipients and those doing the work are aware of the emergent processes and work. Important decisions in Scrum are based on the perception of its three formal artifacts. The lack of transparency in an artifact can lead to decisions that reduce value and increase risk. Transparency allows for inspection. Inspection without transparency is misleading and inefficient [37].

Empiricism is also based on inspection, which is the second pillar. It is essential to inspect Scrum artifacts frequently and diligently to detect any potential undesirable variances or issues. As part of Scrum's five events, it provides a cadence to help with inspection. A thorough inspection allows for adaptation. There is no point in inspecting without adapting. The purpose of Scrum events is to provoke change [37].

As the last pillar, adaptation is crucial. It is necessary to adjust the process used or the materials being used if any part of a process deviates outside acceptable limits. It is imperative to make adjustments as soon as possible so that further deviations can be minimized. Adaptation is more challenging when people aren't empowered and self-managed. Once a Scrum Team learns something new through inspection, it is expected to adapt [37]. The empiricism pillars can be seen in Figure 5.1.

Fig. 5.1 The Three Pillars of Empiricism [57]



5.2 Scrum Values

In order for Scrum to be effectively practiced, people must become adept at living along the five Scrum values of Commitment, Focus, Openness, Respect, and Courage [58] as seen on Figure 5.2.

Commitment is the dedication and resolve to work towards a common goal, despite obstacles and challenges. Team members should be committed to the success of the project and to delivering high-quality work.

Courage refers to the willingness to take risks, to step out of one's comfort zone, and to embrace change. In Scrum, team members should have the courage to speak their minds, to try new approaches, and to take calculated risks that can lead to innovation and progress.

Fig. 5.2 Scrum Values [59]



Focus is about staying centered on the goal and avoiding distractions. The Scrum framework encourages team members to prioritize their work and to avoid multitasking, so they can stay focused on delivering value to the customer.

Openness is about fostering an environment of transparency, trust, and communication. In Scrum, team members should be open and honest with one another, share information freely, and work together to find solutions to problems.

Finally, respect is about treating each other with dignity and empathy, regardless of rank or role. In Scrum, team members should respect each other's opinions, experiences, and expertise, and work together as a team to achieve common goals.

In conclusion, the five Scrum values serve as a guide for building a high-performing, collaborative, and effective team. By embracing these values, organizations can create a positive and productive work environment, where everyone is working together to deliver the best possible results.

5.3 Scrum Team

The Scrum team is a cross-functional group of individuals who work together to deliver a product or service. The team is composed of three primary roles: the Product Owner, the Scrum Master, and the Development Team. Studies have shown that high-performing Scrum teams exhibit a number of characteristics, such as high levels of trust and collaboration, clear roles and responsibilities, and a shared understanding of the goal. In particular, research

has shown that self-organizing teams, like those used in Scrum, are more effective than traditional, hierarchical teams in achieving their goals [37].

The Scrum team is the heart of the Scrum framework, and is designed to embody the principles of empirical process control and to deliver high-quality products through collaboration, transparency, and continuous improvement. The Product Owner, Scrum Master, and Development Team work together to create an environment that is supportive, adaptive, and focused on delivering value to the customer [60].

5.3.1 Product Owner

The Product Owner is responsible for defining the product backlog, which is a prioritized list of work that needs to be done to deliver the product. The Product Owner represents the customer and ensures that the team is working on the most valuable and relevant items in the backlog [37].

5.3.2 Scrum Master

The Scrum Master is the facilitator of the Scrum process. The Scrum Master helps the team to follow the Scrum values and practices, removes any obstacles that the team may encounter, and ensures that the team is working in an environment that supports continuous improvement [37].

5.3.3 Developers

The Development Team is responsible for creating and delivering the product increment. The Development Team is composed of individuals with a variety of skills, such as software developers, designers, and testers, who work together to build the product. The Development Team operates using a self-organizing and self-managing approach, where each team member takes ownership of their work and contributes to the success of the project [37].

5.4 Scrum Events

One of the key aspects of Scrum is its use of events, also known as ceremonies, to structure and manage the work of the Scrum team. There are four key Scrum events: Sprint, Sprint Planning, Daily Scrum, and Sprint Review [37].

5.4.1 The Sprint

The Sprint is the heart of the Scrum framework and is a time-boxed iteration, typically lasting between one and four weeks, during which the team delivers a usable and valuable increment of the product [37].

5.4.2 Sprint Planning

The Sprint Planning event is held at the beginning of each Sprint and is used to plan the work that will be done during the Sprint. The team, including the Product Owner, the Scrum Master, and the Development Team, work together to identify the most important items in the product backlog, and to agree on the work that will be done during the Sprint [37].

5.4.3 Daily Scrum

The Daily Scrum is a short daily meeting, typically held in the morning, during which the Development Team members discuss their progress and plan their work for the day. The Daily Scrum provides the team with a regular opportunity to review their work and to identify any obstacles that need to be addressed [37].

5.4.4 Sprint Review

The Sprint Review is a demonstration of the work that has been done during the Sprint, and is used to gather feedback from stakeholders and to review the progress of the project. The Sprint Review provides the team with an opportunity to demonstrate their work and to receive feedback on their work and to make any necessary adjustments to the product backlog [37].

5.4.5 Sprint Retrospective

The Sprint Retrospective is one of the key events in the Scrum framework and is held at the end of each Sprint. The purpose of the Sprint Retrospective is to reflect on the previous Sprint and to identify areas for improvement. During the Sprint Retrospective, the Scrum team, including the Product Owner, the Scrum Master, and the Development Team, comes together to discuss what went well during the Sprint, what could be improved, and what actions they will take to make improvements in the next Sprint. The Sprint Retrospective is an opportunity for the team to reflect on their work and to identify ways to increase their efficiency and effectiveness. The focus of the Sprint Retrospective is on continuous improvement and the

team works together to identify and implement changes that will help them to deliver better products and services [37].

5.5 Scrum Artifacts

Scrum artifacts are elements of the Scrum framework that help to define and track the work of the Scrum team. The three primary Scrum artifacts are the Product Backlog, the Sprint Backlog, and the Increment. These are essential elements of the Scrum framework and help to define, track, and manage the work of the Scrum team. They help to provide transparency, accountability, and direction to the work of the team and are critical to the success of the project [37].

5.5.1 Product Backlog

The Product Backlog is a prioritized list of items that represents the work that needs to be done in order to deliver a valuable product or service. The Product Backlog is owned by the Product Owner and is continually updated to reflect the changing needs of the customer and the market [37].

5.5.2 Sprint Backlog

The Sprint Backlog is a subset of the Product Backlog and represents the work that the team has committed to completing during the Sprint. The Sprint Backlog is owned by the Development Team and is updated regularly to reflect the team's progress [37].

5.5.3 Increment

The Increment is the result of each Sprint and represents the improvement and value that has been delivered by the team. The Increment is a usable and valuable part of the product or service, and provides stakeholders with a clear view of the team's progress and the value that they are delivering [37].

Chapter 6

Results and Discussion

The development of a smart bracelet prototype for detecting falls in MS patients was successfully completed using the SCRUM framework. The prototype integrates an accelerometer to monitor the patient's movements and employs a fall detection algorithm to distinguish between normal activity and falls. It is programmed to send an alert to a caregiver via a text message, informing them about the patients' information and the exact location of the patient at that very moment, so that help can come fast.

