A New Medication Management System for Elderly Using Augmented Reality

A dissertation submitted for the Degree of Master of Computer Science

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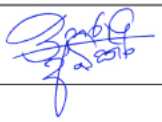	26/10/2024

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DEDICATION

I wish to dedicate this to my parents. Thank you so much for everything! Words can hardly describe my thanks and appreciation to you.

ACKNOWLEDGEMENT

This master's thesis marks the end of my goal of obtaining a master's degree in computer science from the University of Colombo School of Computing. The most important part of a journey that spanned over two years, with its ups and downs, was meeting so many people that I will remember for the rest of my life. I would like to thank some of those people in this section.

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Special thanks to my parents, sister and grandmother who have given me support and courage throughout my life to get this master's degree. I would never have gotten to this point in my life without you.

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Last but not least, I would like to thank everyone who helped me write this thesis and especially the members of the elderly community who participated in my interviews and surveys and helped make this a success - without your help this research would not have been possible, thank you.

A.D.S.I Adhikari

ABSTRACT

This study introduces the development of an Augmented Reality (AR) and Internet of Things (IoT)-based medication management system tailored for elderly individuals.

The system aims to address healthcare accessibility challenges encountered by the elderly, such as medication identification, dosage accuracy, and storage concerns, which can pose risks during medication administration. Despite AR's extensive use in various medication management areas, its potential in guiding medication storage and retrieval within a medicine cabinet has not been explored. To address this gap and overcome challenges, a prototype was developed to identify, store, and guide medication administration.

By integrating AR and IoT technologies, the system provides real-time visual and audio instructions, improving medication administration accuracy and reducing the likelihood of medication-related complications. Interviews conducted during the prototype evaluation revealed mixed feedback on usability. Participants with limited technical knowledge experienced difficulties with app navigation, medication input, and accessibility issues. Conversely, users with strong technical backgrounds appreciated the prototype's audio output for medication identification and found the interface intuitive.

LIST OF PUBLICATIONS

Sandun Isuru Adhikari, Kasun Karunanayaka, 'A New Medication Management System for Elderly Using Augmented Reality', 33rd International Symposium on Industrial Electronics (ISIE 2024), South Korea (Submitted).

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LIST OF ABBREVIATIONS

IoT	Internet of Thing
AR	Augmented Reality
SDK	Software Development Kit
UI	user interface
IT	Information technology
WHO	World Health Organization
QR code	Quick Response Code
OCR	Optical character recognition
API	Application Programming Interface
PIR sensor	Passive infrared sensor
RFID	Radio Frequency Identification
GSM	Global System for Mobile Communications
SMS	Short Message Service
AI	Artificial intelligence
I2C	Inter-Integrated Circuit
PWM	Pulse width modulation
OS	Operating System
US	United States

CHAPTER 1

INTRODUCTION

1.1 Motivation

The elderly population often faces significant challenges in managing medications effectively due to vision defects and other age-related issues (Makmor et al., 2017). In today's busy lifestyle, constant caregiving is challenging, leaving elderly individuals to manage their medication alone (Anon et al., 2019). This can lead to a range of medication errors, including taking unauthorized drugs, incorrect dosages, missing doses, taking doses at the wrong time, and other serious mistakes (MAGER, 2007). These errors can result in severe health complications and even fatalities. For instance, overdosing drugs account significant proportion (0.2%) of total deaths among adults aged 65 and over, with rates increasing over the past two decades (1,2). Between 2000 and 2020, age-adjusted death rates for drug overdoses in this age group rose from 2.7 to 12.3 deaths per 100,000 for men and from 2.3 to 5.8 for women. This alarming trend highlights the critical need for improved medication management solutions for the elderly (Kramarow and Tejada-Vera, 2022).

Globally, in-home drug-storage compliance is often unsatisfactory, particularly among older adults, leading to significant negative health outcomes (Lo et al., 2020). Research indicates that improper storage and management of medications at home can result in medication errors, decreased drug efficacy, and increased risk of adverse effects. Older adults, who frequently use multiple medications, face challenges such as physical difficulties in accessing medications and cognitive issues affecting adherence to prescribed regimens. Studies have shown that over half of U.S. adults do not adhere to their prescriptions, contributing to a substantial number of hospital admissions and preventable deaths annually (Faisal et al., 2021; Gualtieri et al., 2022). Effective home medication management and appropriate storage are crucial to improving adherence and preventing negative health consequences (Gualtieri et al., 2022). Therefore, it is crucial to have a system that provides proper guidance on medication usage and storage for the elderly.

Therefore, the motivation for this research is driven by the pressing need to address the medication management challenges faced by the rapidly growing elderly population.

1.2 Statement of the problem

By 2030, 1 in 6 people in the world will be aged 60 years or over (WHO, 2022). At this time the share of the population aged 60 years and over will increase from 1 billion in 2020 to 1.4 billion. By 2050, the world's population of people aged 60 years and older will double (2.1 billion). The number of persons aged 80 years or older is expected to triple between 2020 and 2050 to reach 426 million (WHO, 2022). The body of the elderly becomes weak, and their eyesight gradually deteriorates (WHO, 2023). Further, their memory is gradually decreasing (Tordoff et al., 2010). Also, they have to face various diseases. Such conditions as hypertension, diabetes, and hypercholesterolemia can be introduced (Wang et al., 2019). Some people need to take medicine for a long time. So, they have to face many problems due to vision defects while using drugs for a long time. (Makmor et al., 2017). Due to today's busy lifestyle, it is difficult for someone else to always take care of these elderly people. Because of that, these people have to face many problems getting drugs alone (Anon et al., 2019).

The problems faced by elderly people when taking medication can be mentioned as follows. Sometimes they forget to take medicine (MAGER, 2007). Sometimes the same medicine is taken several times thinking that the medicine has not been taken (Kentab et al., 2015). There is also a possibility that these people get the wrong medicine because of poor vision. Elderly People with poor eyesight may not be able to read the expiration date of a medicine correctly (Makmor et al., 2017). These people have to face many problems due to taking expired medicines. Therefore, even drug poisoning can occur. Some people have allergic reactions to some medicines. Due to not being able to identify the drug correctly (MAGER, 2007), it is possible to take the same drug again in the future and recur allergic conditions again. These people often use eye medication. There are different places in the eye to apply medication. There is a proper way to apply the medicine to the eye, and there are different places in the eye to apply medication (Makmor et al., 2017). They often get the help of another person when applying the medicine to the eyes. If he is a novice, he will have problems because he does not know how to use it.

Medicines should be stored in a proper place, especially for those people who are elderly with vision defects. Otherwise, they will have to face difficulties in finding medicines (Makmor et al., 2017). Proper in-home drug storage involves keeping medications secure, maintaining original packaging and information, and discarding expired medications. Improper practices, like using incorrect packaging or retaining expired drugs, can lead to poisoning, increased healthcare costs, and harm to users' health. Adhering to storage standards is crucial (Lo et al., 2020). Therefore, it is essential to store medicines in the correct place (Makmor et al., 2017). Also, medicine usage is a task that must be done correctly. For this, these elderly people need proper guidance.

1.3 Research Aims and Objectives

1.3.1 Aim

This research is to introduce an Augmented Reality based prototype for medication management for elderly people. The aim of this research is to create a good guide for medication management for elderly people. The guide supports identifying the medicine, reminding the patient to take the medicine, providing instructions to use the medicine correctly, protecting against the problems that occur when taking the medicine, and supporting the storing and retrieving the medicine.

1.3.2 Objectives

The main objective of this research is to aid elderly individuals in managing their medication regimen through the use of Augmented Reality (AR).

For that, has introduced a prototype. The prototype consists of two main components: an AR-based mobile application and an IoT-based medicine cabinet, as shown in Figure 1.1 The primary objectives of this prototype are to introduce a medicine cabinet with IoT capabilities for elderly individuals to store and manage their medications effectively, and to develop a mobile application with AR guidance to assist users in correctly storing and taking medications.

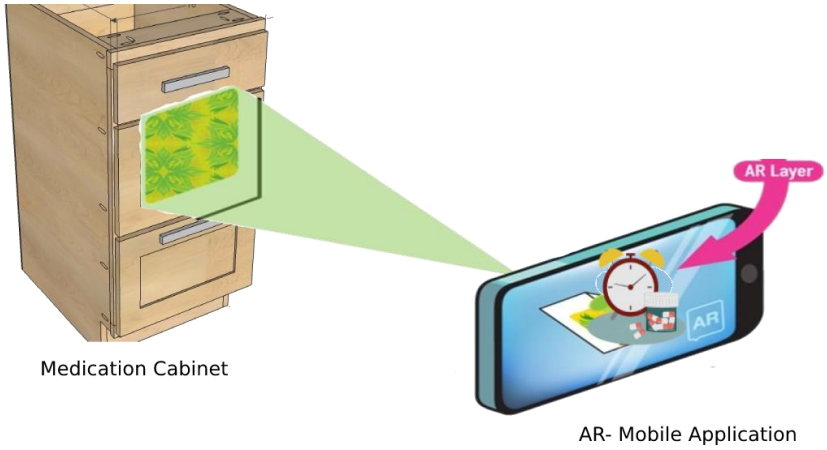


Figure 1.1: Medication management system prototype.

The mobile application focuses on achieving accurate identification of medications, providing instructions on proper medication usage, alerting users about the required pill count per dose, notifying users about the optimal time for medication intake, offering guidance on medication refills and expiration dates, alerting users about any past allergic reactions to medications, and providing touch and voice input capabilities for user convenience.

The IoT-based medicine cabinet enhances medication storage protection and usability by enabling touch and voice input. The AR-based mobile application guides users in storing and retrieving medications correctly, ensuring reliability and performance. It allows users to input medication details such as name, dosage, expiry date, time of intake, audio/video instructions, and special notices. When scanning the medicine box or packet surface using AR, the application displays medication details, usage instructions, and allergy notifications through audio and visual cues. For medications not in the database, the app searches Google for information and presents it via audio. The app guides users in storing medications in the cabinet and finding them based on the schedule. The IoT features of the cabinet include remote unlocking via the mobile app, pre-medication alarms, and compartment markers for daily medication schedules. The AR-based guidance within the cabinet highlights relevant drawers for medication retrieval and provides voice prompts for medication details and timing.

1.4 Research questions

- What are the practical problems faced by elderly persons while identifying and taking medicines in their day today life?

- How to develop Augmented Reality and IoT based medication management system for elderly people?

- How usable is the proposed medication management system for caregivers and elderly people?

1.5 Scope

1.5.1 In-scope

The system architecture and design encompass the development of an AR-based mobile application that aids in the accurate identification and management of medications, and the design and implementation of an IoT-based medicine cabinet that enhances medication storage, retrieval, and user interaction.

