INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

A Smartwatch-Based Intervention for Reducing Medication Non-Adherence: A Digital Health Approach

Manuel António Cruz Patrício - a41764

Thesis presented to the School of Technology and Management in the scope of the Master in Informatics.

Supervisors:
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Dedication

To my family and friends, I would not even be where I am if not for them. To my father and mother that raised me and showed me the value of hard work and dedication. This work is as much mine as the people that stand today by my side. Thank you.

Acknowledgment

I want to thank Balvia Ecosystems from the bottom of my heart for helping me come up with the idea for my master's thesis. Their input has been crucial in determining the course of this study, and I am incredibly grateful for the chance to investigate this topic under their supervision.

I also want to express my sincere gratitude to Professor Rui Pedro Sanches de Castro Lopes, who served as my advisor, for his support and helpful criticism during the course of this project. His knowledge and support have been crucial in helping me polish this work and get past obstacles in the development of this thesis.

Abstract

In healthcare, effective treatment depends on medication adherence because skipping or mistaking doses can result in the worsening of the disease and delay the recovery process. Even though there are some technological solutions available, many of them do not deal with the underlying issues that lead to non-adherence. This project presents a novel way to actively support patient treatment regimens by fusing wearable technology with a smart medication dispenser.

The project, which was created with the Flutter framework, presents an easy-to-use wearable app that tracks important biometric data and medication schedules in real time. The application improves medication management and data collection by utilizing Bluetooth Low Energy and fail-safe API requests to guarantee continuous data retrieval and a stable workflow.

This solution seeks to decrease non-adherence, enhance diagnostic accuracy, and optimize treatment protocols through proactive reminders and personalized health tracking, ultimately improving patient outcomes and advancing digital healthcare.

Keywords: Smartwatch, Wearable Technology, Medication Management, Bluetooth Low Energy (BLE), Flutter, Digital Health, Real-Time Tracking

Resumo

Durante a recuperação de qualquer problema de saúde, a adesão ao regime de medicação é essencial para um tratamento eficaz – doses em falta ou incorretas podem agravar as condições de saúde e prolongar a recuperação. Embora existam soluções tecnológicas, muitas não abordam as causas fundamentais da não adesão. Este projeto apresenta uma abordagem inovadora que combina um dispensador inteligente de medicação com tecnologia wearable para apoiar ativamente os pacientes para cumprir os regimes de tratamento.

Desenvolvido com a framework Flutter, o sistema inclui uma aplicação wearable intuitiva que monitoriza, em tempo real, os horários de medicação e os dados biométricos vitais. Ao recorrer à tecnologia Bluetooth Low Energy e a chamadas à API como medida de segurança, a aplicação garante a recolha contínua de dados e mantém um fluxo de trabalho estável, melhorando a gestão da medicação e a recolha de informações essenciais.

Por meio de alarmes proativos e de um acompanhamento personalizado da saúde, esta solução pretende reduzir a não adesão, melhorar a precisão diagnóstica e otimizar os protocolos de tratamento – contribuindo para melhores resultados nos cuidados aos pacientes e para o avanço da saúde digital.

Palavras-chave: Smartwatch, Wearable Technology, Gestão de Medicação, Bluetooth Low Energy (BLE), Flutter, Saúde Digital, Monitorização em Tempo Real

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Acronyms

AI Artificial Inteligence.

API Application Programming Interface.

ATT Attribute Protocol.

AWS Amazon Web Services.

BLE Bluetooth Low Energy.

BPM Beats per minute.

DTO Data Transfer Object.

DTOs Data Transfer Objects.

EBM Event-Based Management System.

ECG Electrocardiogram.

EHR Electronic Health Records.

GAP Generic Acess Profile.

GATT Generic Attribute Profile.

GPS Global Positioning System.

HCI Host Controller Interface.

HR Heart Rate.

IF Information System.

MCC Multiple Chronic Disease.

NFC Near Field Communication.

OS Operating System.

OSI Open Systems Interconnection.

SMP Security Manager Protocol.

TAM Technology Acceptance Mode.

UI User Interface.

VR Virtual Reality.

Chapter 1

Introduction

Humanity's quality of life has greatly improved in recent years due to several medical advancements and the incorporation of state-of-the-art technologies into treatment. However, these advancements have also brought upon a number of new issues. Even though they are necessary, the growing number of medications and the requirement for rigorous intake schedules can occasionally make recovery more difficult [1].

Medication non-adherence is one of the most urgent problems facing modern medicine. 40% to 50% of patients who are prescribed medications for chronic conditions such as diabetes or hypertension do not follow their treatment plans. Every year, this results in at least 100,000 avoidable deaths and $100 billion in needless medical expenses [2].

This problem's scope is especially worrisome. An estimated 117 million Americans suffer from chronic illnesses [3]. By 2025, it is anticipated that 18 million people in the UK will have a chronic physical illness, up from the current 15 million. Globally, it is estimated that approximately one in three persons have Multiple Chronic Diseases (MCCs), which greatly increases patient burden and healthcare expenses [4].

1.1 Background

Previous work on this scope included a smart pill dispenser to deal with the non-adherence problem. This system consists of an Event-Based Management Systems (EBMs), where all the components of the dispenser follow a distributed architecture. In this architecture, all components are loosely coupled with each other and synchronize using messages [5], [6]. Common problems such as missing doses, improper intake, and erratic medication schedules are addressed by this system. These issues can have serious health repercussions, including disease progression and treatment failure.

To mitigate these risks, the proposed system integrates multiple devices that work together to track medication schedules, alert users when it is time to take their medication and ensure proper dosage administration. The communication protocol used by the system enables real-time interaction between its various components, facilitating effective event-based responses.

This approach allows both formal and informal caregivers to remotely monitor adherence patterns while ensuring users receive timely reminders and feedback. By leveraging event-driven automation and smart healthcare technology, this study contributes to the ongoing effort to enhance patient care and medication adherence. Ultimately, the system aims to improve treatment outcomes and reduce the financial burden of non-adherence on healthcare systems [7].

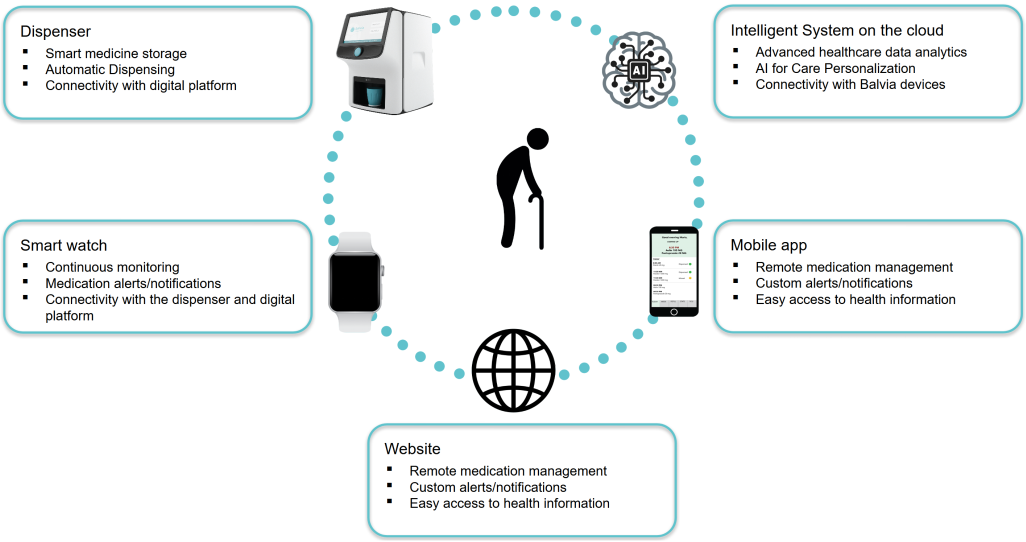


Figure 1.1: Ecosystem Architecture

1.2 Objectives

As the study of wearable devices keeps advancing [8], the number of solutions implemented using wearable technology has increased, softening the workload of every day, mundane tasks [9]. These devices are equipped with technologies that allow for the monitoring of other devices connected to the wearable and interact with them [10]. This characteristic of wearable devices proves very useful when certain situations require an alert to the user. For example, when a user has an irregular heart rate or is confronted with a very stressful situation, the wearable device emits an alert to the user with a report of the situation. This biometric measurement could be used for various purposes, from just alerting the user to a small heart rate rising to very detailed reports about the biometrics of a patient that could help medics to potentially save lives [11].

This study focuses on one of the many ways wearable technology might improve healthcare management. The primary goal is to develop a smartwatch app that integrates an existing healthcare system that consists of a smartphone app, a smart pill dispenser, and a back-end server. After it is put into place, this synchronized system will allow the smartwatch to track particular prescriptions, capture biometric information, and send out customized alerts, such as missed dose reminders, to assist caregivers in keeping an eye on patients' present health. This method greatly enhances conventional pharmaceutical regimens by tackling medication non-adherence and streamlining administration for patients and healthcare professionals.

The smartwatch's ability to facilitate biometric monitoring and medicine reminders is improved by its smooth integration into this well-established ecosystem. How each element works together within this framework to deliver more efficient and patient-centered care is explained in the sections that follow.

1.3 Structure of the document

This paper is structured into six sections, including this Introduction. Section 2 reviews the state of the art relevant to the scope of the application. Section 3 presents the overall ecosystem and the functions of the smartwatch. Section 4 presents the Bluetooth Low Energy (BLE) architecture and the message protocol used for the communication between the smartwatch and the smartphone. Section 5 presents the implementation of the application and finally, the paper concludes in section 6.

Chapter 2

Related Work

This chapter gives a summary of the state of wearable technology and how it is integrating with healthcare systems. Firstly, is necessary to outline the primary types of wearable technology, which include textile-based, biofluidic, and skin-integrated bioelectronics, as well as the significant advancements in wireless connectivity, miniaturized sensing, and on-device processing that have made continuous, real-time health monitoring possible. Next, the focus shifts to discuss exactly how these devices have been used in a variety of clinical settings, including behavioral health, acute diagnostics, rehabilitation, and chronic disease management. This chapter highlights the proven benefits of these devices for patient outcomes as well as the continuous challenges of data privacy, clinical integration, and regulatory alignment.

2.1 Wearable devices

From the first electronic watches of the 1970s and 1980s, which had simple features such as digital screens and calculators, to more advanced gadgets that could track a number of health indicators, smartwatches have come a long way. Miniaturization and sensor technology advancements have made it possible to include functions such as Global Positioning Systems (GPSs) tracking, heart rate monitoring, and smartphone communication into small wrist-worn gadgets [12].