The fall detection system implemented in the prototype was tested using a dataset of falls recorded at home. The results show that the system has enough relevance to be feasible to apply to real situations, with around 70-80% of effectiveness. Although it is not possible to verify the accuracy of these values since exhaustive tests would be necessary inside the MS centre, the results are promising and indicate that the system has the potential to significantly improve patient safety and independence.

Several challenges were encountered during the project, including the difficulty of working with a geographically dispersed team living in three different countries and time zones. This created obstacles to communication and collaboration, as team members had to work around their schedules and different cultural expectations. However, the Scrum framework helped to mitigate some of these challenges by providing a structured approach to project management and fostering regular check-ins and progress updates.

One of the main challenges in the development of the prototype was the need to balance the accuracy of the fall detection algorithm with the need to avoid false alarms, which can be especially distressing for patients. This required a significant amount of testing and refinement of the algorithm, which ultimately led to the current level of effectiveness.

Another challenge was ensuring that the prototype was user-friendly and accessible to patients with varying levels of technological proficiency. This required a thoughtful design of the user interface and clear instructions for use.

The results of this thesis demonstrate that the prototype is a promising solution for improving patient safety and independence. However, there is significant potential for further development and improvement.

Overall, the smart bracelet prototype represents a significant step forward in the development of technology to support MS patients and improve their quality of life. Further work on this prototype could lead to the development of a more comprehensive and effective solution for monitoring and supporting MS patients, and ultimately lead to a positive impact on their lives.

Chapter 7

Conclusions and Recommendations

In conclusion, the development of a prototype for a smart bracelet that detects falls for MS patients using the Scrum framework has been successful. The fall detection algorithm implemented in the prototype has shown around 70-80% of effectiveness, making it feasible to apply to real situations. However, further tests would be necessary to verify its accuracy in more complex situations inside the MS center. The prototype has been designed to alert caregivers via text messages with information about the patient and their location, providing a promising solution for improving patient safety and independence.

During the project, working with a team from three different countries/time zones (Greece, Belgium, and Portugal) was a challenge. However, effective communication and organization using the SCRUM framework helped to overcome this challenge and ensure successful project completion.

In terms of future work, the prototype can be further improved to increase the effectiveness and usability of the prototype.

One key area for future work is the refinement of the fall detection algorithm to reduce the potential for false positives and increase the accuracy of fall detection. This could be achieved through the integration of additional sensors, such as a gyroscope or magnetometer, to provide more comprehensive data on the patient's movement patterns. Machine learning techniques could also be employed to optimize the algorithm and improve the precision of the fall detection system.

Another area for future work is the optimization of the smart bracelet's communication and alert system. The current text message alert system is a promising feature, but additional functionalities could be added to provide more information to caregivers, such as the patient's medical history or any pre-existing conditions that could impact their response to a fall. Additionally, the integration of a voice call or video call feature could provide more direct

communication between the patient and caregiver, allowing for more effective triage and medical attention.

The usability and comfort of the smart bracelet could also be improved through the implementation of user-centered design principles. This could involve the exploration of different materials and form factors to improve comfort and reduce the burden on the patient. Additionally, user testing and feedback could be employed to inform the design of the user interface and ensure that the smart bracelet is intuitive and easy to use for both patients and caregivers.

Finally, further research and development are necessary to validate the effectiveness of the smart bracelet in a real-world setting. This could involve the implementation of the prototype in a larger-scale clinical trial, with a focus on evaluating its effectiveness and impact on patient safety and independence. Long-term studies could also be conducted to assess the durability and reliability of the smart bracelet over extended periods of use.

Taking everything into account, the smart bracelet prototype developed in this thesis represents a promising solution for fall detection in MS patients. However, there are several opportunities for future work that could further optimize its effectiveness, usability, and impact on patient safety and independence.

References

[1] N. Ghasemi, S. Razavi, and E. Nikzad. Multiple sclerosis: Pathogenesis, symptoms, diagnoses and cell-based therapy. *Cell Journal*, 19(1):1–10, 2017.

[2] Hilal Karakas, Barbara Seebacher, and Turhan Kahraman. Technology-based rehabilitation in people with multiple sclerosis: A narrative review. *J Mult Scler Res*, 1(3):54–68, 2021. doi: 10.4274/jmsr.galenos.2021.2021-10-3.

[3] Ron Milo and Ariel Miller. Revised diagnostic criteria of multiple sclerosis. *Autoimmunity Reviews*, 13(4):518–524, 2014. Diagnostic criteria in Autoimmune diseases.

[4] Alfredo Manuli, Maria Grazia Maggio, Daniele Tripoli, Martina Gullì, Antonino Cannavò, Gianluca La Rosa, Francesca Sciarrone, Giuseppe Avena, and Rocco Salvatore Calabrò. Patients' perspective and usability of innovation technology in a new rehabilitation pathway: An exploratory study in patients with multiple sclerosis. *Multiple Sclerosis and Related Disorders*, 44:102312, 2020.

[5] Hilary J. Gunn, Paul Newell, Bernhard Haas, Jonathan F. Marsden, and Jennifer A. Freeman. Identification of Risk Factors for Falls in Multiple Sclerosis: A Systematic Review and Meta-Analysis. *Physical Therapy*, 93(4):504–513, 04 2013.

[6] Susan Coote, Laura Comber, Gillian Quinn, Carme Santoyo-Medina, Alon Kalron, and Hilary Gunn. Falls in people with multiple sclerosis. *International Journal of MS Care*, 22(6), 2020.

[7] Susan Coote, Jacob J. Sosnoff, and Hilary Gunn. Fall incidence as the primary outcome in multiple sclerosis falls-prevention trials. *International Journal of MS Care*, 16(4):178–184, 2014.

[8] Nadina B Lincoln, Lucy E Bradshaw, Cris S Constantinescu, Florence Day, Avril ER Drummond, Deborah Fitzsimmons, Shaun Harris, Alan A Montgomery, and Roshan das Nair. Group cognitive rehabilitation to reduce the psychological impact of multiple sclerosis on quality of life: the cramms rct. *Health Technology Assessment*, 24(4):1–182, 2020.

[9] Derrick Robertson and Natalie Moreo. Disease-modifying therapies in multiple sclerosis: Overview and treatment considerations. *Federal Practitioner*, 33(6):28–34, Jun 2016.

[10] Gianvito Martino, Robin JM Franklin, Anne Baron Van Evercooren, Douglas A Kerr, and Stem Cells in Multiple Sclerosis (STEMS) Consensus Group. Stem cell transplantation in multiple sclerosis: current status and future prospects. *Nature Reviews Neurology*, 6(5):247–255, 2010.

[11] Anna M Kubsik-Gidlewska, Paulina Klimkiewicz, Robert Klimkiewicz, Katarzyna Janczewska, and Marta Zofia Woldańska-Okońska. Rehabilitation in multiple sclerosis. *Advances in Clinical and Experimental Medicine*, 26(4), 2017.

[12] Neusa R. Adão Martins, Simon Annaheim, Christina M. Spengler, and René M. Rossi. Fatigue monitoring through wearables: A state-of-the-art review. *Frontiers in Physiology*, 12, 2021.