In terms of mobile application development, the research focuses on creating an intuitive mobile application interface with touch and voice input capabilities. This includes implementing AR functionalities to guide users in correctly storing and taking medications. The application will integrate medication management features such as dosage instructions, pill count alerts, intake reminders, refill and expiration date notifications, and allergy alerts. Additionally, it will include functionalities for inputting medication details, such as name, dosage, expiry date, intake schedule, and special instructions. AR will be utilized to display medication details and usage instructions through audio and visual cues when scanning medication packages.

The IoT-based medicine cabinet will be designed to be secure and user-friendly, with remote unlocking capabilities. It will incorporate pre-medication alarms and compartment markers for

organizing daily medication schedules. AR guidance will be integrated to highlight relevant drawers for medication retrieval and provide voice prompts with medication details and timing.

For data management and retrieval, the system will include the development of a database to store medication information and user-specific data. A search mechanism will be implemented for medications not in the database, retrieving information from Google and presenting it through audio. Ensuring data security and privacy for user information stored and accessed by the system is also a critical aspect of this research.

1.5.2 Out-of scope

The study does not include pill recognition and expiration date detection using the pre-trained model.

1.6 Structure of the Thesis

This thesis is organized as follows: Chapter 1 introduces the research topic by presenting the area of interest, motivation, statement of the problem, research aims and objectives, poses research questions, scope and structure of the thesis. Chapter 2 is the literature review chapter. Here, past research in which new technologies such as Augmented Reality have been used in relation to the medication management of elderly people will be discussed. Chapter 3 is the methodology chapter. The methodology used in this chapter is thoroughly discussed. This chapter includes process flow diagrams, design assumptions related to the scope of the proof of concept, prototype architecture, algorithm design details, etc. Chapter 4 discusses how to evaluate research and results. This chapter includes aspects such as evaluation protocol, designed experiments, results obtained and critical evaluation of the research work. Chapter 5 is the Conclusion and future work. This chapter summarizes the work, discusses its findings and contributions, points out the limitations of the current work, and suggests directions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 A Literature Review

This section discusses the prior works conducted on managing the medication of elderly people using Augmented Reality. Several cases where Augmented Reality has been used for medication identification can be introduced.

Smart Assist has been developed to build a semantically enriched Augmented Reality based medication compliance solution for elderly people in recognizing medication containers, taking appropriate dose frequency and taking medication on time (Khan et al., 2018). By scanning a medicine box with a QR code, AR shows the number of pills to be taken on time and how long it takes to get the medicine again. A smartphone camera is used to scan a medicine box with a QR code. This includes a website/mobile. The pharmacist adds information related to the medication to the website. The doctor will add the dose and times to take the medicine to the website at the clinic. Here the patient's smartphone acts as a smart assistant to help take the medicine and ensure medication compliance. All old medication reports of the patient can be viewed through the mobile application. Elderly people can use the app for reminders for medication administration, medication availability, dose frequency and compliance.

Rupa et al.(2021) can be introduced as another case of using Augmented Reality to get the name and details of the medication. When a medication box or medication label is scanned using the AR camera, its name is obtained by OCR and the details related to the medication and corresponding 3D model are displayed using Augmented Reality. Here a predefined data set related to the drug name is used. If the recognized text matches the medicine name in the dataset, then the application will return an output that matches the medicine by using the 3D Model.

MedHelp provides regular medication comprehensive support for elderly patients with medication compliance. MedHelp is designed to monitor the user's medication taking activities to plan the next medication period, providing reminders for a user who takes medication

regularly, assisting the user in identifying the correct medication container and providing dosage instructions (Xu et al., 2016). This was created using Google Glass paired with a mobile phone. Data entry will be done by the custodians and he will store several pictures of each drug. Drugs are identified using image matching algorithms.

MED-AR is an intelligent Augmented Reality system to support medication management in older adults (Guerrero et al., 2019). Medicines are managed using a smart medicine cabinet at MED-AR. Three Kinect cameras are used in the cabinet. Kinect cameras are used to perform gesture recognition and text recognition. The medicine name is found by recognizing the text from the medicine boxes. The name of the medicine is sent to the google API and the details related to the drug are retrieved. The details of the medicine and the dose to be taken, the time to take the medicine are shown on a nearby table using projection based Augmented Reality. It also studies the gestures of the patient taking the medicine and analyzes whether the medicine has been taken or not.

Medication Coach Intelligent Agent (MCIA) is a smart mHealth app that calls Medication Coach as an intelligent agent (Ingeson et al., 2018). The MCIA will have to manage different types of information such as the medication plan of the patients, medication restrictions, as well as the patient's preferences and sensor input data from an AR-headset. The aim is to investigate whether Augmented Reality can be used as a tool to improve and maintain medicine-related self- management. It is checked whether elderly people can correctly identify the medicines they are taking. MCIA has automatic reasoning capabilities. This enables the MCIA to make decisions with long-term goals in drug planning.

Ambient Assisted Living (AAL) uses Augmented Reality and IoT to provide various reminders to memory loss individuals with Alzheimer's disease (Ghorbani et al., 2019). The system consists of two main parts. The first one is the smartphone or Windows app. This allows caregivers/family members to monitor a patient's condition at home and notify if the patient is at risk. The second one is smart glasses. QR codes are pasted in the environment and various reminders are given to the patient while scanning by Google Glass. AAL detects data from rain sensor, fire sensor, temperature sensor, PIR motion sensor and corresponding alarm message is notified by Augmented Reality. The smartphone app can activate a relay actuator so that the drawer lock opens, and the user can see an image of the pellets on a screen. In addition, the user receives an audio message as a reminder for his medication period. Although a cabinet is

used here to store medicine, it does not show any connection with Augmented Reality. Augmented Reality is used here to remind people with poor memory about the contents of drawers.

Deep-cARe is built with the aim of reminding the elderly about some of the forgetfulness that happens in their daily life (Park et al., 2019). Deep-cARe detects medications for the elderly and displays the time to take the medication through the projector. A notification is made by sound alarm when the medicine should be taken. By studying the person's motion, Deep-cARe tells them to close the windows if they are open, if he/she is ready to leave the house. Object detection and Deep Learning techniques are used to detect medication and motion. Projection-based Augmented Reality is used to remind the person of various things.

MedVision has developed an assistive medication management system to improve medication adherence among visually impaired people (Farhadyar, 2018). MedVision is a case of using an IoT based medicine box to manage medicines for visually impaired people. This system consists of three parts. RFID device for identification of medications, mobile application for management of the medications, medication box for locating the pills or capsules and providing vibration alerts for each compartment as an identifier for scheduled medication. Identifying medication, prescribing medications, providing medication information, warning and reminding when to take medications, informing when drug errors occur are primarily done by MedVision. MedVision introduces an IoT based medication box to store medication. Here the reminder voice recording is provided through the mobile application. When medication errors occur, they are given by recorded voice. Vibration alerts are applied to each compartment of the medication box so that the correct compartment can be identified. All medicines dispensed by the pharmacy are registered in a SQLite database by a family member of the visually impaired user through the mobile application. The RFID device and the mobile phone are connected to each other via Bluetooth. Data is not directly exchanged between the medication box and the RFID device, but during the medication registration process, the mobile application determines and applies the compartment number of the medication box. The vibration motor in the desired compartment is activated at the appointed time to take the medicine, which helps the visually impaired person to find the medicine quickly. Mobile application user interfaces and the RFID device are used for visually impaired users to identify medicines and access medicine information. The mobile application can provide touch input so that visually impaired people can easily manipulate it.

'Smart pillbox for visually impaired with audio reminders using IoT' is a pill box developed using IoT for storing medicine pills. The main purpose of this smart pill box is to help visually impaired people to take their medicines individually. It contains nine pillboxes (Prakruthi et al., 2022). They are numbered in Braille on the top of the pill box. Here, the doctor will send the number of the container containing the pills, the relevant date and the time of taking the medicine through SMS. The message sent by the doctor can be read by the GSM module installed in the pill box. The medicine box will open at the time specified in the message. A speaker has been added to give the patient an audible reminder when it is time to take the medication. This reduces patients' dependence on others to remind them to take their medication.

MedGlasses is a system for people suffering from chronic diseases to identify pills and remind them when to take medicine (Chang et al., 2020). Augmented reality is not used here. But it is designed for visually impaired people. MedGlasses introduces an AI-based intelligent pill identification box to identify medications for chronically visually impaired patients. MedGlasses uses a predefined training model to identify pills. The QR code on a medicine package is scanned using the mobile device app to obtain the associated medication information for a visually impaired chronic patient. This information is stored in a cloud database. The pill recognition box retrieves this information. When the medication time arrives, the patient will be reminded to take his or her medicine by a voice prompt from the proposed drug pill recognition box. At this time, the patient will place the selected drug pills in his or her hand and press the camera button on the proposed smart glasses to take a drug pill image, which is then transmitted to the drug pill recognition box. Hence the correctness of the medicine is confirmed.

Medicine mobile app built for visually impaired people in Thailand (Nimmolrat et al., 2021). It is called the 'Ru Tan Ya' application. 'Ru Tan Ya' users can get the details of the medication by scanning the barcode of the medication. Relevant messages are given to the user as an alert notification to take the medicine when it is necessary to take the medicine. 'Ru Tan Ya' helps users search for local pharmacies and find a map of the nearest one. A record of an individual's medication history is maintained for further treatment or monitoring. Maintains a personal medical database for future use for visually impaired users.

A comparison table related to the related works mentioned above is shown in Table 2.1 below.

Table 2.1: Comparison Table

Reference	Key Features/Aspects	Research Gap Identified
Khan et al., 2018	Medication identification, Dose frequency, Reminders	Not focused on guidelines on drug storage and not focused on retrieval, as well as a lack of focusing on Informing about the expiry date too.
Rupa et al., 2021	Medication identification, Description of the medication	Not focused on guidelines on drug storage and not focused on retrieval, as well as a lack of focusing on informing about the expiry date too.
Xu et al., 2016	Medication identification, Dose frequency, Reminders	Not included storing medication.
Guerrero et al., 2019	Medication identification, Dose frequency, Monitoring the movement of taking the medicine, Indicates the time to take the medication	Lack of focus on retrieval as well as guidelines on drug storage.
Ingeson et al., 2018	Medication identification	Lack of focus on retrieval as well as guidelines on drug storage.
Ghorbani et al., 2019	Reminders	Not included medication identification and informing about the expiry date.
Park et al., 2019	Medication detection, Indicates medication schedule	Lack of focus on retrieval as well as guidelines on drug storage and retrieval.
Farhadyar et al., 2018	Medication identification, Reminders,	RFID device is required for identifying the drugs, lack of

	Identify medication errors, Touch input, Storage, Identifying the location of the storage	guidelines on drug storage, lack of guidelines for refilling medication and proper use of medication, and not providing the information regarding the expiry dates.
Prakruthi et al., 2022	Storage, Identifying the location of the storage, Reminders	Not contain medication identification, not focused on informing about the expiry dates, and not guiding for refilling medication and proper use.
Chang et al., 2020	Identify pills, Reminders, Correctly identify number of pills	Not focused on guidelines on drug storage and not focused on retrieval, as well as a lack of focusing on Informing about the expiry date too.
Nimmolrat et al., 2021	Medication identification, Reminders, The nearest pharmacy is shown	Not focused on Guidelines on drug storage and not focused on retrieval, as well as a lack of focusing on informing about the expiry date too.