Since its initial birth as basic, function-specific devices, wearable technology has experienced a remarkable transition, developing into complex, multipurpose instruments that are now intricately woven into the fabric of contemporary human-computer interaction. Wearable technology has quickly progressed from its humble origins as digital watches that provided little more than timekeeping and basic calculators to support sophisticated, customized mobile information processing tasks, allowing users to engage with digital environments seamlessly and intuitively. Through features such as augmented reality, voice-activated assistants, and biometric feedback, this technological evolution has not only completely changed how people manage their daily activities but also opened up new possibilities for lifestyle enhancement, immersive entertainment, and the growth of socially connected communities. The ability to integrate hardware and software from various disciplines, including design, engineering, psychology, and data science, while preserving usability and tackling the crucial issues of data privacy, user autonomy, and ethical design, is becoming more and more important as wearables become more integrated into daily life. Because wearable innovation is interdisciplinary, engineers, social scientists, and legislators must work together to make sure that these tools continue to be inclusive, flexible, and helpful to a wide range of users. The ongoing expansion of wearable ecosystems, which include everything from gesture-recognition interfaces to smart textiles and more, portends a future where these gadgets will become even more significant, influencing interaction, identity, and communication in digital society [13].

Wearables are a new class of technologically sophisticated, body-worn technologies that offer tailored, mobile information processing in real time and in a range of scenarios. The term ”wearables” now refers to much more than just traditional clothing or accessories. These gadgets have developed from simple pedometers and fitness bands into extremely complex systems that can carry out intricate tasks such as physiological monitoring, environmental sensing, and even augmented or virtual reality interfacing. This is due to significant advancements in sensor integration, wireless communication technologies, power efficiency, and the continuous miniaturization of hardware components. The advent of ”meta-wearables”, also known as wearable motherboards, is one of the most revolutionary advancements in this field. These platforms combine several sensors, processors, and communication modules into a single, cohesive structure, providing an unparalleled degree of functionality, adaptability, and connectivity. These cutting-edge technologies not only increase the possible uses of wearable technology but also act as the foundation for a networked ecosystem that facilitates ongoing data collection, analysis, and feedback loops. Beyond consumer convenience and personal health monitoring, these systems have enormous potential for use in context-aware computing and real-time responsiveness-critical domains such as public safety, military operations, workplace training, immersive entertainment, and urban infrastructure management. The full realization of this vision, however, calls for more than just technological innovation; it calls for a truly transdisciplinary approach that integrates design, engineering, social sciences, ethics, and policy-making to navigate complex issues related to user experience, system reliability, interoperability, and the societal ramifications of ubiquitous data collection and surveillance [14].

With features such as continuous Heart Rate (HR) monitoring, sleep tracking, and the ability to identify irregular heart rhythms, smartwatches are becoming increasingly useful healthcare tools. Research has shown how useful they are for monitoring vital signs and detecting disorders such as atrial fibrillation, which helps with early identification and treatment of medical problems. When compared to clinical-grade equipment, there are still issues with these measurements' precision and dependability [15].

Decision-making processes, well-being outcomes, behavioral patterns, practical utility, and the increasingly important role of big data analytics are just a few of the topics that collectively reflect the complexity and dynamic evolution of this technological domain. The literature on wearable technology and consumer interaction is characterized by a diverse and quickly growing set of themes. These technologies are redefining the consumer experience in a variety of industries, from retail and fitness to entertainment and lifestyle management, by changing how consumers engage with digital ecosystems and reshaping expectations around personalization, real-time feedback, and user empowerment. Businesses can use the continuous, granular data that wearables gather to improve customer service, hone marketing tactics, and create personalized predictive models. However, converting these capabilities into valuable consumer value requires a deep understanding of user motivations and concerns. Even though this field is innovative and multidisciplinary, there are still many obstacles to overcome, most notably the division between macro-level analyses that try to capture wider societal and technological implications and micro-level studies that concentrate on individual behavioral responses. Inconsistent terminology, redundant research agendas, and a dearth of coherent theoretical underpinnings that may bring different findings together into a cohesive framework for comprehending the consumer-wearable interaction have all been exacerbated by this division. To advance the field and realize the full potential of wearable technology in influencing future consumer interactions and societal norms, it is imperative to address this disjunction through integrated, cross-disciplinary approaches and more robust empirical methodologies [16].

Many aspects of professional life have undergone substantial change as a result of the widespread use of wearable technology, especially in the areas of workplace communication, productivity improvement, and occupational safety. These gadgets, which range from wearable sensors and smartwatches to wristbands and smart glasses, enable continuous monitoring and real-time data collection. This enables businesses to identify possible safety risks before they become serious incidents, greatly lowering workplace accidents and injuries. Wearables not only increase safety but also improve job management by facilitating location monitoring, smooth and automatic communication channels, and even biometric evaluations of stress or fatigue levels. These features boost workforce well-being and operational efficiency. Wearable technology encourages a culture of proactive problem-solving, informed decision-making, and efficient workflow execution by giving management and staff instant access to pertinent data. Wearable technology has many benefits, but there are drawbacks as well. Data privacy, user permission, and technological literacy are some of the major problems that need to be resolved by user-centric design and well-organized governance structures. Additionally, user adoption may be hampered by mistrust about surveillance and the acquisition of personal data, thus in order to achieve buy-in, firms must maintain transparency and provide employees with clear value propositions. A comprehensive analysis of workplace applications indicates that wearable technology plays a crucial role in facilitating the integration of the digital and physical worlds of work by promoting contextual adaptation, situational awareness, and the general digital transformation of corporate operations [17].

A thorough and methodologically sound analysis of the literature covering almost ten years shows that academic and applied research in the field of smart wearable technologies has been expanding quickly and steadily, with a special focus on Information System (IF) perspectives. This vast collection of work explores the ways in which wearable technology, from fitness trackers to smart clothes to augmented reality headsets and more, is being incorporated into different aspects of both personal and professional life, highlighting its increasing pervasiveness and significance in modern digital ecosystems. A number of recurrent themes show up in the reviewed studies, particularly those that deal with user behavior and the psychological aspects that affect the intention to adopt and continue using these technologies. These include design preferences, ease of use, and the sense of value that comes from regular interaction. Simultaneously, technical factors that influence user pleasure and sustained engagement with wearables, such as data processing capabilities, battery economy, interoperability, and device durability, are regularly discussed. Because users frequently voice worries about how their personal data, particularly sensitive biometric or location-based information, is gathered, maintained, and perhaps shared, privacy and security issues are also prevalent in the conversation. The situation is further complicated by social acceptance, as adoption trends are significantly and occasionally unexpectedly shaped by cultural attitudes toward technology, peer pressure, and societal conventions. The Technology Acceptance Mode (TAM), a unifying framework found in the literature, is frequently used to explain the intricate interactions among users' attitudes toward using a device, their perceptions of its utility, and the social pressures that influence their decision-making. This paradigm highlights factors that are essential to comprehending adoption trajectories on both an individual and organizational level, including trust in technology providers, worries about data exploitation, and the device's visibility in social settings. In addition to outlining the current status of smart wearable research, this thorough review identifies enduring gaps and unsolved problems that call for more scholarly attention and empirical investigation, especially in the areas of cross-cultural analyses, longitudinal user engagement, and the ethical implications of ubiquitous monitoring [18].

Going forward, the incorporation of Artificial Inteligence (AI) and machine learning algorithms has the potential to improve wristwatch prediction capabilities, allowing for more preemptive interventions and individualized health insights. Smartwatches are expected to become more and more important in managing chronic diseases and preventive healthcare as technology develops [19].

2.2 Wearables in Health

Wearable technology, which offers individualized insights and ongoing monitoring, has enormous potential to improve healthcare. It is still difficult to incorporate these gadgets into clinical practice, though. Problem description, system integration, technological support, personalization, end-user emphasis, alignment with reimbursement models, and clinician participation are the seven essential elements for effective implementation, according to Smuck et al. These elements provide helpful direction for creating wearable-based digital health initiatives that work [20].

A thorough assessment by Lu et al. [21] focused on the function of these devices in monitoring health and safety, managing chronic diseases, diagnosing and treating illnesses, and rehabilitation. Notwithstanding its potential, the industry has obstacles, for example privacy concerns, usability problems, and a lack of uniform rules. As technology advances and personalized health concepts gain traction, wearable technology is expected to integrate more seamlessly into healthcare, necessitating further research to optimize its clinical applications.

Wearable medical technology has gained popularity in the monitoring and treatment of a wide range of illnesses, from neurological diseases such as Parkinson's and Alzheimer's to cardiovascular and muscle ailments. These devices, which provide noninvasive options for ongoing health monitoring, include skin-based, textile-based, and biofluidic-based wearables, as described by Iqbal et al. [22]. Their application in medicine delivery has also been made possible by recent developments, improving individualized healthcare. Notwithstanding their promise, obstacles to commercialization, material constraints, and data integration still exist. Nonetheless, wearable technology is now much more feasible in clinical and point-of-care settings thanks to advancements in wireless communication and biocompatible materials. By lowering the strain on established healthcare systems and enabling real-time, remote monitoring, these advances are predicted to completely transform the healthcare industry.

Jafleh et al. [23] explore the applications of wearables in chronic disease management, highlighting their role in real-time monitoring and personalized care across specialties such as cardiology, respiratory health, neurology, endocrinology, orthopedics, oncology, and mental health. They examine how wearable health devices are evolving into indispensable tools. The review emphasizes how well wearables work for conditions such as diabetes management, mental health support, asthma management, seizure monitoring, hypertension, and arrhythmia detection. There are still issues with data accuracy, privacy, cost, and integration with healthcare systems, despite their revolutionary potential to improve patient outcomes and engagement.

Kang et al. [24] examine how wearable medical technology can enable people to assume more accountability for their own care and well-being. Wearable technology, from consumer-focused fitness trackers to specialized medical tools, has become more widely accepted in healthcare systems across the globe, including in England's National Health Service's Long Term Plan. Key themes identified by the study include the influence of wearables on behavior change, the role of healthcare providers in promoting wearables, and potential obstacles to wearable adoption. The study points out issues, namely device accuracy, provider engagement, and the need for funding to train medical professionals to properly analyze wearable data, despite the advantages of self-monitoring, diagnosis, and lifestyle modifications. The conclusion was that although wearable technology has a lot of promise for the healthcare industry, more investigation is needed to determine how well it will empower users and affect health-related behaviors over the long run. Maximizing the impact of wearables in personal health management will require removing current obstacles and encouraging cooperation between users, medical professionals, and tech developers.