[13] Irene Cortés-Pérez, Marcelina Sánchez-Alcalá, Francisco Antonio Nieto-Escámez, Yolanda Castellote-Caballero, Esteban Obrero-Gaitán, and María Catalina Osuna-Pérez. Virtual reality-based therapy improves fatigue, impact, and quality of life in patients with multiple sclerosis. a systematic review with a meta-analysis. *Sensors*, 21(21), 2021.

[14] Stephanie L Silveira and Robert W Motl. Activity monitor use among persons with multiple sclerosis: Report on rate, pattern, and association with physical activity levels. *Multiple Sclerosis Journal - Experimental, Translational and Clinical*, 5(4):205521731988798, 2019.

[15] Magdalena Pruszyńska, Marta Milewska-Jundefineddrzejczak, Igor Bednarski, Piotr Szpakowski, Andrzej Głąbiński, and Sławomir Konrad Tadeja. Towards effective telerehabilitation: Assessing effects of applying augmented reality in remote rehabilitation of patients suffering from multiple sclerosis. *ACM Trans. Access. Comput.*, 15(4), nov 2022.

[16] Deirdre E Logan, Laura E Simons, Thomas J Caruso, Jeffrey I Gold, Walter Greenleaf, Anya Griffin, Christopher D King, Maria Menendez, Vanessa A Olbrecht, Samuel Rodriguez, and et al. Leveraging virtual reality and augmented reality to combat chronic pain in youth: Position paper from the interdisciplinary network on virtual and augmented technologies for pain management. *Journal of Medical Internet Research*, 23(4), 2021.

[17] D. Freeman, S. Reeve, A. Robinson, A. Ehlers, D. Clark, B. Spanlang, and M. Slater. Virtual reality in the assessment, understanding, and treatment of mental health disorders. *Psychological Medicine*, 47(14):2393–2400, 2017.

[18] Emmanuel Lourakis and Konstantinos Petridis. Applying scrum in an online physics ii undergraduate course: Effect on student progression and soft skills development. *Education Sciences*, 13(2):126, Jan 2023.

[19] Kent Beck, Mike Beedle, Arie Van Bennekum, Alistair Cockburn, Ward Cunningham, Martin Fowler, James Grenning, Jim Highsmith, Andrew Hunt, Ron Jeffries, et al. Manifesto for agile software development. http://agilemanifesto.org/, 2001.

[20] Alistair Cockburn. *Agile software development: The cooperative game*. Addison-Wesley, 2 edition, 2008.

[21] Andrea Hildebrand, Peter G. Jacobs, Jonathon G. Folsom, Clara Mosquera-Lopez, Eric Wan, and Michelle H. Cameron. Comparing fall detection methods in people with multiple sclerosis: A prospective observational cohort study. *Multiple Sclerosis and Related Disorders*, 56:103270, 2021.

[22] Nazmun Nahar, Mohammad Hossain, and Karl Andersson. *A Machine Learning Based Fall Detection for Elderly People with Neurodegenerative Disorders*, pages 194–203. 09 2020.

[23] Koldo de Miguel, Alberto Brunete, Miguel Hernando, and Ernesto Gambao. Home camera-based fall detection system for the elderly. *Sensors*, 17(12):2864, 2017.

[24] Viknesh Kumar, Boon-Chin Yeo, Way-Soong Lim, Joseph Emerson Ra, and Kim-Boon Koh. Development of electronic floor mat for fall detection and elderly care. *Asian Journal of Scientific Research*, 11(3):344–356, 2018.

[25] Maarit Kangas, Anne Konttila, Peter Lindgren, Ilkka Winblad, and Timo Jämsä. Comparison of low-complexity fall detection algorithms for body attached accelerometers. *Gait & posture*, 28(2):285–291, 2008.

[26] Taylor Mauldin, Marc Canby, Vangelis Metsis, Anne Ngu, and Coralys Rivera. Smartfall: A smartwatch-based fall detection system using deep learning. *Sensors*, 18:3363, 10 2018.

[27] Anju Pillai, Sejal Badgujar, and Sujatha Krishnamoorthy. *Wearable Sensor and Machine Learning Model-Based Fall Detection System for Safety of Elders and Movement Disorders*, pages 47–60. 02 2022.

[28] Soonjae Ahn, Jongman Kim, Bummo Koo, and Youngho Kim. Evaluation of inertial sensor-based pre-impact fall detection algorithms using public dataset. *Sensors (Basel, Switzerland)*, 19(4):774–784, 2019.

[29] Panagiotis G. Tsinganos. Smartphone-based fall detection system for the elderly. Master's thesis, University of Patras, Patras, Greece, 2017.

[30] Thomas Vilarinho, Babak Farshchian, Daniel Gloppestad Bajer, Ole Halvor Dahl, Iver Egge, Sondre Steinsland Hegdal, Andreas Lones, Johan N. Slettevold, and Sam Mathias Weggersen. A combined smartphone and smartwatch fall detection system. *Infor2015 IEEE International Conference on Computer and mation Technology; Ubiquitous Computing and Communications; Dependable, Autonomic and Secure Computing; Pervasive Intelligence and Computing*, page 1443–1448, 2015.

[31] Firdous Kausar, Medhat Awadalla, Mostefa Mesbah, and Taif AlBadi. Automated machine learning based elderly fall detection classification. *Procedia Computer Science*, 203:16–23, 2022. 17th International Conference on Future Networks and Communications / 19th International Conference on Mobile Systems and Pervasive Computing / 12th International Conference on Sustainable Energy Information Technology (FNC/-MobiSPC/SEIT 2022), August 9-11, 2022, Niagara Falls, Ontario, Canada.

[32] Y. Choi, A. S. Ralhan, and S. Ko. A study on machine learning algorithms for fall detection and movement classification. In *2011 International Conference on Information Science and Applications*, pages 1–8, 2011.

[33] Gangireddy Prabhakar Reddy and M. Kalaiselvi Geetha. Video based fall detection using deep convolutional neural network. *European Journal of Molecular &; Clinical Medicine*, 07(11):739–748, 2020.

[34] Myeongseob Ko, Suneung Kim, Mingi Kim, and Kwangtaek Kim. A novel approach for outdoor fall detection using multidimensional features from a single camera. *Applied Sciences*, 8(6), 2018.

[35] Federico Bianchi, Stephen J. Redmond, Michael R. Narayanan, Sergio Cerutti, and Nigel H. Lovell. Barometric pressure and triaxial accelerometry-based falls event detection. *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, 18(6):619–627, 2010.

[36] L. Minvielle, M. Atiq, R. Serra, M. Mougeot, and N. Vayatis. Fall detection using smart floor sensor and supervised learning. In *2017 39th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. IEEE, 2017.

[37] Ken Schwaber and Jeff Sutherland. The scrum guide - the definitive guide to scrum: The rules of the game. Available at: https://scrumguides.org/docs/scrumguide/v2020/2020-Scrum-Guide-US.pdf, Nov 2020. Accessed: 2023-02-08.

[38] Jeffrey Victor Sutherland. *Scrum: The art of doing twice the work in half the time*. Random House, 1 edition, 2019.

[39] Eric Ries. *The Lean Startup: How Today's entrepreneurs use continuous innovation to create radically successful businesses*. Currency, 1 edition, 2017.

[40] M. Cohn. *Agile Estimating and Planning*. Robert C. Martin series. Prentice Hall Professional Technical Reference, 2006.