Existing research shows that Augmented Reality (AR) has been primarily used in medication management to identify medications, display dosage frequency, and present medication details. However, a notable research gap exists in the application of AR for guiding the storage and retrieval of medications in a medicine cabinet. Additionally, AR has not been leveraged to provide detailed medication usage instructions in the user's native language. This proposed research aims to fill these gaps by developing a new medication management system tailored for elderly individuals.

CHAPTER 3

METHODOLOGY

This can be termed as creating innovative artifacts using improved technology and scientific knowledge to solve problems related to medical management of the elderly. Therefore, the methodology should use here is the design science research methodology (Brocke et al., 2020). This design science research methodology process includes six steps: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation, and communication (Brocke et al., 2020). This is as shown in Figure 3.1.

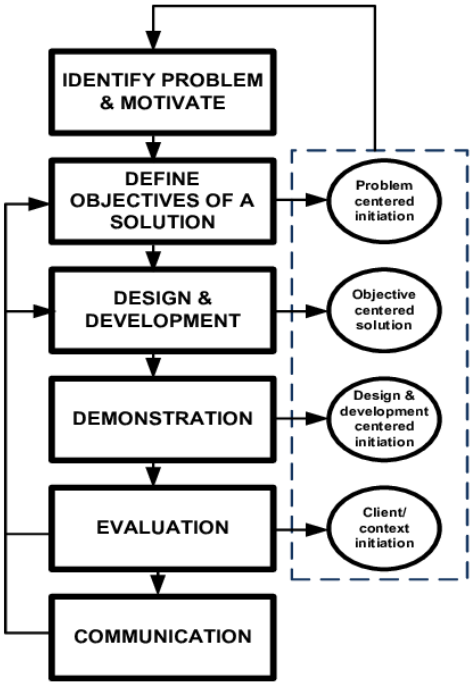


Figure 3.1: Design Science Research Methodology process. (Azasoo and Boateng, 2015)

3.1 Step 1. Problem Identification and Motivation

The initial stage of determining a significant problem is to identify an existing gap and then demonstrate why solving the proposed problem is crucial (Hevner et al., 2004). By clearly stating and developing the research problem, a focus for the research is established.

A common issue within residential facilities is the proper management of medications among the elderly. Research indicates that, on average, 54% of older adults report taking four or more medications daily (Kirzinger et al., 2019). Proper medication management among the elderly is essential due to age-related bodily changes that heighten the risk of adverse drug reactions (Lavan and Gallagher, 2015). Such adverse effects frequently lead to secondary issues, necessitating higher levels of care, which can be both costly and detrimental to patient outcomes. Research indicates that adverse drug events in the elderly not only raise the risk of morbidity but also account for 10% to 30% of hospital admissions (Parameswaran Nair et al., 2016).

Poor home management of medications involves inadequate drug storage practices, the absence of a medication administration schedule, using drugs from multiple prescribers, taking discontinued or expired medications, using medicines that are no longer needed, and taking over-the-counter medications that are unsuitable for their condition (Shrestha et al., 2019). More than 50% of US adults fail to take their prescriptions as prescribed, leading to 33%–69% of hospital admissions and 125,000 deaths annually (Lo et al., 2020). Given the higher prevalence of prescription drug use among middle-aged and older adults, promoting medication adherence is particularly crucial for these age groups. Home medication storage location and the use of digital health devices are two factors believed to enhance medication adherence (Frontiers in Digital Health, 2022).

The problems faced by elderly individuals in medication management are multifaceted. Forgetfulness, accidental double dosing, difficulty reading medication labels, and improper storage of medication are common issues. These difficulties impair medication adherence and put patients at risk for health problems such as drug poisoning and allergic reactions. Moreover, applying eye medication correctly can be daunting without proper guidance (Christopher et al., 2022).

Proper in-home drug storage involves keeping medications in a secure location, maintaining their original packaging and information, and disposing of expired medications. Improper storage practices, such as using incorrect packaging or retaining expired drugs, can lead to accidental poisoning and toxicity. These unsafe practices pose a threat to patient safety and can increase healthcare costs. Furthermore, improperly stored drugs can harm users' health. Therefore, adhering to in-home drug storage standards is essential. Despite the recognized importance of proper storage, compliance is often lacking. Studies have shown that only about half of older adults follow in-home drug storage standards in the Netherlands (51.2%) and Nepal (51.3%) (Vlieland et al., 2019). Additionally, a significant proportion of adults in the United Kingdom (63.8%) and Brazil (52.9%) store medications in kitchens, where temperatures are too high, while many adults in Qatar (19%) keep drugs in bathrooms, which are too humid (Lo et al., 2020).

So, the motivation behind this research is the problems faced by elderly individuals in medication management.

Therefore, it is essential to store medicines in the correct place (Makmor et al., 2017). Also, medicine usage is a task that must be done correctly. For this, these elderly people need proper guidance. Therefore, there is a need for an innovative medication management system.

3.2 Step 2. Define the Objectives for a Solution

This step will attempt to resolve the above stated problem-solving objectives with an information system (Peffers et al., 2007). Achieving goals requires implementing the needs belonging to the artifact (Hevner et al., 2004). An artifact can be considered a solution only if it achieves all the requirements. So technology is developing rapidly. A solution using these advanced technologies is introduced to solve the above-mentioned problems faced by elderly people in managing medication. Based on the analysis of medication management challenges and supporting theories, it is concluded that an IoT-based medicine cabinet, combined with an Augmented Reality (AR) mobile application, offers a comprehensive solution. This integration addresses critical issues such as medication adherence, real-time monitoring, user-friendly interaction, and effective guidance. The IoT cabinet ensures secure storage and timely reminders, while the AR app provides clear visual instructions, helping users, especially the

elderly, manage their medications accurately. This solution leverages the strengths of both technologies to create an efficient and supportive medication management system, aligning with the goals of improving health outcomes and user experience (Brown and Bussell, 2011). The following will go into further detail about the objectives and details of the system.

This mobile application is designed to fulfill several key objectives. Firstly, it aims to accurately identify medications and provide clear instructions on their proper usage. And also, it ensures users are aware of the correct dosage to be taken and provides timely reminders for medication intake. Moreover, if the user uses a drug that needs to be refilled, the app explains how to do it, and notifies users of expiration dates to ensure safety and efficacy. Importantly, users can input allergy information into their profiles, allowing the app to alert them if they unknowingly attempt to take medications, they are allergic to in the future, thereby enhancing their overall safety and well-being. And also, will be provided touch and voice input capabilities for user convenience.

Storing medicines in a cabinet is essential to maintain their efficacy and safety. According to the World Health Organization (WHO), proper storage conditions for pharmaceuticals are critical to prevent degradation caused by environmental factors such as temperature, humidity, and light. A medicine cabinet provides a controlled environment that helps in maintaining the stability of medications, ensuring they remain effective until their expiration date (Lo et al., 2020). Furthermore, it prevents contamination and restricts unauthorized access, which is crucial for safety, particularly in households with children. Following WHO guidelines on good storage practices is important to ensure that medicines are kept in optimal conditions, thereby preserving their quality and effectiveness (Model guidance for the storage and transport of time-and temperature-sensitive pharmaceutical products, 2011). Therefore, medicines are best protected when kept in a medicine cabinet. Because provided voice and touch input features, will provide better user experience (Tubin, Rodriguez and Carolina, 2021). By guiding the correct route for storing and retrieving medicines through the mobile application, it provides better reliability to the user. Prototype performs well because it is always quick to react.

3.3 Step 3. Design and Development

The next step in our design science research process is to design and develop a concept. In the subsequent phase of our Design Science research process, our focus shifts to the design and development of a conceptual solution. Building upon the previously defined objectives, this section aims to illustrate the seamless integration of these objectives into the design and development stages. The design phase entails a comprehensive understanding of the domain under study, coupled with the application of pertinent scientific and technical knowledge. Simultaneously, the implementation of features serves as a tangible manifestation of the viability of the constructed concept, offering valuable contributions to both developers and researchers within the Augmented Reality with IoT domain.

The development focus on establishing the feasibility of the concept rather than achieving a fully operational solution. To construct this feasibility, the development efforts will revolve around creating models that highlight essential components and showcase their interactions within a system architecture. This will be reflected in the formulation of a system architecture, reinforcing the overall concept and facilitating its demonstration in a tangible format. As outlined in the methodology chapter, the structured nature of this chapter aims to provide a clear process for researchers and developers, ensuring a standardized approach for conducting similar studies.

It is necessary to connect Augmented Reality and IoT while developing the proposed prototype. Meanwhile, it is also important to build user interfaces that strengthen the interaction between user groups and the prototype (Miranda et al., 2015; Kang, 2014). These components serve as the foundation of the system. When designing the system architecture, the connections between various components are delineated to facilitate interaction among diverse user groups.

According to the proposed prototype type, will introduce a medicine cabinet for medicine storage using IoT and provide instructions to properly pack, receive and manage their medicine through an Augmented Reality mobile application.

Wil be hoped to develop this phototype under two main parts. Firstly, hoped to create an Augmented Reality based mobile application. Secondly, hoped to create a prototype of a cabinet for storing medicine.

3.3.1 Technologies and Tools

Finding technologies and tools to create an Augmented Reality based mobile application is very important.

Firstly, a suitable programming language had to be chosen to develop this mobile application. Have to develop an Augmented Reality based mobile application, so used the unity game engine, which is easier to develop and used by more people in Augmented Reality related development. And Unity seems to have mastered the art of cross-platform development regarding AR. It allows the integration of custom AR development environments on top of its own framework to allow simultaneous developments for different platforms. Furthermore, like many other development environments, some high-level features may take time to understand, but Unity has maintained a highly simplified interface without compromising on other factors. The modular representation of each feature enables users to study and utilize them independent of other features and allows them to develop rapidly and iteratively. Also, Unity has garnered a massive community online. While there is documentation for all the various parts of Unity, the community can be an ideal part of a framework as some of the capabilities within it may be undiscovered. The large community base for Unity allows its members to access help whenever they require it as well as gain tips and tricks on how to navigate various components of AR development. Unity is based on C# which is why C# programming language had to be selected to develop the mobile application.

Figure 3.2: Unity Engine (Vox-cdn.com, 2024)

When choosing an appropriate Augmented Reality SDK, one should choose an SDK that is easy to develop and has a cloud database that is freely available. AR SDKs offer pre-built functionalities designed to speed the development process. Instead of starting from scratch

when creating AR features, developers can utilize tools and modules provided by an SDK. The AR SDK consists of tested tools and libraries that ensure the AR features will be reliable, robust, and less susceptible to bugs than ever. Vuforia SDK was used to develop the Augmented Reality part of this mobile app because it is easy to use, developer features are available for free, and has a high community. Then the developers can use this SDK to reduce the problems faced in the development related to Augmented Reality.