The integration of wearable technology and AI into healthcare workflows is poised to significantly transform the industry. According to LaBoone and Marques [25], these developments have the potential to provide continuous, real-time health monitoring, which would facilitate early disease identification and better patient care. Wearable technology enables remote monitoring, which eases the strain on healthcare facilities and improves access to care, while AI-powered analytics improve decision-making by finding trends in large datasets. There are still difficulties, though, especially when it comes to handling massive data sets and smoothly incorporating these technologies into current Electronic Health Records (EHR). Notwithstanding these obstacles, it is anticipated that AI-driven solutions will proliferate, changing medical procedures and setting new benchmarks for treatment. Similar to previous technological revolutions, this change will present both opportunities and challenges, ultimately leading to more efficient, data-driven healthcare systems.

Monitoring biometric data is one of the most popular applications of wearable technology. Zhang et al. [26] draw attention to the expanding use of bioelectronics in precision medicine and ongoing healthcare monitoring. Their research examines current developments in wearable bioelectronics, with a focus on adaptive treatments for complex diseases and multimodal monitoring for a range of medical conditions. The discussion of closed-loop monitoring-therapeutic systems, which combine automated treatment modifications with real-time data collection, is a crucial component of their work. Wearable bioelectronics can improve individualized healthcare and ease commercialization by utilizing artificial intelligence, optimizing functional integration, and improving material properties. By ensuring that wearable technology offers both passive and active monitoring, responsive interventions to enhance patient outcomes, these advancements seek to close the gap between research and practical biomedical applications.

Matsumura et al. [27] discuss the use of wearable technology for health monitoring. They introduce a multimodal healthcare sensor patch system that can continuously monitor several vital signs, including skin temperature, electrocardiogram, respiration, skin humidity, and physical activity. Their method eliminates the need for cloud-based data transmission by combining flexible sensors with an edge computing system that processes and analyzes data directly on a smartphone. The system can identify and evaluate intricate health patterns, including coughing, arrhythmias, and posture changes, by utilizing reservoir computing and machine learning algorithms. Users can receive real-time feedback from the system. By facilitating effective, low-power, and real-time personal healthcare data analysis, this advancement expands the applicability of wearable health monitoring.

In a more specific disease case, Mattison et al. [28] delve into the usage of wearable devices with patients suffering from cystic fibrosis and their healthcare providers, highlighting their potential in improving self-management through remote monitoring, early illness detection, and motivation for positive lifestyle changes. Their qualitative study, which included both individuals with cystic fibrosis and members of a multidisciplinary care team, found that while wearables offered real-time data that promoted healthy behaviors and goal-setting, they did not significantly improve adherence to the specific self-management routines needed for the condition, such as medication adherence, airway clearance techniques, and symptom tracking. Concerns were also raised regarding data accuracy, technological limitations, and the potential for patients to feel more anxious about their health. The study advises moving away from wearable applications that are disease-focused and toward a more customized approach to self-management in the treatment of cystic fibrosis in spite of these obstacles.

In the study by Ullankala et al. [29] a live-streaming smart pill dispenser is also presented to help older and visually impaired people remember to take their medications on time. Caregivers may set medicine reminders via Bluetooth thanks to the system's user-friendly Arduino-based interface and integration of IoT technology. A stepper motor regulates the dispenser's several pill storage sections, ensuring precise distribution. An LCD and speaker alert system that can be controlled by voice commands lets consumers know when it's time to take their prescription. A live-streaming feature also makes it possible for caretakers to keep an eye on medication intake from a distance, guaranteeing adherence and lowering mistakes. This dispenser strikes a compromise between automation and human supervision, which makes it both effective and user-friendly in contrast to fully automated systems.

Karthikeyan et al. [30] also an autonomous robotic system made to effectively distribute medication, as a solution to the problem of medication non-adherence. By using pre-programmed instructions, the device makes sure that elderly patients receive the right dosage at the right time. The dispenser finds the patient on its own, gives out medicine, and saves information for later use on a cloud-based platform. Remote system management and monitoring are made possible by a supplementary mobile application. The prototype's efficacy in enhancing medication adherence and lowering caregiver load was demonstrated during development and testing under a variety of circumstances.

In another approach Pandey et al. [31] suggest a Smart Medicine Dispenser that incorporates electromagnetism-based mechanisms to release the appropriate medication at predetermined intervals. The systems uses widely accessible components and is intended to be more affordable than current options. By reducing human error in medicine administration, this innovation seeks to improve patient adherence to prescribed prescriptions.

Mohana Priya et al. [32] present a similar approach, proposing a real-time smart medication dispenser to assist Alzheimer's patients in taking their medication accurately and on time.

The study by Medina et al. [33] is one of the most intriguing and relevant applications of wearable technology in healthcare. In order to automate the dispensing of medications through a low-cost remote dispenser placed at home, they suggest an Intelligent Medication Controller that evaluates body temperature data streams from a wearable device. To maximize medication intake choices, the system combines pharmacokinetic and pharmacodynamic analysis with logic and linguistics. By modifying dosages and waiting periods according to prior intakes, this method improves accuracy and adherence. By contrasting the system's decision-making process with that of human experts, a case study illustrates how well the system manages fever episodes and also indicates that the proposed controller provides medication recommendations that are dependable, safe, and adaptable, guaranteeing patient safety and enhancing treatment compliance.

By combining wearable technology with a smart pill dispenser and a mobile application, the proposed method of this paper prioritizes a more comprehensive medication adherence system, whereas Medina et al.'s work concentrates on optimizing medication dosing through intelligent pharmacological analysis. In addition, the system uses synchronized reminders, real-time monitoring, and remote caregiver support to ensure adherence rather than modifying dosages based on physiological parameters. In order to send notifications for missed doses and prescription refills, the smartwatch app continuously records biometric data and connects via Bluetooth to the pill dispenser.

While both strategies use wearable technology to improve patient outcomes, they deal with different medication management issues. By dynamically modifying dosages, Medina et al.'s system optimizes medication intake while guaranteeing exact pharmacological control. On the other hand, by avoiding missed doses and streamlining medication schedules, this system reduces adherence problems. Table 2.1 reflects the comparison between the proposed method with Medina et al. system.

In contrast to numerous studies that investigate wearables as stand-alone health-monitoring instruments, this research presents a smartwatch application as an extension of an existing multi-component healthcare ecosystem. The addition of a smartwatch offers an extra, non-intrusive layer of contact, even though comparable systems have already integrated smartphones and smart dispensers for medication administration. This makes real-time notifications and passive health tracking possible, which improves the system's responsiveness to patient behavior. The project offers an interoperable and flexible design that complements current initiatives to build connected, patient-centered healthcare settings.

Author	**Medication Adjustment**	**Real-time Monitoring**	**Caregiver Support**
Medina et al. [33]	Yes (Pharmacokinetic and Pharmacodynamic Analysis)	No	No
Casciaro et al. [34]	No	Yes	Yes
Ullankala et al. [29]	No	Yes	Yes
Karthikeyan et al. [30]	No	Yes	Yes
Wearable Application	Yes, when changed by the caretaker	Yes	Yes

Table 2.1: Comparison with the State-Of-Art

Chapter 3

Overall Architecture

This chapter provides a detailed synopsis of the problem setting and the suggested system design. This project's solution expands on an already-existing healthcare ecosystem that consists of a back-end server, a smart pill dispenser, and a smartphone application. The goal for this project is to incorporate a smartwatch application to improve usefulness, especially in the specific areas of medicine reminders and biometric monitoring. The ways in which each element incoportates together within the estabilished architecture to promote better patient care are explained in the sections that follow.

3.1 Ecosystem

As discussed in the preceding chapter, wearable technology has been used in numerous studies and initiatives, mostly to gather biometric data. Since this data is essential for evaluating and improving patient care, it is one of the most alluring features of wearable technology. Wearables' ability to monitor continuously and inconspicuously has opened up new avenues for long-term ailment management and real-time health surveillance. Medina et al. [33] provide a relevant endeavor that offers helpful parallels to the project covered in this chapter. Their work similarly combines wearable technology for healthcare monitoring.

Through the integration of three essential components, a smartwatch, a mobile application, and a smart pill dispenser. The solution put forth here expands on the idea of omnipresent healthcare. These gadgets work together to provide a responsive and integrated ecosystem that improves medication adherence, makes biometric data gathering easier, and guarantees that health information is synchronized across platforms.

Through built-in health tracking apps, the wristwatch gathers information, including heart rate, step count, and sleep habits, in addition to serving as a biometric sensor and medicine alarm generator. However, the smartwatch application is unable to directly access this data due to current constraints in cross-platform development tools, namely the lack of support for the *Google Health Connect API* in Flutter. Rather, the smartphone receives biometric data from the smartwatch, processes it locally, stores it, and then sends it to a cloud-based Application Programming Interface (API). Instead of sending confidential data over Bluetooth, the watch can use that API to get processed insights, such the average heart rate or the amount of sleep the user has had thus far throughout the day.

This design maintains data confidentiality and integrity while guaranteeing that every device in the ecosystem stays in sync. The smartwatch functions as a passive health monitor and alerting device, the smartphone as a data integration hub and control interface, and the pill dispenser as a medication management tool. It also allows each component to play a unique, optimal role. An overview of the interactions between these parts of the system is shown in Figure 3.1.

Each ecosystem module is thoroughly examined in this chapter, along with its unique features, communication protocols, and integration into the larger architecture intended to facilitate efficient and individualized patient care.