[41] Suman Lata Tripathi, Valentina E. Balas, S. K. Mohapatra, Kolla Bhanu Prakash, and Janmenjoy Nayak, editors. *Electronic Devices, circuits, and systems for biomedical applications*. Academic Press, 2021.

[42] Alan Bensky. Chapter 12 - wireless personal area networks. In Alan Bensky, editor, *Short-range Wireless Communication (Third Edition)*, pages 317–360. Newnes, third edition edition, 2019.

[43] Cung Lian Sang, Michael Adams, Timm Hörmann, Marc Hesse, Mario Porrmann, and Ulrich Rückert. Numerical and experimental evaluation of error estimation for two-way ranging methods. *Sensors*, 19(3), 2019.

[44] Dries Neirynck, Eric Luk, and Michael McLaughlin. 13th workshop on positioning, navigation and communication, wpnc. pages 1–4. IEEE.

[45] Richard C. Dorf and James A. Svoboda. *Energy Storage Elements*, page 269–275. John Wiley &; Sons, 2014.

[46] Charles Platt. *Capacitor*, volume 1. O'Reilly Media, Inc., 2013.

[47] R. P. Deshpande. *Capacitors*. McGraw-Hill Education, 2015.

[48] Gilbert Held. *Introduction to light emitting diode technology and applications*. CRC Press, 2009.

[49] N. Thejo Kalyani, Hendrik Swart, and S. J. Dhoble. *Principles and applications of Organic Light Emitting Diodes (oleds)*. Woodhead Publishing, 2017.

[50] Bruno Scrosati and Jürgen Garche. Lithium batteries: Status, prospects and future. *Journal of Power Sources*, 195(9):2419–2430, 2010.

[51] Texas Instruments. *BQ2409x 1-A, Single-Input, Single-Cell Li-Ion and Li-Pol Battery Chargers*, 2010. Rev. April 2021.

[52] K. Müllen and Ullrich Scherf. *Organic light-emitting devices: Synthesis, Properties, and Applications*. Wiley-VCH, 2006.

[53] Raghbir Singh Khandpur. Printed circuit boards design, fabrication, and assembly. 2006.

[54] Charles Platt. *Resistor*, volume 1. O'Reilly Media, Inc., 2013.

[55] Charles Platt. *Voltage regulator*, volume 1. O'Reilly Media, Inc., 2013.

[56] Node.js. https://nodejs.org/. Accessed: 2023-02-07.

[57] The three pillars of empiricism. https://premieragile.com/the-three-pillars-of-empiricism/. Image from PremierAgile.

[58] Maja Due Kadenic, Konstantinos Koumaditis, and Louis Junker-Jensen. Mastering scrum with a focus on team maturity and key components of scrum. *Information and Software Technology*, 153:107079, 2023.

[59] Scrum values poster. https://www.scrum.org/resources/scrum-values-poster. Image from Scrum.org.

[60] Ken Schwaber. *Agile Project Management with scrum*. Microsoft Press, 2015.

Appendix A

Technical specifications

A.1 ESP32WROOM32

Table A.1 ESP32WROOM32 Specifications

Categories	Items	Specifications
Certification	RF certification	See certificates for ESP32-WROOM-32
	Wi-Fi certification	Wi-Fi Alliance
	Bluetooth certification	BQB
	Green certification	RoHS/REACH
Test	Reliablity	HTOL/HTSL/uHAST/TCT/ESD
Wi-Fi	Protocols	802.11 b/g/n (802.11n up to 150 Mbps)
		A-MPDU and A-MSDU aggregation and 0.4 μs guard interval support
	Center frequency range of operating channel	2412 ∼2484 MHz
Bluetooth	Protocols	Bluetooth v4.2 BR/EDR and Bluetooth LE specification
	Radio	NZIF receiver with –97 dBm sensitivity
		Class-1, class-2 and class-3 transmitter
		AFH
	Audio	CVSD and SBC
Hardware	Module interfaces	SD card, UART, SPI, SDIO, I2C, LED PWM, Motor PWM, I2S, IR, pulse counter, GPIO, capacitive touch sensor, ADC, DAC, Two-Wire Automotive Interface (TWAI®), compatible with ISO11898-1 (CAN Specification 2.0)
	On-chip sensor	Hall sensor
	Integrated crystal	40 MHz crystal
	Integrated SPI flash	4 MB
	Operating voltage/Power supply	3.0 V ∼3.6 V
	Operating current	Average: 80 mA
	Minimum current delivered by power supply	500 mA
	Recommended operating ambient temperature range	–40 °C ∼+85 °C
	Package size	18 mm × 25.5 mm × 3.10 mm
	Moisture sensitivity level (MSL)	Level 3

A.2 Esp32 WeMos LOLIN32

Table A.2 Esp32 WeMos LOLIN32 Specifications

Operating Voltage	3.3V
Supported Battery	Lipo 3.7V
Battery Connector	PH-2 2.0mm
Digital I/O Pins	22
Analog Input Pins	6 (VP, VN, 32, 33, 34, 35)
Analog Output Pins	2 (25, 26)
LED_BUILTIN	GPIO5
Clock Speed(Max)	240MHz
Flash	4M Bytes
Size	57*25.4mm
Weight	6.1g

A.3 ADXL335

T_A = 25°C, V_S = 3 V, $C_X = C_Y = C_Z$ = 0.1 μF, acceleration = 0 g, unless otherwise noted. All minimum and maximum specifications are guaranteed. Typical specifications are not g.

[1]Defined as coupling between any two axes.

[2]Sensitivity is essentially ratiometric to V_S.

[3]Defined as the output change from ambient-to-maximum temperature or ambient-to-minimum temperature.

[4]Actual frequency response controlled by user-supplied external filter capacitors (C_X, C_Y, C_Z).

[5]Bandwidth with external capacitors = $1/(2\times\pi\times 32k\Omega\times C)$.*For*C$_X$, C_Y = 0.003 μF, bandwidth = 1.6 kHz. For $C_Z = 0.01\mu$F, bandwidth = 500 Hz. For C_X, C_Y, $C_Z = 10\mu$F, bandwidth = 0.5 Hz.

[6]Self-test response changes cubically with VS.

[7]Turn-on time is dependent on C_X, C_Y, C_Z and is approximately 160 $\times$C$_X$ or C_Y or C_Z + 1 ms, where C_X, C_Y, C_Z are in microfarads (μF).