Figure 3.3: Vuforia Augmented Reality SDK (Githubusercontent.com, 2024)

Had to choose a database to store the data about the medicines. There has decided to choose a database that can be easily used without hosting. Accordingly, firebase was chosen to store the data. Firebase Realtime database allows applications to approach cross-platform data within Realtime after joining NoSQL cloud-storage. This Realtime database also enables us to work without internet connectivity. Even data is still being cached in the memory of our device when offline and start synchronizing after the internet connectivity. Besides, the integration of Firebase Authentication feature also deals with the data security concerns of users. When use a Realtime database, can be set the data permissions, which is another great advantage of using Firebase. NoSQL cloud-storage as well as Fire Store is in the Firebase. It's a RDBMS so can be used both according to the requirements. Also, if need to implement the push notifications, then can develop them on Firebase without any difficulties. Using these technologies, the foundation was laid to develop the Augmented Reality based mobile application.

Figure 3.4: Firebase (Gstatic.com, 2024)

Finding relevant technologies, tools and materials to create a prototype of a cabinet that can automatically open doors for storing medicine.

It was decided to use Chip board which is a light type of board to create Cabinet. Very light and thin plastic is used for the doors. The doors should open automatically, and the cabinet should be connected to the mobile app, so it was decided to do this using the Internet. An internet enabled module was required to connect the cabinet to the internet and capture an input from the mobile side of the cabinet. A NodeMCU ESP8266 module was used for this. Because the NodeMCU is chosen as a cost-effective and versatile platform for IoT applications, contributing to cost reduction in the overall system. With built-in WiFi connectivity, it enables remote monitoring and control of the entire system, offering a high level of flexibility. The expandable nature of NodeMCU, coupled with easily extendable firmware, makes it adaptable to various applications. In this context, the NodeMCU functions as the communication device, ensuring smooth and seamless interaction between microcontrollers, servo motors, and the node-server.

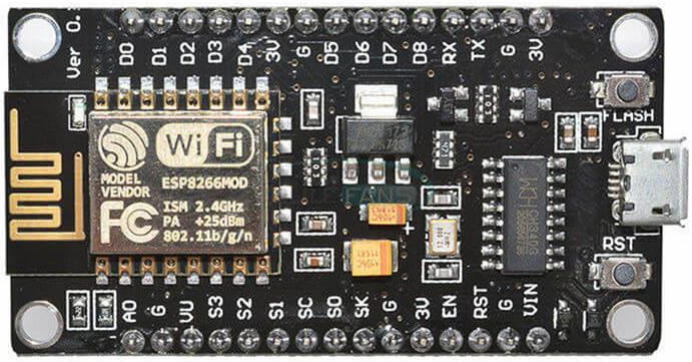


Figure 3.5: NodeMCU ESP8266 (Flixcart.com, 2024)

It was decided to use a motor to open the cabinet doors automatically. Hence, servo motors were used for this purpose. Servo motor is a rotator device that allows the control of angular as well as linear motion. Its drive transmits electrical signals to the servo motor to produce motion.

Figure 3.6: Servo Motor (Robocraze.com, 2024)

This cabinet has many doors. Therefore, more servo motors are needed to open those doors. But only a limited number of servo motors can be directly connected to the NodeMCU selected. PCA9685 Servo motor Driver 16 Channel 12-bit PWM is used as a solution to this problem. The PCA9685 16-Channel Servo Driver is a device that allows you to control multiple servo motors using a single I2C interface. It uses an onboard PWM controller to generate the pulse width modulated (PWM) signals required to drive the servo motors and can control up to 16 servos at the same time. One of the benefits of using the PCA9685 16-Channel Servo Driver is that it allows to control a large number of servos using a single I2C interface, which can save on the number of pins required on the microcontroller or another control device. Additionally, can connect multiple PCA9685 drivers in a chain, allowing to control up to 992 servos using just two I2C pins. Therefore, used this PCA9685 Servo motor Driver 16 Channel 12-bit PWM to open multiple doors in the cabinet.

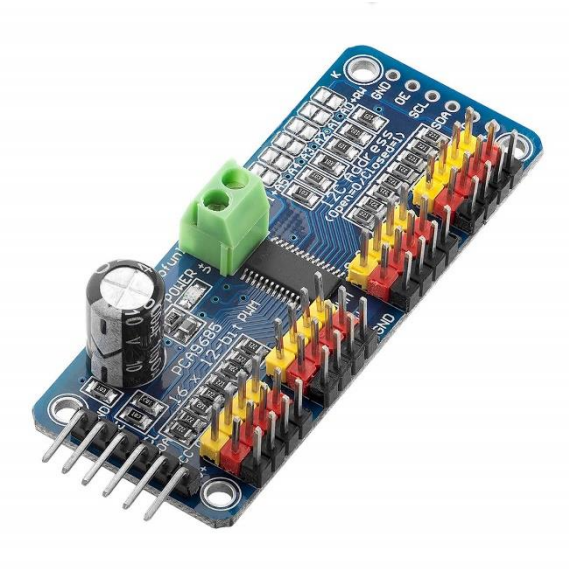


Figure 3.7: PCA9685 16-Channel Servo Driver (Alicdn.com, 2024)

A command given by the mobile app cannot be received directly by the NodeMCU. As a solution to this, hosted a NodeServer and connect the mobile application and the NodeMCU to that server. Here data is passed from mobile to NodeMcu by Socket IO. Socket.IO allows bi-directional communication between client and server. Bi-directional communications are enabled when a client has Socket.IO in the browser, and a server has also integrated the Socket.IO package. While data can be sent in a number of forms, JSON is the simplest. To establish the connection, and to exchange data between client and server, Socket.IO uses Engine.IO. This is a lower-level implementation used under the hood. Engine.IO is used for the server implementation and Engine. IO-client is used for the client.

Figure 3.8: Socket io in Nodejs (Genius, 2022)

The system architecture related to the proposed prototype was created using the technologies and tools found. This emphasizes how each user group within the platform benefits from the proposed solution. This can be clearly seen in the system architecture of the proposed prototype. This is as shown in Figure 3.9.

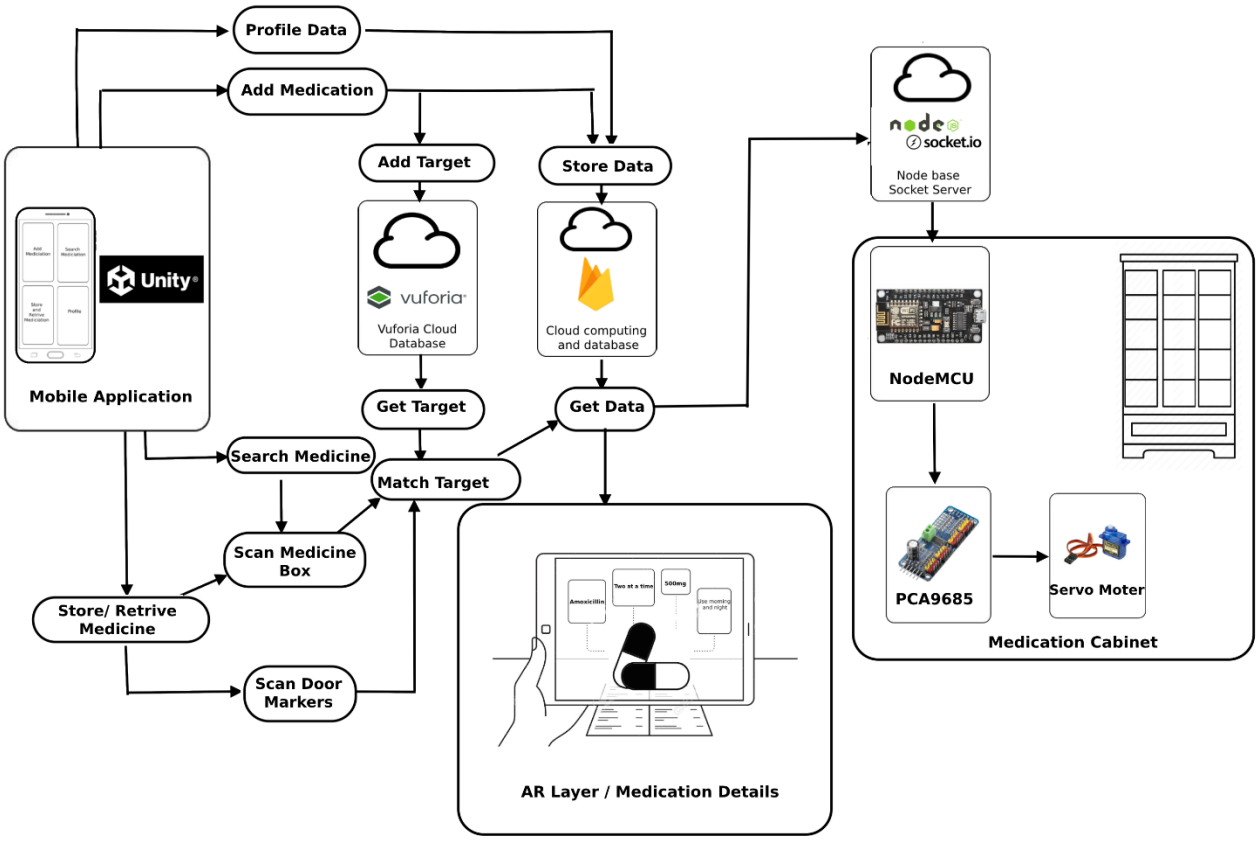


Figure 3.9: System Architecture

3.3.2 Development of mobile application prototype

According to the system architecture, the mobile application should be developed first. This mobile application is used by caregivers and elderly people. The mobile application is developed under four main parts. Adding a medication, searching for a medication, storing and retrieving a medication, and maintaining the user profile belong to these four parts. This is as shown in Figure 3.10.