3.1.1 Pill Dispenser

An essential part of the ecosystem, the pill dispenser, figure 3.2, releases recommended doses at predetermined times to encourage medication adherence. To keep patient data

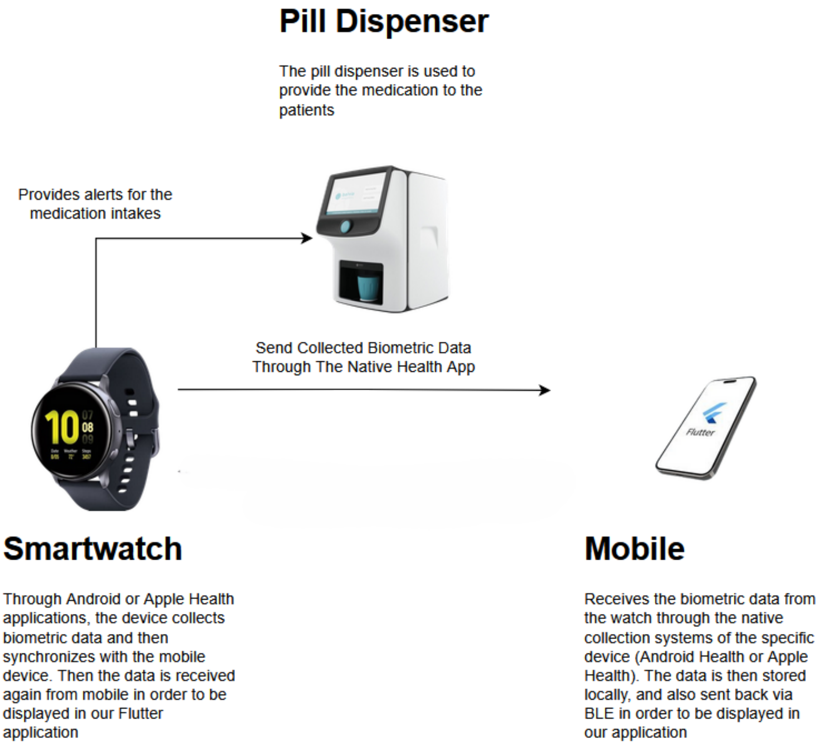


Figure 3.1: Architecture Diagram

updated and synchronized, it collaborates with the wearable, mobile app, and back-end server. Its design is event-driven, which guarantees that it responds promptly to user input and planned events. Each module contributes to the overall, effective management of patient treatment through this integration, which serves to establish a coherent system [5].

Motors in the mechanical module of the dispenser regulate the actual release of pills, and built-in sensors confirm that the dosage is accurately administered. To guarantee that the right medication is given securely, the system waits for user confirmation via specified input methods before releasing any dose. By offering precise control over the dispensing process and real-time feedback, this setup reduces the possibility of intake errors [5].

In addition to remote communication through Wi-Fi, connectivity is accomplished through local interfaces such as BLE. These channels allow the pill dispenser to communicate with the back-end server for dispensing logs and to obtain updated prescription data. The device maintains communication with the rest of the ecosystem by sharing data through defined events, enabling a strong and flexible system for patient care management [5].

Figure 3.2: Pill Dispenser

3.1.2 Mobile Application

Another key component of the ecosystem is the smartphone application, figure 3.3, also built using Flutter. This application coordinates the information exchange between the wearable, the cloud, and dispenser. When a patient puts on their smartwatch every morning, the watch itself depends on the smartphone. This serves the proposed structure, making the smartphone into a reliable middleman. This is convenient due to the fact that Flutter plugins are unable to extract the biometric data from the smartwatch because of the lack of support for the *Google Connect API* in these systems, this API is fundamental for the Flutter's Health plugin to correctly extract the biometric data from the device. Similar to the smartwatch the smartphone retrieves the day's prescription updates and medication schedules via secure, authenticated RESTful calls from the Spring Boot-powered backend, which is hosted on AWS alongside the database. The smartphone then shows this data locally and makes it accessible to the smartwatch through synchronized API-based communication.

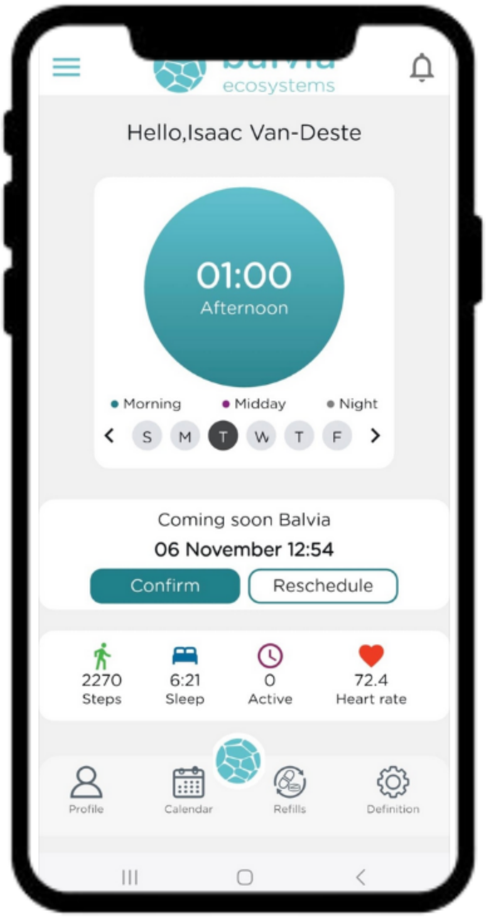
In the smartphone, the native *Health* application will keep receiving the patient's data for biometrics, which is recorded by native health apps and then acessed by *Google's Health Connect* where the Flutter plugin can acess it and making it available in the application. In certain intervals of time these informations must be stored in the database. In order to guarantee that only relevant data is transmitted, the smartphone gathers biometric readings, timestamps them, and bundles them into data actual helpful health information, such as average heartbeats per minute in the last day or hours slept in the previous 24 hours.

By doing this, the smartphone transforms from a conduit into a smart hub that ensures continuity and availability of data throught the ecosystem. Through the seamless integration of the AWS-hosted backend with the smartwatch's sensing capabilities, the mobile application unifies disparate information streams into cohesive and helpful data.

3.1.3 Back-End Server

Important patient data, such as prescription , intake timings, and medication schedules, are centrally stored and managed by the back-end server. The smartwatch, smartphone app, and smart pill dispenser are all part of the ecosystem, and this centralization guarantees that data is consistent and synchronized throughout.

Spring Boot, a flexible Java-based framework that makes it easier to create scalable and maintainable web services, is used to design the system's back-end. RESTful APIs are



Hello,Isaac Van-Deste

Coming soon Balvia

06 November 12:54

2270 Steps

6:21 Sleep

0 Active

72.4 Heart rate

Figure 3.3: Smartphone Application

created using Spring Boot to enable structured, safe communication between the server-side database and client applications. To guarantee that every device in the ecosystem runs with the most recent data available, these APIs are made to facilitate real-time actions including retrieving, saving, and updating patient-related data.

Data Transfer Object (DTO) are used to structure all API answers in order to preserve a clear and uniform data exchange format. By defining precisely what information is exchanged between the server and clients, these Data Transfer Objects (DTOs) increase maintainability and clarity while protecting important backend models. DTOs reinforce the system's security model by limiting the fields that are made public via the APIs, which also lowers the possibility of unintentional data exposure.

Amazon Web Services (AWS) hosts all back-end services and API endpoints. Using AWS cloud infrastructure gives the system a strong base and offers advantages such as security, scalability, and high availability. Additionally, AWS incorporates vital functions that are necessary for managing sensitive medical data, such as infrastructure monitoring, data encryption, and access control. Furthermore, tight integration, simpler deployment pipelines, and improved disaster recovery capabilities are guaranteed when the database and application logic are hosted on AWS.

This is where the smartwatch will extract the patient's schedule medication information as well as the biometrics that will be stored a completely separated entity.

It is worth mentioning that although the entire database is not displayed in the image 3.4, these are the entities used in the application lifecycle.

Because of its scalable and modular architecture, the database makes it possible to store, retrieve, and manage vital medical data effectively. The application will use three main entities present in the database. They are Person, Prescription, and Schedule. Each component contributes uniquely to the system's operation and allows for smooth synchronization across the different devices, namely the smart dispenser, smartphone app, and specially in the smartwatch. Below there is a descriptive explanation of the characteristics of each of the three entities.

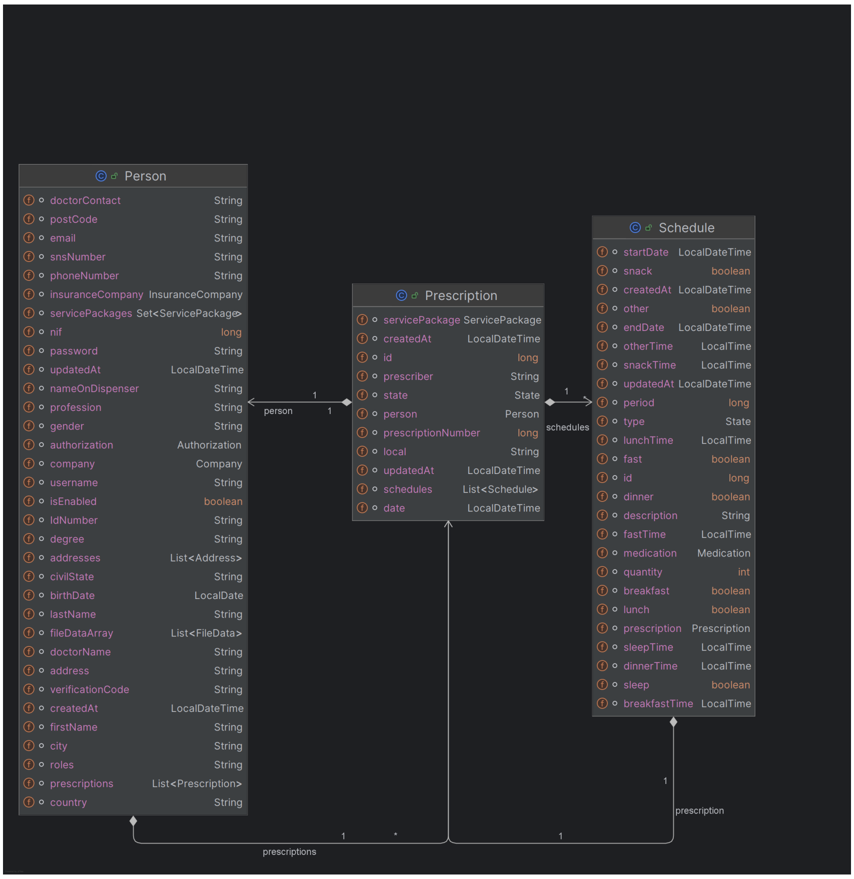


Figure 3.4: Diagram Of The Database

Database - Person

Every patient in the system is represented by the Person entity. Since it serves as the anchor point for all patient-specific data, this entity is fundamental. It keeps important data including the user's unique ID, demographic information (e.g., name, age, gender), and metadata required for access control and authentication. This guarantees that caregivers can only read information for patients who have been permitted and enables the system to link each prescription and schedule to the appropriate user.

Additionally, as the system stores biometric information obtained from the smartphone's health integration services, such as heart rate and step count, which will be stored in a specific entity, they are logically connected to the Person entity. Health and pharmaceutical records are easier to manage and database normalization is improved by this division of responsibilities.