Table A.3 ADXL335 Specifications

Parameter	Conditions	Min	Typ	Max	Unit
SENSOR INPUT Measurement Range Nonlinearity Package Alignment Error Interaxis Alignment Error Cross-Axis Sensitivity[1]	 Each axis % of full scale	 ±3	 ±3.6 ±0.3 ±1 ±0.1 ±1		 g % Degrees Degrees %
SENSITIVITY (RATIOMETRIC)[2] Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT} Sensitivity Change Due to Temperature[3]	Each axis V_S = 3 V V_S = 3 V	270	300 ±0.01	330	mV/g %/°C
ZERO g BIAS LEVEL (RATIOMETRIC) 0 g Voltage at X_{OUT}, Y_{OUT} 0 g Voltage at Z_{OUT} 0 g Offset vs. Temperature	 V_S = 3 V V_S = 3 V	 1.35 1.2	 1.5 1.5 ±1	 1.65 1.8	 V V mg/°C
NOISE PERFORMANCE Noise Density $XOUT$, Y_{OUT} Noise Density Z_{OUT}			150 300		$\mu g/\sqrt{Hz} rms$ $\mu g/\sqrt{Hz} rms$
FREQUENCY RESPONSE[4] Bandwidth X_{OUT}, Y_{OUT}[5] Bandwidth Z_{OUT} R_{FILT} Tolerance Sensor Resonant Frequency	 No external filter No external filter		1600 550 32 ± 15% 5.5		Hz Hz kΩ kHz
SELF-TEST[6] Logic Input Low Logic Input High ST Actuation Current Output Change at X_{OUT} Output Change at Y_{OUT} Output Change at Z_{OUT}	 Self-Test 0 to Self-Test 1 Self-Test 0 to Self-Test 1 Self-Test 0 to Self-Test 1	 -150 +150 +150	+0.6 +2.4 +60 -325 +325 +550	 -600 +600 +1000	V V µA mV mV mV
OUTPUT AMPLIFIER Output Swing Low Output Swing High	No load No load		0.1 2.8		V V
POWER SUPPLY Operating Voltage Range Supply Current Turn-On Time[7]	V_S = 3 V No external filter	1.8	350 1	3.6	V µAµs
TEMPERATURE Operating Temperature Range		-40		+85	°C

A.4 DWM1000

A.4.1 Nominal Operating Conditions

Table A.4 DWM1000 Operating Conditions

Parameter	Min.	Typ.	Max.	Units	Condition/Note
Operating Temperature	-40		+85	$^{\circ}C$	
Supply voltage VDDAON, VDD3V3	2.8	3.3	3.6	V	Normal operation
Supply voltage VDD3V3 for programming OTP	3.7	3.8	3.9	V	Note that for programming the OTP in the DWM1000 the VDD3V3 voltage must be increased to 3.8 V nominal for short periods.
Voltage on GPIO0..7, WAKEUP, RSTn, SPICSn, SPIMOSI, SPICLK			3.6	V	Note that 3.6 V is the max voltage that may be applied to these pins

A.4.2 DC Characteristics

Table A.5 DWM1000 DC Characteristics

Parameter	Min.	Typ.	Max.	Units	Condition/Note
Supply current DEEP SLEEP mode		200		nA	Total current drawn from all supplies.
Supply current SLEEP mode		550		nA	
Supply current IDLE mode		13.4		mA	
Supply current INIT mode		3.5		mA	
TX : 3.3 V supplies (VDDAON, VDD)				mA	Channel 5:TX Power: 9.3 dBm/500 MHz
RX : 3.3 V supplies (VDDAON, VDD)				mA	Channel 5
Digital input voltage high				V	
Digital input voltage low				V	
Digital output voltage high				V	Assumes 500 Ω load
Digital output voltage low				V	Assumes 500 Ω load
Digital Output Drive Current GPIOx, IRQ SPIMISO EXTON	 4 8 3	 6 10 4		mA	

A.4.3 Receiver AC Characteristics

Table A.6 DWM1000 Receiver AC Characteristics

Parameter	Min.	Typ.	Max.	Units	Condition/Note
Frequency range	3244		6999	MHz	
Channel bandwidth		500		MHz	Channel 1,2,3 and 5
In-band blocking level		30		dBc	Continuous wave interferer
Out-of-band blocking level		55		dBc	Continuous wave interferer

A.4.4 Receiver Sensitivity Characteristics

T_{amb} = 25°C, all supplies centred on typical values. 20 byte payload. These sensitivity figures assume an antenna gain of 0 dBi and should be modified by the antenna characteristics depending on the orientation of the DWM1000.

Table A.7 DWM1000 Typical Receiver Sensitivity Characteristics

Packet Error Rate	Data Rate	Receiver Sensitivity	Units	Condition/Note		
1%	110 kbps	-102	dBm/500 MHz	Preamble 2048	Carrier frequency offset ±10 ppm	All measurements performed on Channel 5, PRF 16 MHz Channel 2 is approximately 1 dB less sensitive
	850 kbps	-101	dBm/500 MHz	Preamble 1024		
	6.8 Mbps	-93	dBm/500 MHz	Preamble 256		
10%	110 kbps	-106	dBm/500 MHz	Preamble 2048		
	850 kbps	-102	dBm/500 MHz	Preamble 1024		
	6.8 Mbps	-94	dBm/500 MHz	Preamble 256		

A.4.5 Reference Clock AC Characteristics

T_{amb} = 25°C, all supplies centred on typical values.

A.4.5.1 Reference Frequency

Table A.8 DWM1000 Reference Clock AC Characteristics

Parameter	Min.	Typ.	Max.	Units	Condition/Note
On-board crystal oscillator reference frequency		38.4		MHz	
On-board crystal trimming range		±25[1]		ppm	Internally trimmed to +/- 2 ppm under typical conditions.
On-board crystal frequency stability with temperature			±30[1]	ppm	−40°C to +85°C
On-board crystal aging			±3	ppm/3year	@25°C ±2°C
Low Power RC Oscillator	5	12	15	kHz	

[1]By using the temperature monitoring capability of the DW1000 chip on the DWM1000 module it is possible to dynamically trim the crystal during run time to maintain the +/- 2ppm specification over the full temperature range of operation.

A.4.5.2 Transmitter AC Characteristics

T_{amb} = 25°C, all supplies centred on typical values.

Table A.9 WM1000 Transmitter AC Characteristics

Parameter	Min.	Typ.	Max.	Units	Condition/Note
Frequency tange	3244		6999	MHz	
Channel Bandwidths		500		MHz	Channel 1, 2, 3 and 5
Output power spectral density (programmable)		-39	-35	dBm/MHz	See DW1000 Datasheet
Power level range		37		dB	
Coarse Power level step		3		dB	
Fine Power level step		0.5		dB	
Output power variation with temperature		0.05		dB/°C	
Output power variation with voltage		2.73 3.34		dB/V	Channel 2 Channel 5

A.4.5.3 Temperature and Voltage Monitor Characteristics

Table A.10 DWM1000 Temperature and Voltage Monitor Characteristics

Parameter	Min.	Typ.	Max.	Units	Condition/Note
Voltage Monitor Range	2.4		3.75	V	
Voltage Monitor Precision		20		mV	
Voltage Monitor Accuracy		140		mV	
Temperature Monitor Range	-40		+100	°C	
Temperature Monitor Precision		0.9		°C	

A.5 Buttons

A.5.1 Button 12x12x(7.3)mm

Table A.11 Button 12x12x(7.3)mm

Items		Standard
Operating Temperature range		-20°C to +70°C
Electrical performance	Rating	50mA, 12V DC
	Insulation Resistance	100mΩ min, 100V DC
	Dielectric strength	250V AC for 1 min.
	Contact resistance	100mΩ max.
Durability	Lifetime	50,000 Cycles, 100,000 Cycles
Mechanical performance	Operating force	1:100 +- 50gf, 2:160+- 50gf, 3:260+- 70gf
	Travel	0.30 +- 0.15mm