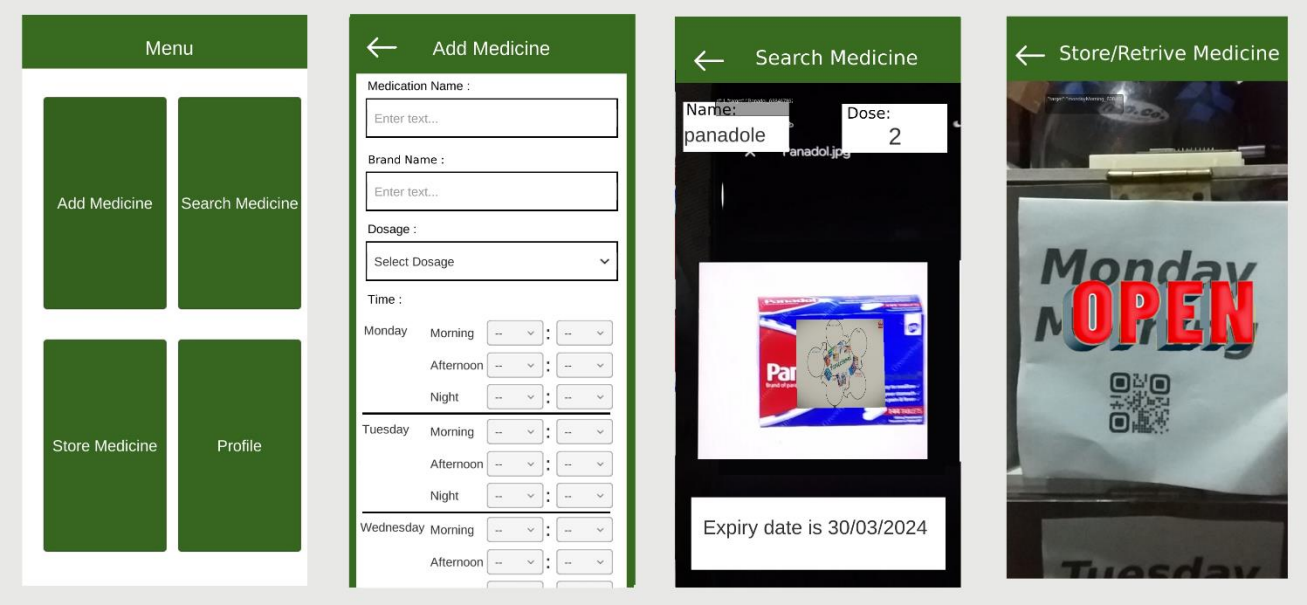


Figure 3.10: UI Models

Adding Medication

The add medication part is a task that needs to be done correctly by the caregiver. Here the caregiver can enter the details of the medication. In here should include the name of the medication, the dosage to be taken, the time to take the medicine, an image of the medicine box, and a video or audio with instructions on how to use the medicine. And if there is an expiry date for the medicine, the expiry date and what disease the medicine is used for also need to be included. Have stored the data that are related to the medicine in the firebase database.

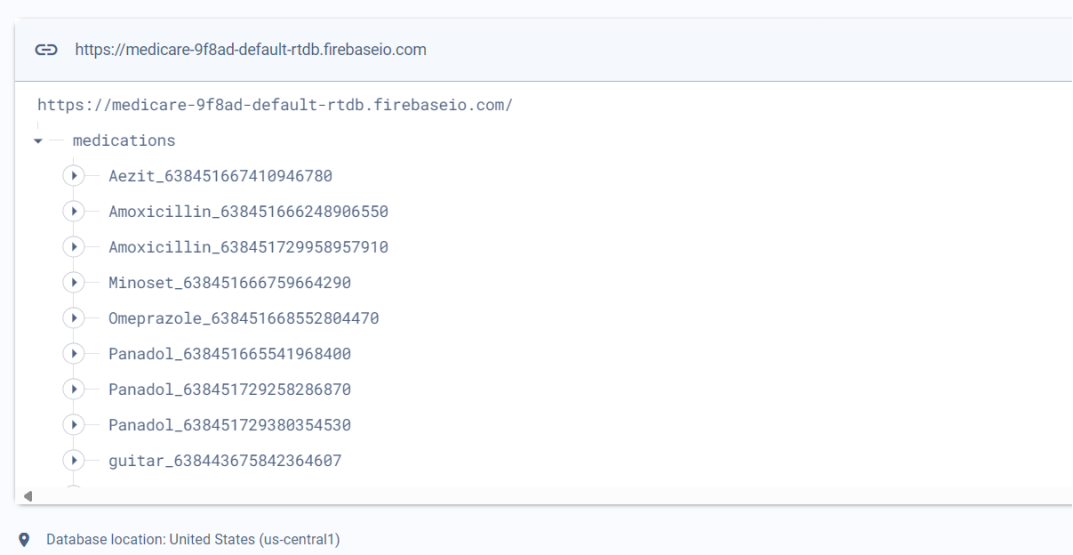


Figure 3.11: Firebase Database

After that, have stored the image of the medication box which is related to the medicine in the Vuforia cloud database using the Vuforia API. This image has been considered as the target image for Augmented Reality. Vuforia has a suitable standard for uploading images. File must be 8- or 24-bit PNG or JPG. JPG must be RGB or grayscale. Maximum size is 2.25MB. Images must be uploaded in accordance with these restrictions.

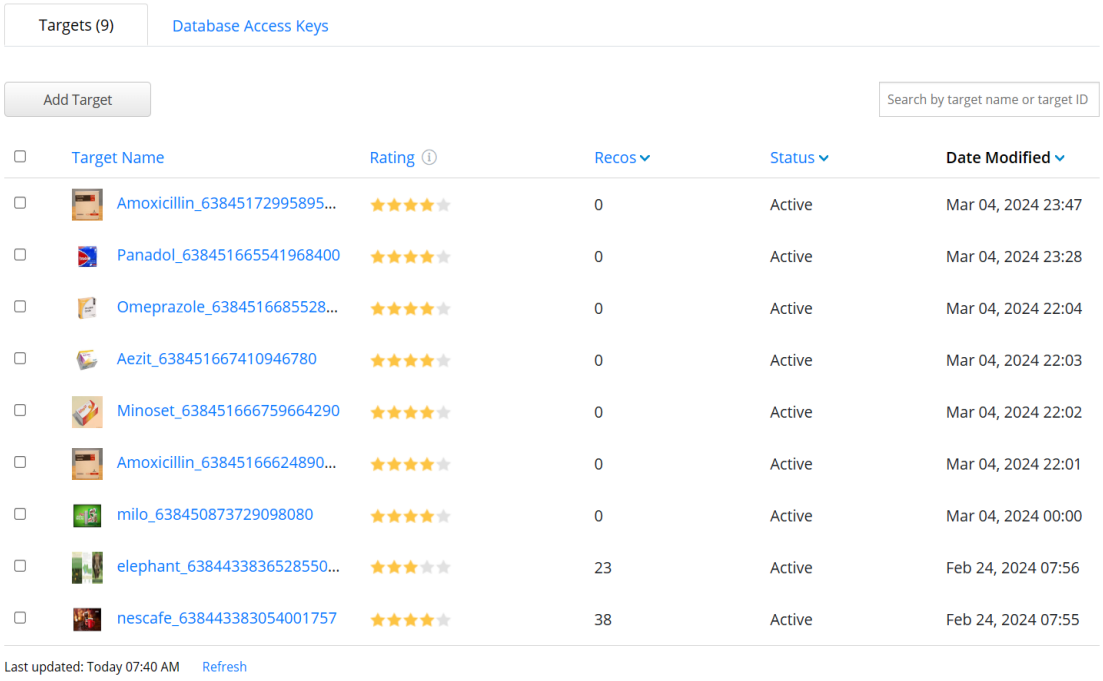


Figure 3.12: Vuforia Cloud Database

Searching Medication

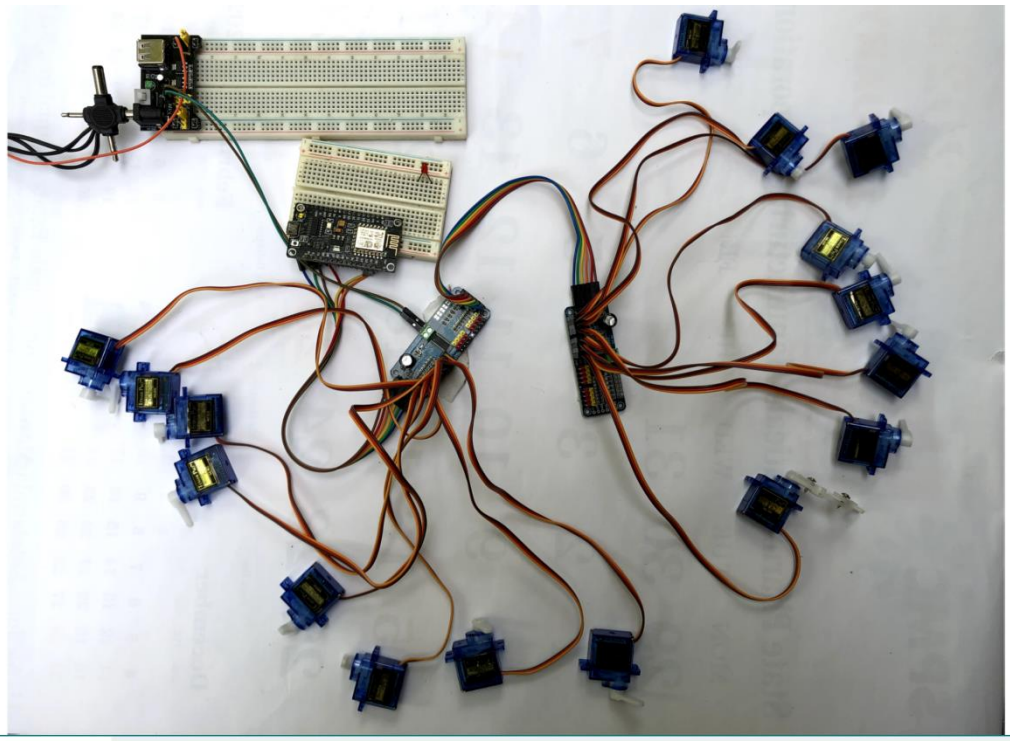
The Search Medication section of the mobile application is used by the elderly person to get details of the medication. It contains a scanner. Elderly person should scan the medication box related to the medications previously entered in the database by the attendant using the scanner in the search medication section. Then will be given the name of the medication, the dosage to be taken and the details of how to take the medicine in the form of Augmented Reality through Audio or Video. After retrieved the medicine details, edit details and delete features will be enabled.

Storing and Retrieving Medication

The store and retrieval section are used by caregivers or elderly people to store medications in the cabinet. An elderly person must interact with this section while retrieving medicine from the cabinet. This section of the mobile app also contains a scanner. Caregiver or elderly person needs to scan the medication box related to the previously collected medicine while storing the medicine in the cabinet. Then the name matching the scanned image with the image of the medicine box in the Vuforia cloud is obtained from the Vuforia API. The dates and times should store the medicine related to that name are obtained from the firebase. After that, need to pass those data to the cabinet side. But the cabinet doesn't have the ability to access these data directly.