Database - Prescription

The particular medication that are prescribed to a patient are specified by the Prescription entity. This table contains information on each record, including the name of the medication, dosage, among other data. A strong foreign key relationship between the Prescription and Person entities enables the system to assign several prescriptions to a single person while preserving data coherence.

A thorough record of a patient's prescription history can be preserved by the system thanks to this entity's capabilities for versioning and historical tracking. This kind of functionality is essential for patient safety, caregiver analysis, and legal compliance, especially when medications are changed over time.

Database - Schedules

The Schedule entity contains information about when and how often to take medications. Every Schedule record identifies the structured regimen that a drug must be taken according to and is linked to a particular prescription. This covers variables such as the time of day, alert levels, and periods in which the medication should be taken (every 2 hours, every 6 hours, etc.).

The approach enables flexible modifications to medication timing without requiring changes to the underlying prescription data by separating the schedule from the prescription itself. This architecture is particularly helpful for modifying regimens to accommodate patient behavior or physiological requirements because it allows for real-time adjustments based on biometric feedback or caregiver advice.

The Schedule entity, which is the source of the daily medication notifications and ingestion reminders, powers the smartwatch application's essential features. Following initial synchronization, the smartwatch stores this data locally and updates it every night via API calls to guarantee accuracy.

3.1.4 Smartwatch

The smartwatch application, figure 3.5 is the ultimate goal for this project.

In order to track patient health, the smartwatch continuously gathers physiological data, such as heart rate (HR) and steps taken among others. This data is automatically synchronized with the associated smartphone using the smartwatch's built-in health apps, including Apple Health or Samsung Health. However, the application is unable to directly retrieve this data from the smartwatch due to system-level constraints. To get around this, the smartwatch uses the same API endpoints to receive pertinent processed data, for example the daily average heart rate or the total number of hours of sleep, after the smartphone periodically gathers and uploads the biometric data to the cloud via API.

The smartwatch actively enforces medication adherence in addition to biometric monitoring. The smartwatch is in charge of creating real-time alerts and reminders to let users know when it's time to take their medication based on the prescription data and intake regimens that were obtained from the API.

Additionally, the smartwatch connects directly to the pill dispenser, mostly via BLE, to verify the user before enabling the discharge of medication. This authentication method gives the system an essential degree of security and personalization by guaranteeing that only the right, authorized patient can access the medication that has been supplied.

The smartwatch functions as a synchronized extension of the larger system architecture to provide a smooth and dependable information flow between the wearable and the mobile application. With this design, patients may easily and conveniently track important health indicators on their wrist, such as average heart rate changes, step count, and sleep quality and other relevant information.

This particular system of continuous biometric tracking, made by both smartwatch and smartphone applications, not only makes patient self-monitoring easier, but it can also gives medical staff vital information on the patient's health trends and medication compliance. Clinicians can identify abnormal trends, including sudden shifts in physical activity or resting heart rate, and take preventative action if they have access to longitudinal data. Additionally, a more accurate assessment of treatment effectiveness and patient participation is made possible by the correlation of physiological data with medication ingestion events.

By keeping health and prescription data current and readily available across all platforms, this integrated ecosystem not only gives consumers the ability to take charge of their own healthcare but also enhances clinical outcomes. Moreover this all-encompassing approach is a prime example of how wearable technology may help in helping to improve patients healthcare.

Figure 3.5: Smartwatch Application

Chapter 4

Development

The main goal of the implementation is to incorporate a smartwatch application into an existing healthcare system that consists of a mobile application, a smart pill dispenser, and a back-end server. As a supplemental tool, the smartwatch collects biometric data through integrated health services and provides prescription reminders. Because direct data access across platforms is limited, the smartwatch uses synchronized APIs to connect with the smartphone and back-end, guaranteeing accurate and safe data management. Reliability, interoperability, and minimal user load across devices are prioritized in the implementation.

The development of these features within the program is thoroughly described in this chapter, including insights into design choices, communication protocols, and system integration.

Use Case	**Description**
Biometric Data Collection	The smartwatch continuously collects biometric data such as heart rate, steps taken, and sleep metrics using its native sensors and health apps (e.g., Apple Health, Samsung Health). Data is locally stored and periodically synchronized with the smartphone.

Use Case	Description
Biometric Data Synchronization	Due to app limitations, the smartwatch cannot access raw sensor data directly. Instead, it retrieves processed health summaries (e.g., average Beats per minute (BPM), hours slept) via API calls from the backend, after the smartphone pushes the data.
Medication Intake Alerts	The smartwatch downloads medication schedules from the backend and generates timed notifications to alert the user about their intakes. These reminders help improve adherence and user compliance.
User Authentication with Pill Dispenser	For security, the smartwatch connects to the pill dispenser via BLE and transmits identification credentials to authenticate the user before allowing medication release.
Local Data Display	Displays relevant information such as biometric summaries and upcoming medication reminders directly on the watch screen, allowing patients to monitor their health at a glance.
Nightly Synchronization	At defined intervals (e.g., overnight), the smartwatch fetches updated biometric summaries and prescription data via secure API calls to ensure it holds the latest information.

Table 4.1: Smartwatch Use Cases

4.1 Bluetooth Communication

A dependable communication protocol is necessary to guarantee a strong connection between different devices in an integrated healthcare system. Due to its significant benefits, BLE was selected to ensure data security and consistency. BLE is perfect for linking devices such the smartphone app and smartwatch since it has cheap energy costs, low latency, and wide interoperability with wearable and mobile devices. Its short-range communication capacity lowers the risk of interference and data loss while preserving energy efficiency, ensuring that sensitive data can be exchanged safely inside restricted contexts.

The design of BLE is tailored for sporadic data bursts, offering a useful trade-off between response time and energy usage. BLE greatly increases the battery life of wearable sensors and mobile devices by using low power levels, which is essential for ongoing health monitoring. Because of its low latency, real-time data transfers are made possible, which is crucial in healthcare settings where biometric data must be updated promptly. According to [35], BLE is designed to support a scalable, networked ecosystem by managing trade-offs between throughput and network size.

BLE has strong security features that guarantee data consistency and confidentiality in addition to energy efficiency and quick data exchange. The protocol uses cutting-edge authentication and encryption methods to protect private patient data while it is being transmitted. Its architecture reduces any interference and enables efficient data processing by separating the controller from the host. The network's different components, from smartphones to advanced wearables, may interact safely and dependably thanks to this structural design and high device adaptability.

In a BLE communication system, one device must function as a peripheral and the other as a key component. While the central looks for peripherals and establishes connections, the peripheral usually promotes its existence. The smartwatch is the main component of the entire system; it actively connects to and retrieves data from the pill dispenser, which is the peripheral. This setup preserves the low-power advantages of BLE while enabling the smartwatch to effectively handle and synchronize data.

To sum up, using BLE as the system's communication backbone provides a reliable, safe, and effective way to link devices. Its strong security features, low power consumption, and low latency create the ideal setting for data management and real-time health monitoring. The system's integration of BLE not only improves device interoperability

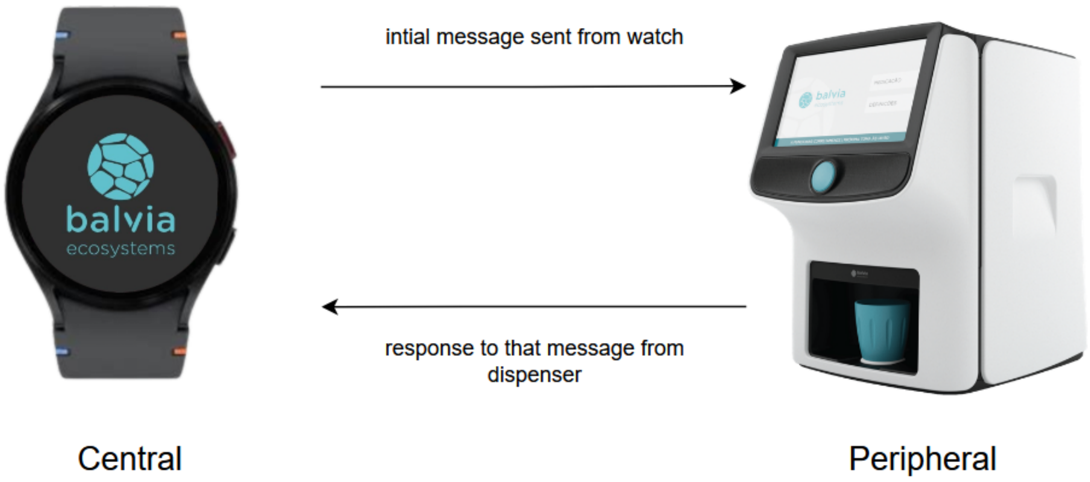


Figure 4.1: Representation Of BLE Connection

but also guarantees that patient data is protected and updated regularly, which is in line with current IoT healthcare trends as covered in [35].

4.1.1 Topology

Network topology defines how devices are organized and communicate with each other inside a system. In the context of BLE, the choice of the topology is essential to guarantee the high energy efficiency, low latency and trustable connectivity between the devices. BLE supports different types of topologies [36]:

- unicast communication: point to point communication between two devices. Data can flow in both directions;
- broadcast communication: one-to-many communication, creating a mesh networking where multiple devices can communicate with each other.

In the context of this paper, it will be adopted the one-to-one communication, due to have only two devices: a smartwatch and a smartphone. HR and number of steps are gathered by the smartphone via the native health application, which synchronizes with the wearable application. Data is stored in the smartwatch via Bluetooth connection. The smartwatch receives information from the smartphone, such as information about the patient and medicines to take.

Similar to Open Systems Interconnection (OSI) Model, BLE is based in a hierarchy communication model where each layer has specific responsibilities. Some of them are mandatory, while others are optional. The stack is divided into two architecture blocks, being them, the host and the controller, and the logic interface that define how the two components communicate, named the Host Controller Interface (HCI). It is important to highlight that the BLE stack covers all layers of the OSI reference model, unlike many other wireless systems that only operate within a limited subset, such as the physical and data link layers. One key advantage of Bluetooth technology being a complete communication stack is its independence from external standards organizations. This lack of dependency allows for greater flexibility in technological advancements without being restricted by external standards. Figure 4.2 demonstrates all the layers for the host and the controller.