A.5.2 Switch SMD 5.2x5.2x1.5mm

Table A.12 Switch SMD 5.2x5.2x1.5mm

Items	Standard
Operating force	0.98N
Operating direction	Vertical
Travel	0.25
Rating (max.)	50mA 12V DV
Rating (min.)	10μA 1V DC
Operating life (5mA 5V DC)	500,000 cycles
Initial contact resistance	100mΩ max.
Variery	With stem

A.6 Capacitors

A.6.1 Tantalum capacitor smd 10uF 25V tolerance 10%

Table A.13 Tantalum capacitor smd 10uF 25V tolerance 10% Performance Characteristics

Parameter	Performance Characteristics
Operating Temperature	@$-55°C$ to @$125°C$
Rated Capacitance Range	0.1 – 1,000 μF at 120 Hz/@$25°C$
Capacitance Tolerance	K tolerance (10%), M tolerance (20%)
Rated Voltage Range	2.5 – 50 V
DF (120 Hz)	
ESR (100 kHz)	
Leakage Current	$\leq$ 0.01 CV (μA) at rated voltage after 5 minutes

A.6.2 Ceramic capacitor smd 100pF 50V tolerance 5%

Table A.14 Ceramic capacitor smd 100pF 50V tolerance 5% Performance Characteristics

Parameter	Performance Characteristics
Capacitor type	ceramic
Capacitor kind	MLCC
Capacitance	100pF
Operating voltage	50V
Dielectric	C0G
Tolerance	±5%
Mounting	SMD
Operating temperature	55...125°C

A.7 Light-emitting diode

Table A.15 Light-emitting diode

Item	Value		Unit
	B5/G5	G8/Y5/O5/R5	
DC Forward Current	30	30	mA
Pulse Forward Current	100	100	mA
Reverse Voltage	5	5	V
Power Dissipation	108	78	mW
Operating Temperature	-40 ∼+85		°C
Storage Temperature	-40 ∼+85		°C
Lead Soldering Temperature	260°C/10sec		-

A.8 Lithium-Polymer Battery

Table A.16 3.7V Rechargeable Li Polymer Battery 550mAh

Parameter	Performance Characteristics
Voltage	3.7V
Capacity	550mAh
Wat-Hou Rating	2.035Wh
Weight	Appr. 11.0g
Protection Circuit(PCM)	Yes
Thermistor(NTC)	No
Connector	No
Wires/Cables	Yes
Dimension/Size	3.7×36×45mm
Max. Operating voltage range	2.75V to 4.2V
Max. Charging voltage	4.2V± 50mV
Max. Charging current	275mA
Max. Continuous discharge currenct	550mA

A.9 OLED Display

Table A.17 OLED Display

Item	Symbol	Condition	Standard Value			Unit.
			MIN.	TYP.	MAX.	
Supply voltage for logic	V_{DD}	-	2.8	3.0	3.3	V
Supply voltage for display	V_{CC}	-	7.0	7.25	8.0	
Input high voltage	V_{IH}	-	0.8 V_{DD}	-	$V_{DDI/O}$	
Input low voltage	V_{IL}	-	0	-	0.2 V_{DD}	
Output high voltage	V_{OH}	-	0.9 V_{DD}	-	$V_{DDI/O}$	
Output low voltage	V_{OL}	-	0	-	0.1 V_{DD}	
Operating current for V_{CC} (V_{CC} supplied externally)	I_{CC}	V_{CC} = 7.25 V	5	6	7	mA

A.10 Resistor

Table A.18 Resistor Technical Specifications

DESCRIPTION	RCC0402 e3	RCC0603 e3	RCC0805 e3	RCC1206 e3
Imperial size	402	603	805	1206
Metric size code	RR1005M	RR1608M	RR2012M	RR3216M
Resistance range	1 Ω to 10 MΩ; jumper (0 Ω)			1 Ω to 1 MΩ; jumper (0 Ω)
Resistance tolerance	± 5 %; ± 1 %			
Temperature coefficient	± 200 ppm/K; ± 100 ppm/K			
Rated dissipation, P70 (1)	0.125 W	0.2 W	0.25 W	0.5 W
Operating voltage, Umax. ACRMS/DC	75 V	150 V	200 V	200 V
Permissible film temperature, $/varthetaF_{max.}$	155 °C			
Operating temperature range	-55 °C to +155 °C			
Max. resistance change at P70 for resistance range, |DR/R| after (2): 1000 h 8000 h	≤ 3.0 % -	≤ 1.0 % ≤ 2.0 %		
Permissible voltage against ambient (insulation): 1 min, Uins	-	200 V	300 V	300 V
Failure rate: FITobserved	≤ 0.1 x $10^{-9}/h$			

A.11 Voltage regulator

T_A=25°C unless otherwise noted

Table A.19 AMS1117 Electrical Characteristics

Symbol	Parameter	Conditions	Min.	Typ.	Max.	Unit
Vref	Reference voltage	AMS1117-Adj 10mA≤lout≤1A, Vin=3.25V	1.225	1.25	1.275	V
Vout	Output voltage	-1.2V 0≤lout≤1A, Vin=3.2V	1.176	1.2	1.224	V
		-1.8V 0≤lout≤1A, Vin=3.8V	1.764	1.8	1.836	V
		-2.5V 0≤lout≤1A, Vin=4.5V	2.45	2.5	2.55	V
		-2.85V 0≤lout≤1A, Vin=4.85V	2.793	2.85	2.907	V
		-3.3V 0≤lout≤1A, Vin=5.3V	3.234	3.3	3.366	V
		-5.0V 0≤lout≤1A, Vin=7.0V	4.9	5	5.1	V
ΔVout	Line regulation	-1.2V lout=10mA, 2.7V≤Vin≤10V		0.03	0.2	%/V
		-ADJ lout=10mA, 2.75V≤Vin≤12V		0.03	0.2	%/V
		-1.8V lout=10mA, 3.3V≤Vin≤12V		0.03	0.2	%/V
		-2.5V lout=10mA, 4.0V≤Vin≤12V		0.03	0.2	%/V

		-2.85V lout=10mA, 4.35V≤Vin≤12V		0.03	0.2	%/V
		-3.3V lout=10mA, 4.8V≤Vin≤12V		0.03	0.2	%/V
		-5.0V lout=10mA, 6.5V≤Vin≤12V		0.03	0.2	%/V
ΔVout	Load regulation	-1.2V Vin=2.7V, 10mA≤lout≤1A		2	8	mV
		-ADJ Vin=2.75V, 10mA≤lout≤1A		2	8	mV
		-1.8V Vin=3.3V, 10mA≤lout≤1A		3	12	mV
		AMS1117-2.5V Vin=4.0V, 10mA≤lout≤1A		4	16	mV
		-2.85V Vin=4.35V, 10mA≤lout≤1A		5	20	mV
		-3.3V Vin=4.8V, 10mA≤lout≤1A		6	24	mV
		-5.0V Vin=6.5V, 10mA≤lout≤1A		9	36	mV
Vdrop	Dropout voltage	Iout =100mA		1.15	1.3	V
		Iout=1A		1.3	1.5	V
lmin	Minimum load current	AMS1117-ADJ		2	10	mA
lq	Quiescent Current	AMS1117-1.2V, Vin=10V		2	5	mA
		-1.8V,Vin=12V		2	5	mA
		-2.5V,Vin=12V		2	5	mA
		-2.85V,Vin=12V		2	5	mA
		-3.3V,Vin=12V		2	5	mA
		-5.0V,Vin=12V		2	5	mA
lAdj	Adjust pin current	AMS1117-ADJ Vin=5V, 10mA≤lout≤1A		55	120	uA
lchange	Iadj change	AMS1117-ADJ Vin=5V, 10mA≤lout≤1A		0.2	10	uA
ΔV/ΔT	Temperature coefficient			±100		ppm
θ_{JC}	Thermal resistance	SOT-223		20		$^{\circ}C$/W

Note1: All test are conducted under ambient temperature 25°C and within a short period of time 20ms.