Connecting Mobile Application prototype with Medication cabinet prototype

Because of that, used the node server to connect the mobile application and the cabinet. For that, have to host the node server and sent these data to that node server through the Socket IO. After that, built the cabinet with providing the ability to access these data. For that, have attached a NodeMCU in the cabinet. Then every time, it keeps a listener to our node server. From that, can be obtained the data which are passing from node server to NodeMCU.



sketch_jan25a.ino

```
#include <Wire.h>
#include <ESP8266WiFi.h>
#include <ESP8266HTTPClient.h>
#include <ArduinoJson.h>
#include <Adafruit_PWMServoDriver.h>  //Include the PWM Driver library

const char* ssid = "Dialog 4G 626";
const char* password = "8Fc3e1ED";

Adafruit_PWMServoDriver pwm1 = Adafruit_PWMServoDriver(0x40);
Adafruit_PWMServoDriver pwm2 = Adafruit_PWMServoDriver(0x41);


void setup() {

  Serial.begin(115200);  // Start the serial monitor.
  delay(10);             // Give it a moment.

  pwm1.begin();
  pwm2.begin();

  pwm1.setOscillatorFrequency(27000000);

  pwm2.setOscillatorFrequency(27000000);

  pwm1.setPWMFreq(60);
```

Output Serial Monitor ×

Message (Enter to send message to 'NodeMCU 1.0 (ESP-12E Module)' on 'COM5')

```
{"hello":{"A":false,"B":false,"C":false,"D":false,"E":false,"F":false,"G":false,"H":false,"I":false,"J":false,"K":false,
State value: 0
We got a repsonse!
{"hello":{"A":false,"B":false,"C":false,"D":false,"E":false,"F":false,"G":false,"H":false,"I":false,"J":false,"K":false,
State value: 0
```

Figure 3.13: Hardware Configuration

3.3.3 Developing Medication Cabinet prototype

When building the cabinet, have settled the twenty-one chambers for storing the medicine separately in each chamber for a week as morning, afternoon and night.

Have attached the servo motors for every chamber to open the doors of them automatically. Because of that, in here, had to use twenty-one servo motors, due to that, was an issue is that how to connect those twenty-one servo motors to NodeMCU. The reason is for that there are not enough pins in NodeMCU to connect them. After done some investigations, found the way for resolving that. So, used two PCA9685 servo motor drivers as the solution. Then connected those two with NodeMCU. After those, will be executed the servo motors that are related to those dates and the times according to the data that are passing from mobile app to NodeMCU.

Opening the door of the cabinet

A marker is placed on the doors of all chambers of the cabinet. The markers are stored in the Vuforia Cloud Database. The time that wants to take medicine will be informed through the alarm which is attached to the cabinet to elderly person. Then the door of the chamber that is related that date and the time will be opened automatically when scanning the markers of doors in the cabinet with going to the retrieve medication section on the mobile app. In here, as previously, from matching the image that is included in Vuforia cloud with the marker that is included in the door, will obtain the name of that using Vuforia API. Then after, from the Firebase getting the date and the time that are related to that name, will pass these data to the node server. The door will be opened which is related to the day and the time which are obtained from the NodeMCU that is keeping a listener to the node server. From this procedure, elderly person can be found right place which includes the relevant medicine.

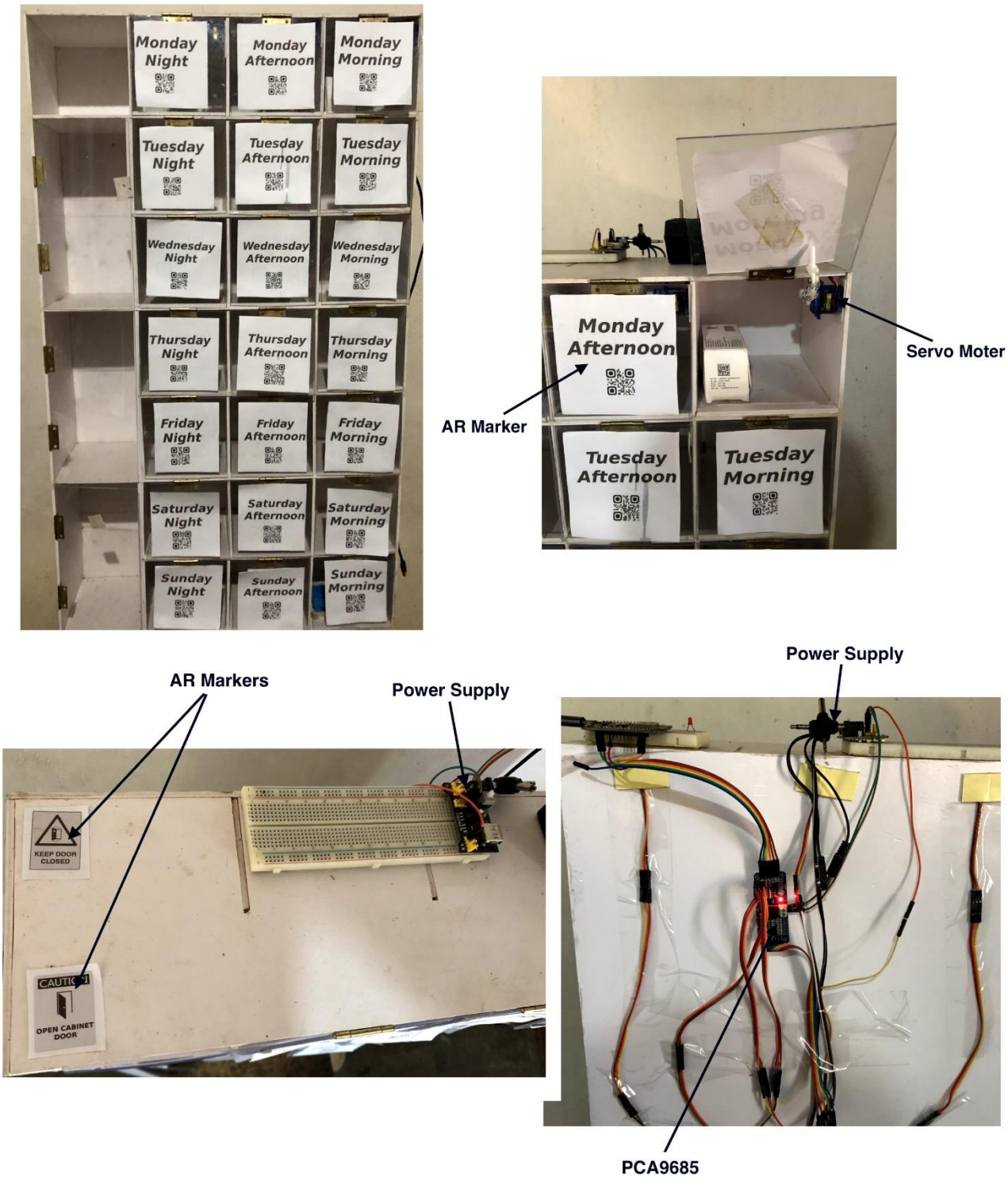


Figure 3.14: Medication Cabinet

The profile of the mobile application

The profile section of the mobile application is used by the caregiver. A patient profile is maintained here. If the patient has previous diseases, they can be included here. If the patient has been allergic to any medication in the past, the details of that medication can be entered here. Prescriptions related to the patient's existing ailments can be stored here. All data related to this section is stored in firebase.

Accessibility of the prototype

Accessible design should be used because the mobile application is used by elderly people. Mobile app accessibility means making mobile software functionality easy for everyone to use, regardless of their ability level (Davydov et al., 2023). Mobile application accessibility is grounded in four key principles, ensuring that the content is perceivable, operable, understandable, and robust (Davydov et al., 2023). The principle of perceivability emphasizes the presentation of information and UI components in a manner that is easily understandable for users. The operability principle focuses on making UI elements and content navigable, ensuring that users can interact with the application effortlessly. Under the principle of understandability, content should be intelligible and readable, while the application's functionality should follow predictable patterns. Lastly, the robustness principle requires that app content is easily interpretable by various users and compatible with assistive technologies, promoting inclusivity and a seamless user experience for individuals with diverse needs and abilities (Davydov et al., 2023).

The above key principles as well as the below guidelines are important for improving the accessibility of the prototype.

Touch and pointer target sizes and Target spacing.

An icon should appear to be 24 x 24dp. And also, the padding surrounding it should comprise the full 48 x 48dp touch target. The target size for touchscreen elements should be 7-10mm. The target size for pointers should be 44 x 44dp. The targets should be separated by 8dp of space (Material Design, 2023).

Color & contrast

Contrast ratios represent how different one color is from another color, commonly written as 1:1 or 21:1. The greater the difference is between the two numbers in the ratio, the greater the difference in relative luminance between the colors. The contrast ratio between a color and its background ranges from 1-21 based on its luminance (the intensity of light emitted) according to the World Wide Web Consortium (W3C) (Material Design, 2023).

Text resizing

Background - People with low vision or those who prefer large text must be able to scale up the size of text in a UI. This adjustment is often performed through a device OS setting or in-app option. UIs should support a minimum text increase of 200%. Most components should behave the same when text is resized (Material Design, 2023).

3.4 Step 4. Demonstration

Design Science research aims to assess the effectiveness of an artifact in solving a problem, recognizing that pure theorizing may not sufficiently demonstrate why the artifact functions or its efficacy as a solution (Hevner et al., 2004). The artifact will be exhibited to demonstrate its capacity in addressing one or multiple instances of the problem, as described by Peffers et al. (2007). Hevner et al. (2004) also suggest utilizing descriptive methods for innovative artifacts. The descriptive approach would manifest as a well-informed argument, wherein the pertinent collection of primary data will bolster a compelling case for the utility of the artifact. Moreover, the presentation of the artifact through constructed scenarios will showcase its practicality.

Before doing the demonstration, came up to these hypothesizes. Therefore, adding medication to this system should be done by the caregiver. He should also add all the details about the doses to be taken and the times to be taken. caregiver should upload videos, audios to be augmented. For this, assumed that the caregiver has clear knowledge and that he performs the task correctly. Furthermore, assumed that the internet connection is stable during the executing interactions between the mobile application and the medication cabinet.

When demonstrate regarding this prototype, there are two user roles, Such as caregiver and elderly person. For the demonstration, assumed following scenario. According to that scenario, the elderly person wanted to take medicine for a week for some sickness. In there, for every day of the week, some medicines are only morning and night, but some medicines are for morning, afternoon and night, some of them are for only night. So, in here, have provided to the elderly person the way for taking medicine by himself because caregiver's other works, he can't involve properly for providing the medicines to the elderly person properly.

Caregiver will add all details of the elderly person's medicines to mobile app that is provided by us. When click the app icon, app will open, then will display the menu screen.

In the menu screen, there are four buttons like add medicine, search medicine, store and retrieve medicine and the profile. Caregiver should click add medicine button to include the details about medicines. In there, has a form to add the details of the medicines. According to that form, definitely should be added a image of the medication box. And also, a video or a audio

need to be added which is included name of the medication box, the dosage, amount of the tablets for a one time, date and time of the medicine use, way how to use. After then, To the medication cabinet, have to include medicine which are related to the medication details that are include in the mobile. So, need to click the store and retrieve button on the menu. Then will be displayed new mobile UI page with a scanning UI. From that scanner, when scan the medicine box which is needed to store, Will open the door of relevant chamber of the cabinet which is related to store that medicine. Then can store the medicine properly.