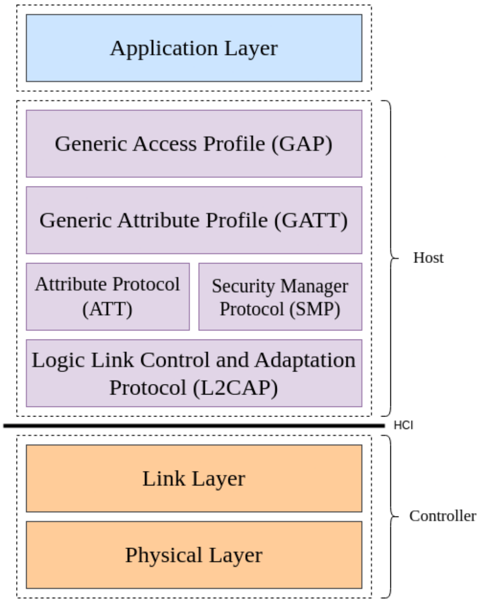


Figure 4.2: BLE Stack [36]

From all the layers of the BLE stack, it is important to discuss the Generic Attribute

Profile (GATT). It defines a hierarchical data structure known as services, characteristic, and descriptors to define the way BLE devices send and receive standard messages. A profile is composed by one or more services, each one containing at least one characteristic. It is in the characteristic where the data is contained, followed by properties that describe how the characteristic should behave, for example, read, write, notify, broadcast, etc.

As said before, BLE Stack follows hierarchical structure by using layers to organize and categorize the functions of each specific layer. However, the OSI Model is a general reference for all communication protocols, and BLE follows its own specification. Regardless, it is important to demonstrate how the BLE Stack compares to the OSI reference model. The Physical Layer of BLE maps to the Physical Layer of the OSI, the BLE Link Layer maps to the OSI Data Link Layer, the BLE L2CAP maps to the Network and Transport Layer of the OSI, the BLE Attribute Protocol (ATT) and Security Manager Protocol (SMP) maps the OSI Presentation and Session Layers and the Application layer along with the Generic Acess Profile (GAP) and Generic Attribute Profile (GATT) maps the OSI Application Layer (Figure 4.3).

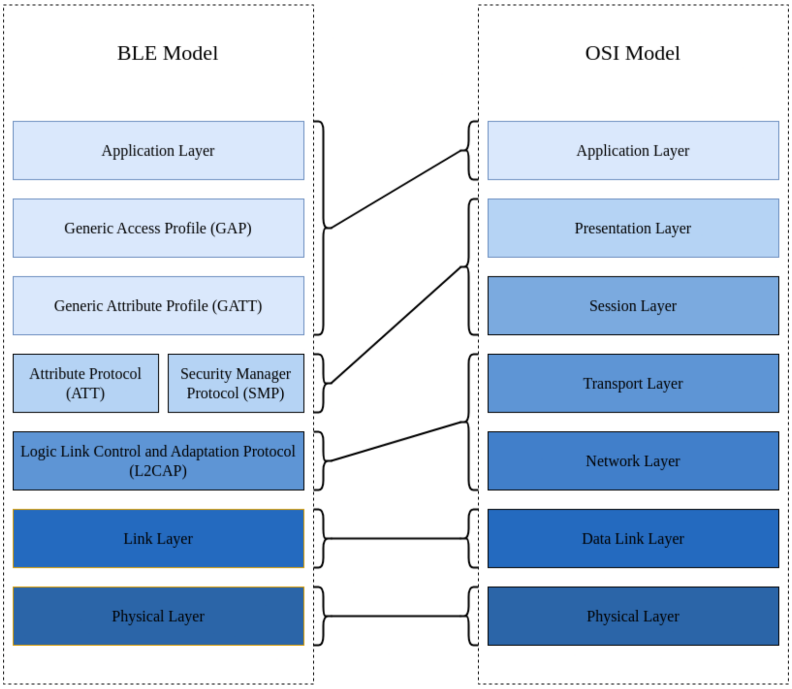


Figure 4.3: Comparison between BLE Stack and OSI model

4.1.2 Protocol

With the defined communication protocol, it is necessary to implement a message system in order that multiple devices can exchange messages. The message protocol via the wearable application and the mobile application follows the same perspective of the protocol defined by Van-Deste et al. [5] on the research of the pill dispenser architecture, that relies on a message composed by four parameters: version, command, length, and parameters. The version corresponds to the version of the protocol; the command, as a number corresponding to a user custom command; length, the length of the parameters and the parameters, as the parameters sent with the command. The final message got this format: Version-Command-Length-Parameters (V-C-L-P).

Therefore, messages were defined using this message protocol in order to synchronize the smartwatch with the rest of ecosystem. This is done through the dispenser, to which the watch needs to connect to receive the token needed to execute the calls to the API. This process starts when the watch connects to the dispenser via BLE, after a message is sent from the smartwatch triggering a response from the dispenser in the form of the list of emails from the users associated with that particular dispenser. After a the user specifies his email a message is sent to the dispenser to which there is a response containing a token that is used to gather information about that user, username, schedules of medication and biometric data. Figure 4.4 shows the representation of the message workflow.

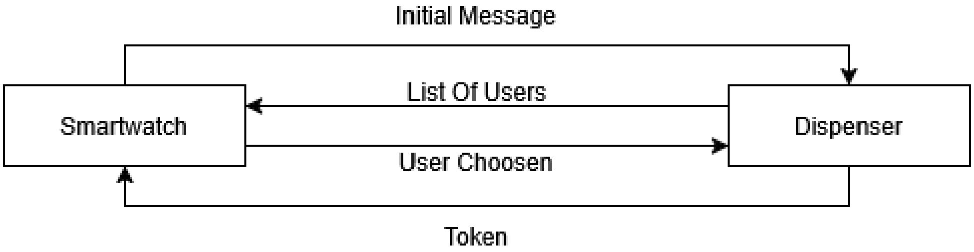


Figure 4.4: Messages exchanged between the smartwatch and the dispenser

4.2 Flutter Architecture

Using a single codebase, developers can create visually consistent, high-performing applications for several platforms with Google's open-source Flutter User Interface (UI) toolkit, which is based on the Dart programming language. Because Flutter drastically simplifies feature integration and ensures similar behavior on both Wear Operating System (OS) and proprietary platforms, it was decided to adopt it for the wearable application. The flexibility and maintainability of the user interface was maintained by building displays, such the biometric dashboards and daily medicine list, using modular widgets.

Development was further sped up by Flutter's hot-reload feature, as it was possible to avoid writing custom platform channels, shortening the time required to develop or modifying features.

Additionally, Flutter allows developers the advantage of community-driven enhancements and bug fixes thanks to its robust plugin ecosystem, which includes BLE communication (flutter_blue_plus), local caching (sqflite), secure token storage (shared_preferences), RESTful networking (http), and date formatting (intl). Flutter's combination of fast iteration, cross-platform consistency, and plugin-powered extensibility makes it the perfect starting point for a dependable, stable smartwatch solution.

Flutter Plugins

Platform-specific APIs and services (such as Bluetooth, alerts, and local storage) that Flutter cannot directly access are made available using plugins. Plugins are essential for the smartwatch application app since they allow:

- Hardware communication (such as Bluetooth devices);
- Handling of background tasks;
- Alerts, notifications;
- Storing and retrieving data;

- Checks for connectivity and the internet;

In the table 4.2 is displayed the full flutter plugin list used for this project.

Plugin	**Purpose**
`alarm`	Schedule and manage alarms. Triggers medication reminders at specific times, even if the app is closed.
`carousel_slider`	Image/content slider UI widget. Used for swipeable screens.
`connectivity_plus`	Checks internet connection status. Ensures the app adapts to online/offline states.
`flutter_blue_plus`	Bluetooth Low Energy (BLE) communication. Connects the smartwatch with the smart pill dispenser to exchange data.
`flutter_local_notifications`	Displays notifications on the device. Used to send timely medication and health alerts to the user.
`http`	Makes network requests (e.g., to APIs). Retrieves patient data, medication schedules, and sends syncs to the cloud.
`path`	File path manipulation. Supports file or local database storage paths used in `sqflite`.
`permission_handler`	Requests and manages runtime permissions. Requests BLE, notification, and health tracking permissions from the user.
`shared_preferences`	Local storage for key-value pairs. Stores user preferences such as alarm toggles, login state, and settings.
`sqflite`	SQLite database interface. Stores medication schedules and logs locally for offline access.

`workmanager`	Schedules background tasks. Allows for background data syncs (e.g., fetching next-day schedules at midnight).

Table 4.2: Flutter Plugins

4.2.1 Biometric Collection, Health Connect Integration, and BLE Synchronization

The collection and display of the user's daily medication schedule, including the medicine's name, dosage, and time of ingestion, is the main purpose of the smartwatch application. In order to identify the patient and retrieve a unique patient identifier, the smartwatch first connects via BLE to the smart pill dispenser. The matching intake schedule is then requested using this identity using an AWS-hosted API. To provide clear and reliable data delivery to the watch, the back-end server handles the request, makes a query to the schedule database, and uses Data Transfer Objects (DTOs) to organize the response.

The program parses the DTOs and translates them into a local data model after the smartwatch receives the API response. A lightweight on-device database houses this local data model, guaranteeing low-latency access and offline availability for everyday use. At first launch, the local schedule database is initialized, and it is automatically updated by re-querying the API at midnight each day. Even in the event that connectivity is momentarily disrupted, this method ensures that the intake plan for the next day is always current.

An interactive alarm system is then set up using the data received by the process described above. The user is shown a comprehensive intake screen with the medicine name, recommended dosage, and a confirmation button when the alarm goes off. The system records the event, deletes the finished entry from the active schedule, and gets ready for the next scheduled alert after the patient certifies that they have taken the medication.

In order to preview future medication times, users can access at any time a ”Next Intakes” screen. This screen is updated dynamically throughout the day when intakes are confirmed.

By gathering important physiological information such as heart rate and step count, the wristwatch also serves as a health monitoring tool. The device’s built-in health app (like Apple Health or Samsung Health) initially records these measurements, which are then immediately synchronized with the user’s smartphone. The smartphone serves as a middleman by extracting the biometric data from the local health app, formatting it, and sending it to the back-end API because smartwatches have restricted direct access to biometric data via Flutter. After retrieving this data from the API, the smartwatch then presents it in an intuitive manner, enabling users to see hourly step counts and 24-hour heart rate patterns right on their watch among other relevant data.

4.2.2 Retrieving and Translating Schedule Data

The project’s Spring Boot API, which is also hosted on AWS along with the database and back-end, provides medication regimens in JSON format. The watch sends out an HTTP GET request at midnight every night or whenever the user manually requests a refresh.