Note2: Load current smaller than minimum load current of AMS1117-ADJ will lead to unstable or oscillation output.

A.12 DOIT ESP32 DEVKIT V1

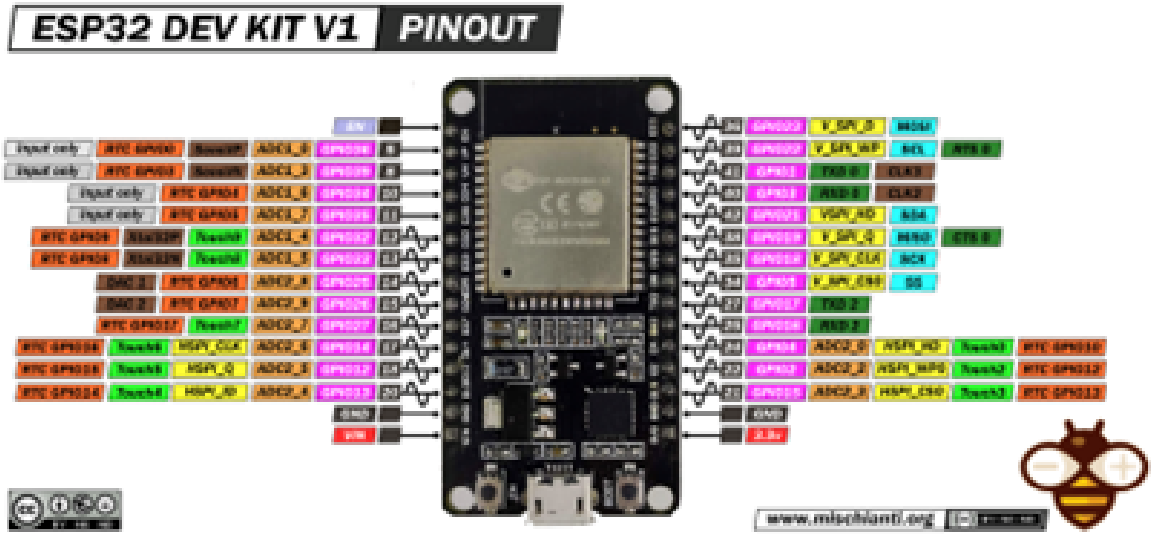
A.12.1 DOIT ESP32 DEVKIT V1 Specifications

Table A.20 DOIT ESP32 DEVKIT V1 Specifications

Specifications	
Wireless Protocol	Wireless 802.11 b / g / n standard
Bluetooth Version	BLE 4.0
Operating Frequency	2.4 GHz to 2.5 GHz
Data Transmission rate	150 Mb/s
Output Power	20 dBm
Operating Voltage	2.7 – 3.6V
Operating Temperature	-40 to 85 ?C
Dimension	52 mm x 28 mm x 14 mm
Weight	10 g