Furthermore, when need to take the medicine in the proper time, an alarm will ring informing that. In that moment, the elderly person should open the mobile application and need to click store and retrieve button in there. Then will obtain the mobile page with a scanning UI. From this scanner, should scan the marker which is in each chamber in the cabinet. Then will open the door of chamber which is related to relevant date and the time and will present that date and time in verbally. Then can be find the medicine without any difficulties for proper time.

So, caregiver should maintain the profile which is related to the elderly person. For that, should be accessed to the menu of the mobile application and should be clicked the profile button. Then will be displayed the details of the elderly person. Can be edited this. For that, there is an edit button and need to click that. Then will be active the form. Using that form, can be added the details of that elderly person to the profile. And also, if that patient has got some diseases previously, then can be added them also in there. Moreover, if there are prescriptions of them, then can be added them also. And also, if he or she had faced for some allergies previously, then can be included them also.

So according to above demonstration, the aim of this was developing a prototype proving our concept with presenting the above needs as a solution for the difficulties which are facing by the elderly person.

3.5 Step 5. Evaluation

The evaluation step is to observe and measure whether the proposed solution solves the problem (Peffers et al., 2007). According to Hevner et al. (2004), demonstrating the effectiveness and efficiency of an artifact requires the implementation of thorough evaluation methods to highlight its ability to address the problem effectively. Moreover, the proposed solution will undergo testing to assess its utility by examining its compatibility with end-users, as well as its accuracy and comprehensiveness, which will ultimately determine its rate of success (Hevner et al., 2004).

The proposed evaluation strategy for the medication management system utilizes both experiment-based and opinion and interview-based approaches. The experiment-based approach focuses on two key aspects. Such as the accuracy of medication identification and medication storage and retrieval accuracy. The accuracy of medication identification is assessed by comparing the medication details provided through the Augmented Reality system with known information to ensure correctness. This method offers quantitative data on the system's performance. Additionally, the effectiveness of the IoT-based medicine cabinet is evaluated by observing participants during the storage and retrieval processes, noting any discrepancies or difficulties.

The opinion and interview-based approach centers on user experience, particularly the ease of use for elderly individuals. Feedback on the user interface, navigation, and overall experience is collected through observations and direct feedback from participants. User satisfaction is also gauged through interviews and surveys, focusing on aspects such as user comfort, convenience, and confidence in using the system. Combining these qualitative insights with quantitative data provides a comprehensive assessment of the system's overall effectiveness.

The prototype evaluation process involves participant selection, training, observation, feedback collection, data analysis, and improvement iteration. Elderly individuals and caregivers with varying degrees of impairment are selected and trained on using the prototype. Participants are observed as they use the system, and their feedback is collected through interviews and surveys. Both quantitative and qualitative data are analyzed to draw conclusions about the system's performance, leading to necessary improvements to enhance accuracy, usability, and user satisfaction.

Interview questions aim to gather detailed feedback from users and caregivers about their experience with the system. Analysis of this feedback reveals several issues, such as difficulties in navigating the mobile app, unclear instructions, small buttons, and problems with scanning medication boxes. While some participants with technical knowledge found the system satisfactory, others faced challenges. Quantitative evaluation involves measuring the time taken by caregivers to add medications and store medications in the cabinet, as well as the time between scanning markers and the cabinet door opening.

In summary, the evaluation strategy combines empirical data on system performance with subjective user feedback to provide a well-rounded assessment of the medication management system's effectiveness in meeting user needs.

3.6 Step 6. Communication

According to Hevner et al. (2004), Design Science research is expected to make clear and verifiable contributions in design methodologies or aspects of the designed artifact. The research should articulate "what are the new and interesting contributions" it brings forth. The designed artifact must embody one or more of the following qualities: novelty, generality, and significance, as outlined by Hevner et al. (2004). The communication of the problem's significance, the characteristics of the artifact, its utility, novelty, the rigor of its design, and its effectiveness is crucial. This communication should be directed towards an appropriate audience, including professionals and researchers, as emphasized by Peffers et al. (2007).

So according to the above, in this phase, intend to publicize the findings so that interested practitioners and stakeholders can learn about them. Additionally, work has been done on the thesis and the research paper for this study, which will eventually be published.

CHAPTER 4

EVALUATION AND RESULTS

The medication management system was evaluated based on a multifaceted approach that combined experiment-based and opinion/interview-based methodologies. The experiment-based methodology was selected due to its critical role in assessing the accuracy of medication identification and evaluating the practical functionality of the IoT-based medicine cabinet regarding storage and retrieval capabilities. This approach generated empirical data, enabling quantitative assessments of system performance and capturing real world usage scenarios and challenges. In parallel, opinion and interview-based methods were employed to gauge user satisfaction, ease of use, and overall system effectiveness. These qualitative approaches provided insights into subjective usability aspects and offered a holistic view of user sentiments. The evaluation involved 4 caregivers (2 females and 2 males) with ages ranging from 38 to 45. Additionally, 6 elderly participants (2 females and 4 males) aged 60 and above, including 3 government workers and 3 individuals with a normal education level, contributed to the evaluation process, providing diverse perspectives on the system's functionality and usability.

4.1 Experiment-based Approach

The experiment-based approach was centered on two primary aspects: the accuracy of medication identification and the effectiveness of the IoT-based medicine cabinet in storing and retrieving medications. The system demonstrated a high level of accuracy in medication identification, correctly identifying all ten medications out of ten scanning and providing corresponding information accurately. This accuracy is pivotal for ensuring patient safety, medication adherence, and system reliability. In evaluating the effectiveness of the IoT-based medicine cabinet's storage and retrieval, the time caregivers spent on tasks like adding a medication box and storing medication in the cabinet was measured, as illustrated in Figure 4.1. When participants retrieved medication, the time between scanning the marker on the cabinet door and opening it was recorded, as shown in Figure 4.2. Likewise, the time between scanning the medication box and opening the cabinet door during medication storage was also measured. Observations of participant interactions uncovered some discrepancies and challenges with the IoT-based medicine cabinet, such as slow or malfunctioning servo motors

and difficulties in scanning medication boxes. Although the experiment confirmed the core functionality of storage and retrieval, it also highlighted areas for improvement.

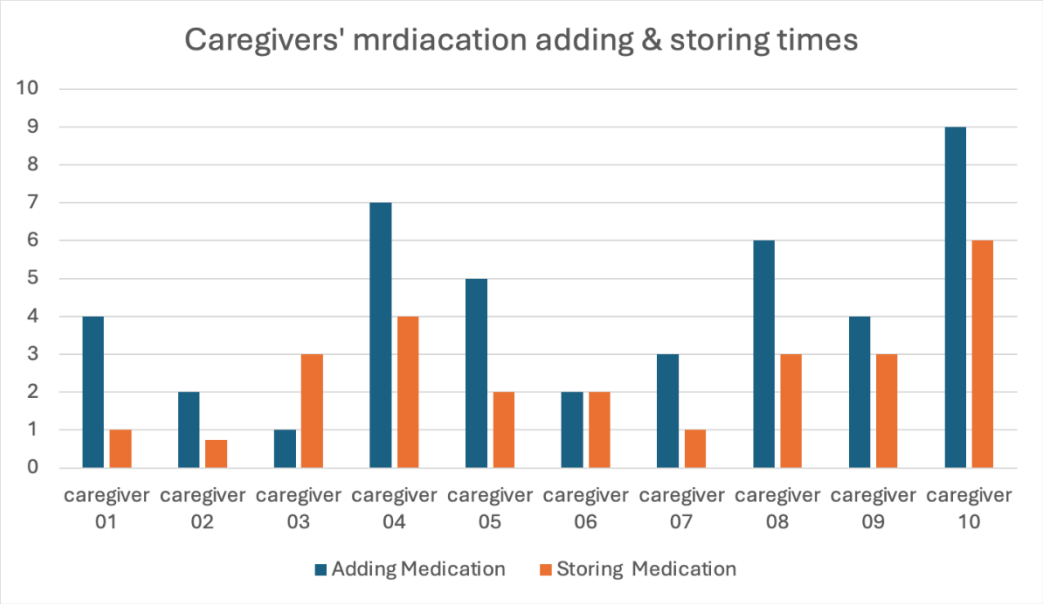


Figure 4.1: Time Spent by Caregivers on Adding a Medication Box and Storing

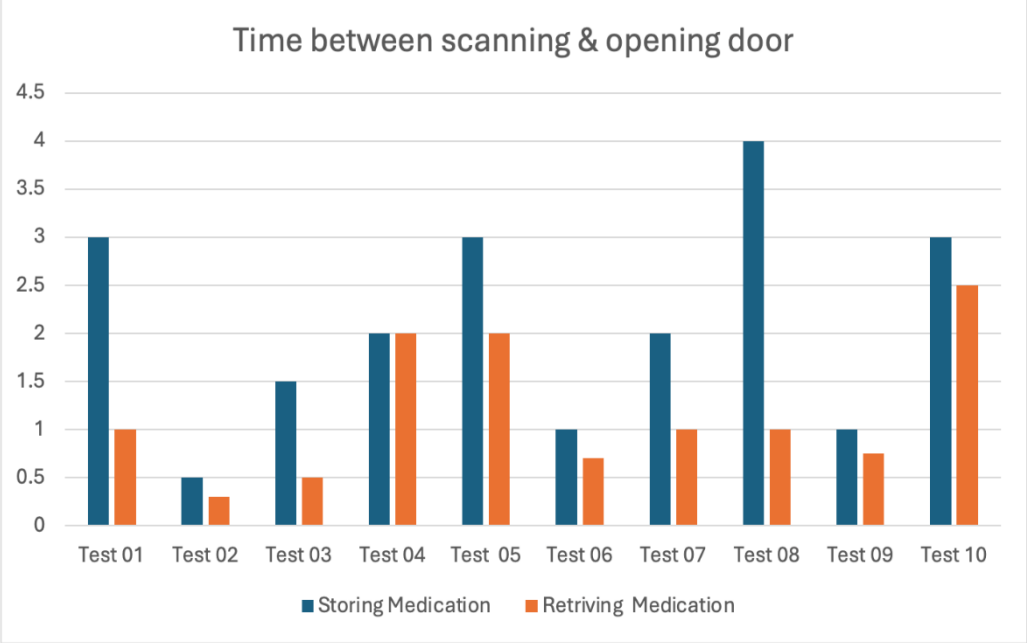


Figure 4.2: Time Between Scanning and Opening the Door

4.2 Opinion and Interview-based Approach

The opinion and interview-based methods provided valuable insights into user experience, satisfaction, and usability. This structured evaluation process encompassed participant selection, comprehensive training, observation of interactions, feedback collection through interviews and surveys, and data analysis of both quantitative and qualitative data. The iterative improvements based on evaluation findings are crucial for enhancing the system's performance and user satisfaction levels. Below are some interview questions prepared to gather feedback from caregivers and elderly individuals:

- Can you share your experience using our medication management system?
- Were there any aspects of the system that you found challenging or frustrating?
- Were there any aspects of the system you would prefer to see changed or improved?
- On a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the system?