`https://api.balviaecosystems.com/api/v2/wearable/schedules/{email}`

The endpoint replies with a Data Transfer Object (DTO) that neatly contains each schedule’s id, startDate, endDate, period, medicationName, quantity, and a map of scheduleTimes after being authenticated by a bearer token. This DTO is parsed by a *ScheduleService* class in Dart, which instantly saves the updated token in SharedPreferences. Each schedule element is then iterated through: flexible "otherTime" entries generate a sequence of times separated by the specified period, while fixed timings are transformed into DateTime stamps for that calendar day. These dynamic dosages are internally determined from the seed time and period by a helper function called *generateTodayMedicationSchedule()*, which takes into account any end-of-day or treatment-end limits.

4.2.3 Local Database Synchronization

The program concatenates the names of concurrent medications to create a single list after each possible intake timestamp has been generated. It removes stale or duplicate entries by purging any rows that already exist in the local userIntakes SQLite table and share the same date before persisting. Each intake record, which now includes the timestamp, medicationName, scheduleId, and period, is inserted in ascending order using the *DatabaseService.insertData()* helper. With the help of this local cache, the watch is able to set off alarms and completely shut off the ”Next Intakes” displays without requiring instantaneous network or phone connectivity.

4.2.4 Interactive Alerts and Intake Confirmation

The Flutter UI automatically switches to the alarm screen when the clock reaches a scheduled intake. In this format, there is only one ”OK” button and the medicine name, dosage, and exact time are displayed in large, readable font. When you press it, two things happen simultaneously: the associated userIntakes entry is removed from the local database, and the next reminder is scheduled based on the timestamps that are left. The transitory alarm screen prevents unintentional dismissal by requiring an explicit tap to continue, while haptic vibrations, aural cues, and visual feedback all work together to enforce adherence.

4.2.5 Extra Features

In addition to its primary biometric and pharmaceutical flows, the program has a User Profile part for personal information and emergency contacts, as well as a Device Management system that boths displays the connection status of the associated dispenser and its name.

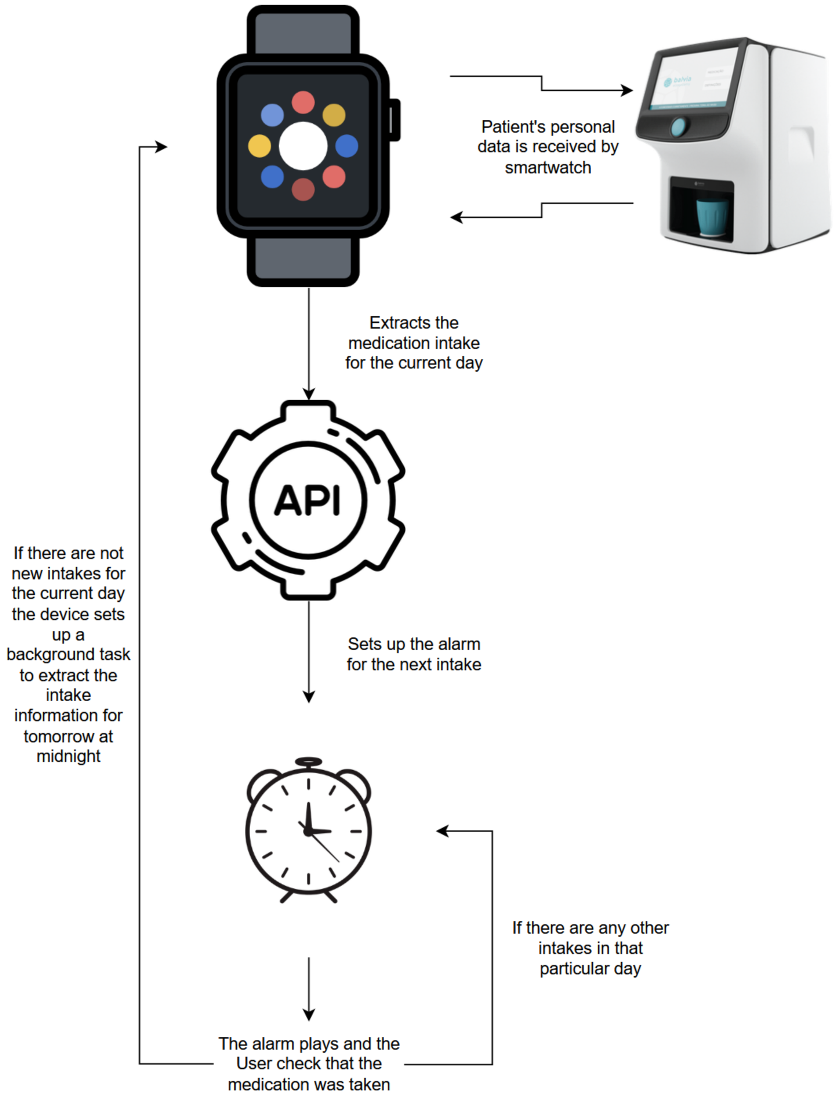


Figure 4.5: Alarm Flow

Chapter 5

Tests and Discussion

From the first smartwatch application launch to the continuous interactions between the many parts, such as the pill dispenser, cloud service, and supporting devices, this section provides a thorough picture of how the system operates over the course of its whole lifecycle. This section attempts to provide a thorough knowledge of how users engage with the system on a daily basis and how the various modules cooperate to assist medication adherence and health monitoring by describing the primary stages of operation.

The objective is to show how the system may be used practically in a real-world setting, emphasizing the user experience and how the system behaves in various stages. Every stage is essential to guaranteeing a smooth and dependable user experience, from setup and data syncing to daily usage and health tracking. This walkthrough highlights the application's fundamental design concepts, usability considerations, and system responsiveness, demonstrating how it promotes continuous care and strengthens the bond between patients and caregivers.

This section therefore, provides a comprehensive understanding of the application's lifecycle and better understand the reasoning behind its structure and functioning by following the orders of screens, interactions, and data flows outlined in the ensuing subsections.

5.1 Application Lifecycle/Demo

Beginning with the initialization procedure, this section describes the important phases of the application lifecycle. It describes how the smartwatch app starts up, establishes communication with other gadgets, and gets the system ready to provide its essential features. To give users a clear grasp of how the program works from the first time they open it, each step is explained in depth.

5.1.1 App Initialization

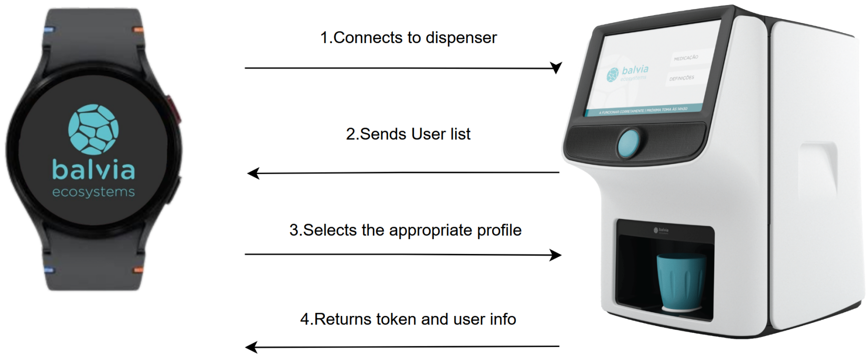


Figure 5.1: Application Initialization Flow

When the smartwatch application is used for the first time, it displays a single page that provides instructions on how to use the app appropriately (figure 5.2). This onboarding process is essential since it creates a basic grasp of the app's operation, which is especially important when targeting older or less tech-savvy customers. To lessen cognitive burden, these interfaces are purposefully kept straightforward and easy to use, with simple text and graphics.

The user is instructed to start the initial communication between the smartwatch and the smart pill dispenser after finishing the instructions. BLE, a crucial part of the communication architecture, is used for this (figure 5.3). BLE offers secure short-range pairing, which is perfect for settings similar to home healthcare, in addition to ensuring effective and low-energy communication. The smartwatch looks for dispensers in the

Para se mover entre páginas, passe o seu indicador pelo ecrã na direção horizontal direita.

Para se mover em uma página, passe o seu indicador pelo ecrã na direção vertical.

Figure 5.2: Instructions

vicinity and, after connecting, obtains a list of patient profiles that are kept on that specific dispenser.

Conexão BLE não está estabelecida

Por favor conecte/reconecte com o seu dispositivo móvel e aguarde que os seus dados sejam sincronizados

Figure 5.3: Initial Page

Then, from the list, the user chooses his correspondent profile. This phase enables the app to connect the current device session to the appropriate patient profile and acts as a simple authentication method. The smartwatch enters its synchronization mode after a user is chosen, starting a sequence of setup procedures that get it ready to perform its two primary functions: tracking biometric data and controlling medication compliance (figure 5.4).

5.1.2 Patient's Synchronization

The application synchronizes with the cloud-based system backend after a successful user identification. The smartwatch uses the system's RESTful API to request and obtain the user's customized medication schedule over this secure connection. Structured data, such

Figure 5.4: User Information

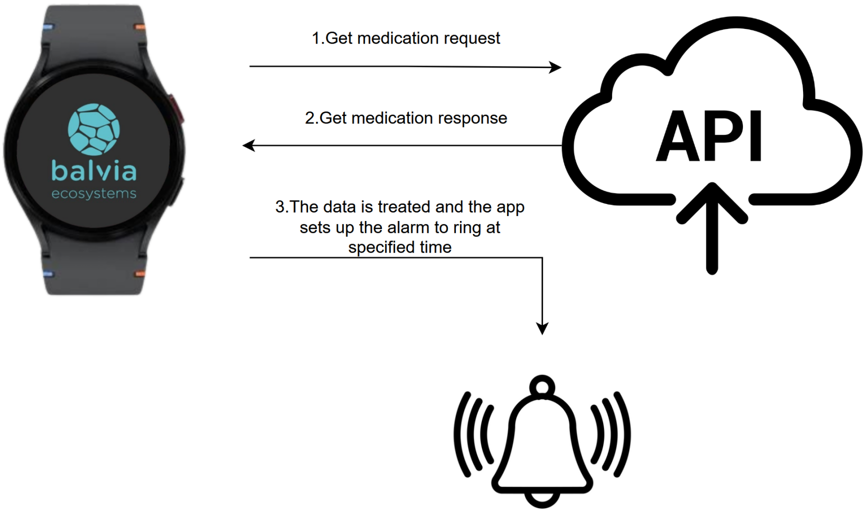


Figure 5.5: Application Alarm Setup Flow

as the names of prescription medication, dosages, and the general times for each dose throughout the day, are returned by the backend, this process is described in figure 5.5.