A.12.2 DOIT ESP32 DEVKIT V1 Pinout

Fig. A.1 DOIT ESP32 DEVKIT V1 Pinout



Appendix B

Code

```
#include <ESP32Time.h>
#include <WiFi.h>
#include <HTTPClient.h>
#include <ArduinoJson.h>
#include <NTPClient.h>
#include <WiFiUdp.h>
#include <Wire.h>
#include <Adafruit_SSD1306.h>
#include <Adafruit_GFX.h>
#include <SPI.h>
#include "DW1000Ranging.h"

#define ESP32_RTOS
#include "OTA.h"

#define UTC_OFFSET_IN_SECONDS 7200
#define TAG_ADD "7D:00:22:EA:82:60:3B:9C"
#define SPI_SCK 18
#define SPI_MISO 19
#define SPI_MOSI 23
#define DW_CS 4

String ancor_add= "1783";
String mac = WiFi.macAddress();
String jsonOutput;
```

```
const uint8_t PIN_RST = 27;
const uint8_t PIN_IRQ = 34;
const uint8_t PIN_SS = 4;
float old_distance;

const int vout_pin = 2;
const int alarm_but = 5;
const int cancel_but = 33;
const int led = 32;

const int batteryPin = 25;
int map_bat, bat, bat_oled, bat_new;
int bat_level = 0;

const int xpin = 13;
const int ypin = 14;
const int zpin = 35;
int acc_x, acc_y, acc_z, x, y, z;
float ax, ay, az, g, g_second;
unsigned long last_millis;
unsigned long batteryAndTime = 0;
bool check_g = false;
bool skip = true;
bool remove_1 = true;
bool first_time = true;

String URL = "http://brace-guardian.herokuapp.com/test-alert";
String host_GET = "https://brace-guardian.herokuapp.com/";
String access_route = "test";
int httpResponseCode;

float readAndProcessData();
void printData(float g_print);
void actualize_batteryAndTime();
void trigger_alarm();
void blink_led();
void getdistance();
void hibernation();
```

```
//Adafruit_SSD1306 display = Adafruit_SSD1306(128, 32, &Wire);
ESP32Time rtc;
WiFiUDP ntpUDP;
NTPClient timeClient(ntpUDP, "pool.ntp.org", UTC_OFFSET_IN_SECONDS);

void setup()
{
  pinMode(alarm_but, INPUT);
  pinMode(cancel_but, INPUT_PULLUP);
  pinMode(led, OUTPUT);
  pinMode(vout_pin, OUTPUT);
  digitalWrite(vout_pin, HIGH);
  Serial.begin(9600);
  display.begin(SSD1306_SWITCHCAPVCC, 0x3C);
  delay(10);
  display.ssd1306_command(SSD1306_SETCONTRAST);
  display.ssd1306_command(80);                //from 0 to 255
  display.setTextColor(WHITE);
  display.setTextSize(2);

  SPI.begin(SPI_SCK, SPI_MISO, SPI_MOSI);
  DW1000Ranging.initCommunication(PIN_RST, PIN_SS, PIN_IRQ);
  delay(100);
  DW1000.deepSleep();

  setupOTA("TemplateSketch", "aaaaa", "12345678");
  while (digitalRead(cancel_but) != HIGH);

  /*WiFi.begin("aaaaa", "12345678");
  while (WiFi.status() != WL_CONNECTED) {
    display.setCursor(21, 2);
    display.clearDisplay();
    display.print("Welcome!");
    for (int i = 0; i < 4; i++)
    {
      display.fillCircle(n, 25, 2, WHITE);
      display.display();
      delay(300);
      n += 7;
```

```
    }
    n = 56;
  }

  n = 70;*/

  timeClient.begin();
  timeClient.update();
  rtc.setTime(timeClient.getSeconds(), timeClient.getMinutes(),
      timeClient.getHours(), 1, 1, 2022);
  actualize_batteryAndTime();

  WiFi.disconnect(true);
  WiFi.mode(WIFI_OFF);
}


void loop()
{
  if (remove_1 == true) {
    actualize_batteryAndTime();
    remove_1 = false;
  }

  if (digitalRead(alarm_but) == HIGH)
  {
    trigger_alarm();
    blink_led();
  }

  if (millis() - batteryAndTime >= 15000)
  {
    batteryAndTime = millis();
    actualize_batteryAndTime();
  }

  g = readAndProcessData();
  printData(g);
  last_millis = millis();
```

```
if (g >= 4.5)
{
  g_second = readAndProcessData();
  printData(g_second);
  while (g_second >= g)
  {
    last_millis = millis();
    g = g_second;
    g_second = readAndProcessData();
    printData(g_second);
  }

  while (millis() - last_millis <= 200)
  {
    g = readAndProcessData();
    printData(g);
    if (g <= 1.2)
    {
      check_g = true;
      last_millis = millis();
      break;
    }
  }
  if (check_g == true) {
    check_g = false;
    while (millis() - last_millis <= 100)
    {
      g = readAndProcessData();
      printData(g);
      if (g >= 1.5)
      {
        trigger_alarm();
        blink_led();
        break;
      }
    }
  }
}
```

```
}

float readAndProcessData() {

  delay(10);
  acc_x = analogRead(xpin);
  acc_y = analogRead(ypin);
  acc_z = analogRead(zpin);

  x = map(acc_x, 1520, 2320, -100, 100);
  ax = (float)x / (-100.00);

  y = map(acc_y, 1450, 2260, -100, 100);
  ay = (float)y / (-100.00);

  z = map(acc_z, 1480, 2260, -100, 100);
  az = (float)z / (100.00);

  return sqrt(ax * ax + ay * ay + az * az);
}

void printData(float g_print) {

  Serial.println(g_print);
}

void actualize_batteryAndTime() {

  display.setTextSize(2);
  display.clearDisplay();
  display.setCursor(26, 12);
  display.print(rtc.getTime("%H:%M"));

  display.setTextSize(1);
  display.setCursor(85, 2);
  display.drawRect(105, 0, 20, 11, WHITE);
  display.fillRect(125, 2, 2, 6, WHITE);
```

```
for (int i = 0; i < 10; i++) {
  bat_level += analogRead(batteryPin);
}
bat_level = bat_level / 10;

map_bat = map(bat_level, 3000, 3990, 3300, 3870);
bat_new = map(map_bat, 3300, 4200, 0, 100);
bat_level = 0;

if (skip == false)
{
  if (first_time == true)
  {
    bat = bat_new;
    first_time = false;
  }

  if (bat_new <= bat)
    bat = bat_new;

  if (map_bat < 3200) {
    display.clearDisplay();
    display.setTextSize(2);
    display.setCursor(21, 10);
    display.print("Low Bat");
    display.display();
    delay(1000);
    display.ssd1306_command(SSD1306_DISPLAYOFF);
    DW1000.deepSleep();
    hibernation();
  }

  if (bat >= 100)
    bat = 100;

  if (bat <= 1)
    bat = 1;

  if (bat < 10) {
```

```
      display.print(" ");
      display.print(bat); display.print("%");
    }

    else {
      display.print(bat); display.print("%");
    }

    bat_oled = map(bat, 1, 100, 1, 20);
    display.fillRect(105, 0, bat_oled, 11, WHITE);
    display.display();
  }
  skip = false;
}

void trigger_alarm()
{

  WiFi.disconnect(false);
  WiFi.mode(WIFI_STA);
  bool connect_again = false;

  display.setTextSize(2);
  display.clearDisplay();
  display.setCursor(20, 0);
  display.print("Fall");
  display.setCursor(20, 17);
  display.print("Detected");
  display.display();

  DW1000.spiWakeup();
  delay(100);
  DW1000.reset();
  delay(100);
  DW1000Ranging.initCommunication(PIN_RST, PIN_SS, PIN_IRQ);
  delay(100);
  DW1000Ranging.startAsTag(TAG_ADD, DW1000.MODE_LONGDATA_RANGE_LOWPOWER);
  delay(100);
  getdistance();
```

```
WiFi.begin("aaaaa", "12345678");
long timer = millis();

while (WiFi.status() != WL_CONNECTED) {
  if (millis() - timer >= 3000 && connect_again == false)
  {
    WiFi.disconnect();
    WiFi.begin("aaaaa", "12345678");
    connect_again = true;
  }
  display.setCursor(0, 0);
  display.clearDisplay();
  display.print("Sending\nAlarm");
  for (int i = 0; i < 4; i++)
  {
    display.fillCircle(n, 26, 2, WHITE);
    display.display();
    delay(300);
    n += 7;
  }
  n = 70;
}
display.clearDisplay();

jump:
HTTPClient http;
StaticJsonDocument<200> doc;
doc["macAddress"] = mac;
doc["battery"] = bat;
doc["distance"] = DW1000Ranging.getDistantDevice()->getRange();
doc["address"] = ancor_add;
serializeJson(doc, jsonOutput);
bool http_begin = http.begin(URL);
http.addHeader("Content-Type", "application/json");

httpResponseCode = http.POST(jsonOutput);
if(httpResponseCode != 200){
  Serial.println("aaa");
```

```
    goto jump;
  }

  Serial.print("HTTP Response code: ");
  Serial.println(httpResponseCode);
  httpResponseCode = 0;
  http.end();

  WiFi.disconnect(true);
  WiFi.mode(WIFI_OFF);

}


void blink_led()
{

  display.setTextSize(1);
  display.setCursor(10, 2);
  display.print("Help has been sent");
  display.setCursor(0, 14);
  display.print("Press the gray button to stop the alarm");
  display.display();

  while (digitalRead(cancel_but) != LOW)
  {
    digitalWrite(led, HIGH);
    delay(100);
    digitalWrite(led, LOW);
    delay(100);
  }

  display.clearDisplay();
  display.setCursor(10, 2);
  display.println(" alarm finished");
  display.setCursor(0, 14);
  display.print(" returning to normal functionality...");
  display.display();
  delay(2500);
```

```
  ESP.restart();
  //actualize_batteryAndTime();
}

void getdistance()
{
  old_distance= DW1000Ranging.getDistantDevice()->getRange();
  Serial.println(old_distance);
  while ((DW1000Ranging.getDistantDevice()->getRange()) == old_distance or
      (DW1000Ranging.getDistantDevice()->getRange()) < 0 or
      (DW1000Ranging.getDistantDevice()->getRange()) > 13.0)
  {
    DW1000Ranging.loop();
  }
  Serial.print("the distance is: ");
  Serial.println(DW1000Ranging.getDistantDevice()->getRange());
  //DW1000.deepSleep();
}

void hibernation()
{
  //esp_sleep_pd_config(ESP_PD_DOMAIN_RTC_PERIPH, ESP_PD_OPTION_OFF);
  esp_sleep_pd_config(ESP_PD_DOMAIN_RTC_SLOW_MEM, ESP_PD_OPTION_OFF);
  esp_sleep_pd_config(ESP_PD_DOMAIN_RTC_FAST_MEM, ESP_PD_OPTION_OFF);
  esp_sleep_enable_ext0_wakeup(GPIO_NUM_33, LOW);
  esp_deep_sleep_start();
}
```