After receiving this data, the app processes it locally, turning broad timeframes into time-based warnings that are accurate and appropriate for everyday use (figure 5.6). Depending on their particular routine, these alerts are crucial for making sure the user is reminded to take their meds on a regular basis. Crucially, the smartwatch can function even when offline because all schedule data is cached on it.

Próximas tomas

Ottoduo_1 mg/m...
20-05-2025
23:00

Figure 5.6: Next Intakes

The app actively warns the user with a notification at each set intake time. The application shows pertinent details about the medication to be taken, including the medication's name and dosage, when the alert is opened (figure 5.7). After then, the user is asked to verify that they have taken the prescription. Future iterations of this technology hope to incorporate automatic verification through sensor feedback from the pill dispenser, albeit for now it depends on user honesty, although the dispenser already has its particular process of checking if the user has taken the medication through the usage of scales to measure if the medication dispensed has been consumed.

Toma Pendente!

Ottoduo_1 mg/ml + 3 mg/ml x 3 vezes

Figure 5.7: Alarm Playing

The system records what has been verified as the day goes on and prescribed medication is taken. When all of the intakes that are planned for that day are finished, a background task is scheduled using a Flutter's plugin named *Workmanager*. At this time the program automatically makes a request to the API to get the new scheduled medication for the following day, keeping the process of the schedule of alarms completely automated. To ensure that the app stays updated without manual user intervention, this procedure re-connects to the cloud service to retrieve the medication schedule for the next day (figure 5.8).

Additionally, users can temporarily quiet or deactivate alarm notifications through the alarm page to match personal preferences or contextual conditions (e.g., during meetings or sleep) (figure 5.9).

Figure 5.8: Next Intakes After Midnight

Figure 5.9: Enable/Disable Alarm Page

5.1.3 Biometrics

Through its integrated health sensors, the smartwatch continuously gathers biometric data in addition to tracking medicine. Depending on the smartwatch's hardware capabilities, these measurements usually include heart rate, physical activity levels (such as steps taken), and other vital signs. However, the watch cannot send this biometric information straight to the app because of the constraints of the current operating system.

Rather, depending on the user's device, the health data is synchronized to the native health platform of the smartphone, which may be Samsung Health or Apple Health. In the smartphone application this data is then sent over to the established back-end server where it is stored and available throught all devices in the ecosystem.

5.1.4 Health Tracking

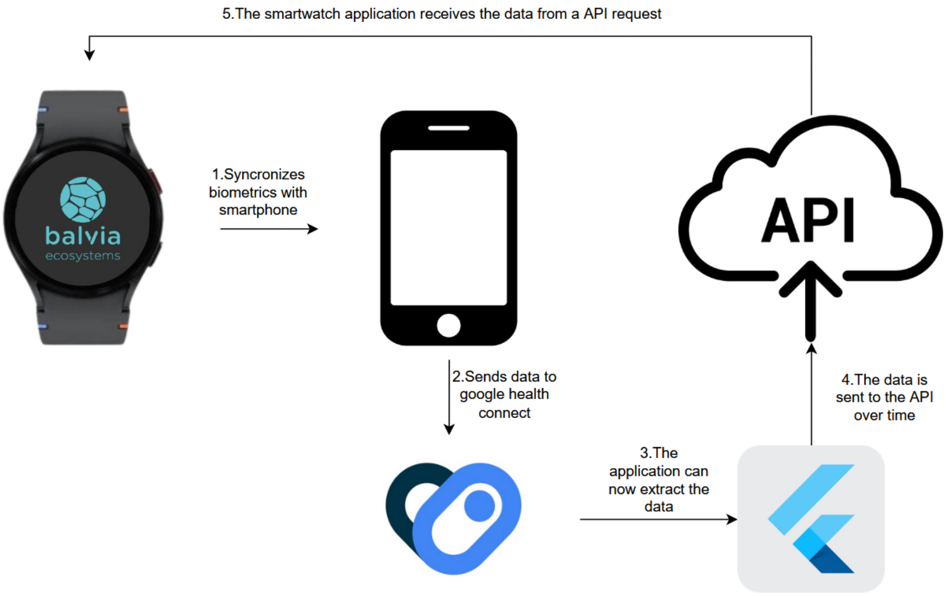


Figure 5.10: Application Biometrics Setup Flow

With this approach the smartwatch is now able to give consumers a visual summary of their daily health parameters in an effort to increase user engagement and health awareness. The software shows trends such as recent heart rate changes and hourly step counts directly on the smartwatch interface using data obtained from the smartphone health API (figure 5.11).

Figure 5.11: Fetching Biometrics

In addition to keeping people informed and motivated about their physical health, this image acts as a link between professional medical assistance and self-care. By making this information available to healthcare professionals, the patient-clinical team feedback loop could be strengthened, encouraging better decision-making and prompt treatments.

5.1.5 Modularity

The system's modular design is one of its main architectural advantages. The program is made to function dependably even in the event of a brief outage of connectivity. The device keeps its complete functionality offline for lengthy periods of time by locally recording the user's status and current medication schedule on the smartwatch.

Every day at midnight, the app is set to reconnect to the cloud and retrieve the most recent schedule information for the next 24 hours. By minimizing continuous network activity, this design lowers power consumption while guaranteeing continuous operation in a variety of real-world scenarios, such as while traveling or in areas with spotty internet coverage.

Scalability is also made possible by modularity. Every part is separately changeable and upgradeable, from medicine alerts to biometric tracking. Because of its adaptability, the system can develop with little interference and accommodate upcoming improvements such as direct biometric uploads or more sensor integration.

5.2 What can be learned from the results

The application's final implementation demonstrates how wearable technology and smart pharmaceutical systems can be combined to improve health tracking and treatment adherence. The fact that the smartwatch can be paired with the smart pill dispenser using BLE, which is a dependable and effective communication technology, enables smooth data transfer while using little power, which is crucial in wearable settings.

Furthermore, there is significant value added when biometric tracking is integrated into the same application environment. When paired with medication intake records, the ability to track health trends such as heart rate and activity levels improves the comprehensiveness and usefulness of patient data for caregivers. While using cellphones to access health data draws attention to existing restrictions on hardware access and platform permissions, it also points the way for future innovation, especially when it comes to giving the smartwatch direct access to cloud services or health APIs.

5.3 What Could Be Done Differently

Although the existing UI is functional, it might be improved to make it easier to use, particularly for older people who might not be accustomed to using a smartwatch. Usability would be greatly increased by improving visual accessibility (e.g., larger letters, clearer contrast, streamlined menus).

Although limited by platform constraints today, future smartwatch OS developments may permit direct cloud uploads or peer-to-peer sharing, which could be leveraged for efficiency and independence, eliminating the need for a smartphone intermediary to access biometric data would streamline the ecosystem.

5.4 What Was Beyond Initial Objectives

The project's initial objective was to promote medication adherence by creating a complementary application for a smart pill dispenser that could allow for the organized scheduling and prompt reminders of the medication intakes of the patient. However, by providing a more complete health management system, the final execution surpassed expectations in regards to usefulness in a medical context by providing patients biometric data along with the intake schedules which could benefit both caretaker and patient.

5.5 What Objectives Were Not Met and Why

Allowing the smartwatch to manage and upload biometric data directly to the cloud or application interface was an unmet objective. However, third-party apps are unable to receive health data straight from the watch due to operating system limitations. This calls for the usage of a coupled smartphone as an intermediary device, adding another layer of dependency and somewhat reducing the wearable's independence.

5.6 Future Work

Leveraging Near Field Communication (NFC) to make sure that only the assigned patient can interact with the dispenser is one of the future intended features.

Predictive analytics and customized alarms can be implemented thanks to the integration of biometric patterns and medication adherence data. The system might alert caretakers, for instance, if a patient's heart rate exhibits unusual trends in addition to missed prescriptions.

Chapter 6

Conclusions

Wearable technology has shown great promise in enhancing patient adherence to drug regimens, decreasing the likelihood of missed or erroneous dosages, and improving treatment outcomes. Wearable technology has been creatively used into healthcare to allow for ongoing monitoring and prompt actions, guaranteeing that patients take their prescription medication as directed. These technologies offer scalable and efficient ways to address the widespread problems of pharmaceutical non-adherence in both acute and chronic illnesses, bridging the gap between traditional treatment and contemporary digital solutions.

A smartwatch app was created for this study in order to add a new level of integration to the ecosystem in the form of a wearable device. The application collects important health data from the wearable and sends it to the mobile device centralizing the data, also storing the data from the smartphone for display and analysis, apart from creating alerts in real time to help users remember to take their medications on time. This approach makes it easier for medical professionals to monitor patients remotely and improves the general effectiveness of treatment plans, which eventually leads to better patient outcomes.

Through low-energy and low-latency data transfer, Bluetooth, the system's main communication method—ensures seamless device-to-device interaction. Furthermore, a fail-safe method that uses API calls has been put in place to ensure that data is continuously retrieved even in the event that Bluetooth connectivity is briefly lost. This dual communication approach strengthens the integrity of the patient monitoring framework by improving system stability and guaranteeing that vital health data is consistently available across all connected devices.

The mobile application's user-centered design greatly improves dependability and accessibility. Patients may easily follow their medication schedules with the help of the system's features, which include interactive alarms, an organized intake confirmation process, and real-time updates to a local database. Improved features including caregiver monitoring, biometric tracking, and emergency alerts increase the system's usefulness by allowing patients and medical professionals to stay informed and react appropriately to treatment adherence issues.

Looking ahead, future work will focus on refining the system's usability and efficacy through additional studies and practical testing to evaluate long-term patient outcomes. An exciting avenue for development is the integration of Near Field Communication (NFC) technology into the smartwatch, which will facilitate secure authorization at the pill dispenser when an alarm is triggered. This enhancement is expected to further streamline the medication management process and provide an extra layer of security for user interactions.

In order to assess long-term patient outcomes, future research will concentrate on improving the system's usability and effectiveness through more studies and real-world testing. The incorporation of Near Field Communication (NFC) technology into the smartwatch is an intriguing development path that will enable secure authorization at the pill dispenser in the event of an alarm. It is anticipated that this improvement will further expedite the drug management procedure and add an additional degree of security to user interactions.

In conclusion, wearable technology has the potential to revolutionize healthcare by providing effective, scalable answers to ongoing problems with drug adherence. By connecting patient-centered care and digital health interventions, the proposed system not only increases treatment compliance but also improves general well-being. Better results, lower costs, and more individualized treatment plans are anticipated as technology advances and is incorporated into routine healthcare procedures, guaranteeing that digital innovations stay at the forefront of contemporary medicine.

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