Quantitative data from participant ratings showed a range of satisfaction levels. Caregivers' ratings ranged from 3 to 8 as shown in Figure 4.3, with some finding the system helpful and others encountering usability challenges. Elderly individuals' ratings ranged from 2 to 8 as shown in Figure 4.3, with those comfortable with technology appreciating the system's assistance, while others faced significant usability barriers. During the qualitative evaluation, the following feedback was obtained: Some individuals lacked technical knowledge, leading to difficulties while using the prototype. They found the mobile app confusing to navigate, with unclear instructions for adding medications and difficulty inputting necessary details. One individual mentioned that the buttons were too small, and the text was hard to read even with a screen reader, resulting in a less user-friendly experience. Additionally, a participant reported that the prototype did not scan medication boxes properly, hindering their ability to use the system effectively. Caregivers also noted that adding data consumed more time than expected. However, elderly participants with good technical backgrounds expressed satisfaction with the prototype, particularly appreciating the audio output through AR for medication identification. One caregiver praised the straightforward process and intuitive interfaces, highlighting the step-by-step guidance. Feedback from participants high-lighted both positive aspects and areas for improvement.

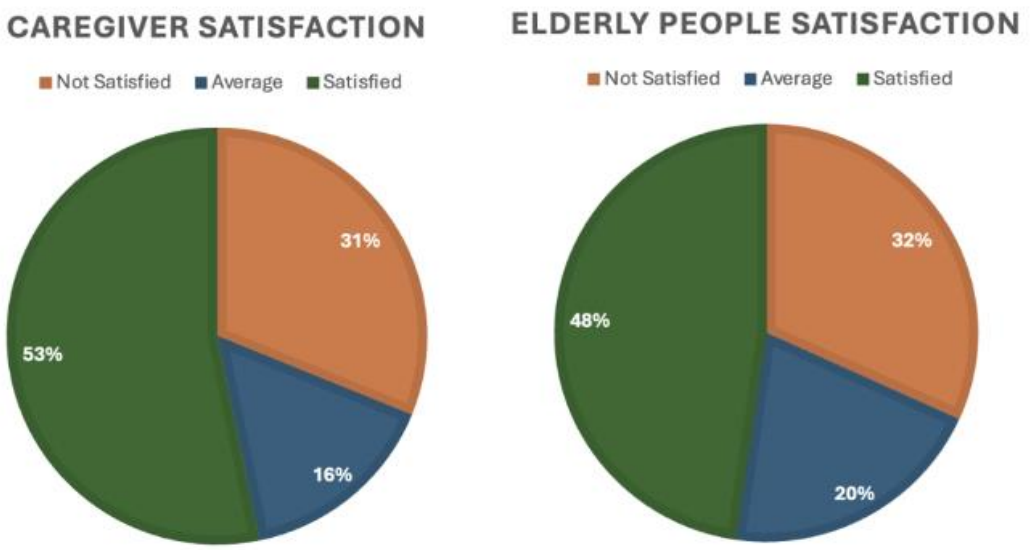


Figure 4.3: Satisfaction Levels of Caregivers and Elderly Participants

4.3 Datasets

Regarding datasets, potential use is identified for assessing medication identification accuracy and user interaction and accessibility. Public datasets containing information about various medications could be employed to evaluate the accuracy of medication identification, encompassing details such as medication names, dosages, and relevant information. Additionally, public datasets related to accessibility and user interaction in mobile applications could offer insights into best practices, containing information about user preferences, challenges faced by elderly individuals, and successful design principles. Credibility considerations involve assessing dataset reputation, relevance to the target population, cost, applicability, ethical considerations, and transparency in documentation.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

Considering the problems faced by elderly people in using, storing and retrieving their medicines, this thesis attempted to develop a sustainable solution using Augmented Reality and IoT to provide accurate guidance to those people in using, storing and retrieving their medicines.

To gain familiarity with the topic of research and construct a solid theoretical framework, a survey into existing literature within the area of study has been conducted. As the literature review shows, Augmented Reality has been used in various situations to manage medications in elderly people. According to the previous research findings, Augmented Reality was used only to identify a drug, present its details, show the drug schedule and indicate the dosage. Still Augmented Reality has not been used to provide instructions for storing and retrieving a drug. To fill this research gap, have introduced a medicine cabinet to store medicines using IoT and provide instructions to properly pack and retrieve medicines through an Augmented Reality mobile application.

In terms of the chosen research methodology, a Design Science research approach was applied, aiming to acquire knowledge and comprehension of the problem domain by developing an IoT and Augmented Reality base concept. This approach encompasses multiple phases, including problem identification, formulation of solution objectives, design and development, demonstration, evaluation and communication. The combination of Design Science research and Exploratory study techniques was deemed suitable for this thesis, providing flexibility to adapt to changing circumstances while aligning with the research goals. This approach allows for a dynamic and adaptable exploration of the chosen problem domain. This approach allows for a dynamic and adaptable exploration of the chosen problem domain.

To underscore the issues related to the research goal in achieving the research objectives, a re-examination of the literature review was undertaken during the initial two stages. The formulation of solution objectives followed, strategically designed to tackle identified issues and respond to the proposed research question. These objectives encompassed multiple goals

for each concept, accompanied by specific requirements essential for deeming the research effective in resolving the targeted problem.

In the third, sought to integrate the objectives into the design and development of the solution. Therefore, have designed the architecture in this phase. Based on the architectural design, have split the whole prototype into two parts. As hardware prototype and Mobile application prototype. After then have developed both and integrated both together. As a result of this phase, delivered the IoT and Augmented Reality based medicine cabinet.

In the Demonstration chapter, showcased key features and functionalities of the prototype system. Moreover, overall, this demonstration had aimed to provide a overview of the prototype of Augmented Reality based medication management, showcasing its capabilities in enhancing identifying the medicine as well as these functions. Such as reminding the patient to take the medicine, providing instructions to use the medicine correctly, protecting against the problems that occur when taking the medicine, and storing and retrieving the medicine. Upon revisiting the Evaluation chapter, a comprehensive analysis was conducted, aligning the research questions and objectives with the obtained results. The examination revealed that a substantial portion of the research objectives was successfully met during the course of the study. Notably, reusability and user-friendliness emerged as particularly noteworthy achievements, as these objectives were not only confirmed but further validated through in-depth interviews. The confirmation of these objectives through interviews highlighted the successful realization of key aspects outlined in the research.

To conclude, this study sought to find an answer to how the development of an IoT and Augmented Reality based product can combat the sustainable problems which are facing by elderly persons. Through the Design Science research methodology, were able to develop a prototype that sought to fill the research gap where an IoT and Augmented Reality based solution contributes to the challenges when facing by elderly persons. And evaluation shows that does deserve to be further explored.

5.2 Future Works

For future research there is a couple of things that need to be addressed.

Moving forward, in future research focus to bolster the capabilities of medication recognition through the implementation of advanced image processing and machine learning algorithms. The focus is on improving accuracy and efficiency, potentially involving extensive training on a larger dataset to broaden the system's ability to recognize various medication types, shapes, and packaging variations.

Moreover, through using pre-trained models for pill detections and expiry date detections, can be confirmed the number of pills taken by a patient and whether those pills expired or not. From this, can be increased the accuracy of the prototype.

Another future work will be the integration of the medication management system with wearable devices such as smartwatches and health trackers. This strategic integration seeks to enable real-time monitoring of medication adherence and overall health status. The potential benefits include the direct transmission of reminders or alerts to the user's wearable device, tailored to their specific medication schedule and health condition.

To address scenarios where medication details are not pre-existing in the system's database, the research will hope to develop a streamlined procedure. In such cases, when scanning a medication, the system would initiate a search for details through Google, retrieve the necessary information, and seamlessly store it in the database for future reference and display.

Another innovative aspect of the research involves the application of computer vision and sensor-based techniques to identify and track the activities of elderly individuals. This inclusion aims to enhance the system's utility by providing insights into the daily activities of users who may require additional support, thereby contributing to a more comprehensive and user-centric healthcare approach.

Furthermore, in the future research emphasizes the development of accessibility features. These include the implementation of voice-controlled interfaces and support for multiple languages, making the medication management system more user-friendly for individuals with disabilities or those who speak languages other than the default.

Lastly, research hope to underscores the importance of emergency response integration. Exploring the seamless integration of emergency response systems into the application, the goal is to enable the system to send timely alerts to designated contacts or emergency services in instances of missed doses or critical health events. This integration aims to enhance the overall safety and support mechanisms within the medication management system.

APPENDICES

Appendix 1: Interview Guide

Below is an interview guide that can be used for conducting the interviews on the proposed IoT and Augmented Reality based medication management system. The questions are designed to elicit both positive and negative feedback on different aspects of the research.

Introduction

Thank you for participating in this interview and appreciate your time and willingness to share your thoughts on the proposed IoT and Augmented Reality based medication management system. Your input is crucial in shaping the development of this system, and your feedback will contribute significantly to its enhancement. The purpose of this interview is to gather valuable insights, both positive and negative, on various aspects of the vehicle parking system. Your perspectives will play a key role in refining the design and ensuring that the system meets the needs and expectations of its users. Once again, thank you for your time and valuable contribution to the improvement of the medication management system.

Interview Questions

1. Can you tell us about your experience using our medication management system?

2. Were there any other aspects of the system that you found challenging or frustrating?

3. We'll take note of these issues and work on improving the app's usability and Augmented Reality functionality. Is there anything else you would like to mention?

4. On a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the system?

Appendix 2: Interview Transcription: Patient 1

Interviewer: Hello, thank you for agreeing to speak with us today. Can you tell us about your experience using our medication management system?

Patient1: Honestly, I wasn't very satisfied with it. The mobile app was quite confusing to navigate, and the instructions for adding medications were not very clear. I found it difficult to input all the necessary details, especially since I'm not very tech-savvy.

Interviewer: I'm sorry to hear that. Were there any other aspects of the system that you found challenging or frustrating?

Patient1: Yes, definitely. The Augmented Reality feature in the app didn't work well for me at all. It was difficult to scan the medication boxes, and even when I managed to do so, the audio instructions were often incorrect or incomplete.

Interviewer: Thank you for sharing your experience. We'll take note of these issues and work on improving the app's usability and Augmented Reality functionality. Is there anything else you would like to mention?

Patient1: Well, the medication cabinet itself was also quite problematic. The servo motors were unreliable and would sometimes get stuck, making it impossible for me to access my medications. Overall, the system just didn't feel very user-friendly or reliable to me.

Interviewer: Understood, we'll investigate the issues with the medication cabinet and work on improving its functionality. On a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the system?

Patient1: I would say around a 3. There's definitely room for improvement, and I hope you'll take my feedback into consideration when making updates to the system.

Interviewer: Thank you for your feedback. We'll strive to address these issues and ensure a better experience for users like you in the future.

Appendix 3: Interview Transcription: Patient 2

Interviewer: Thank you for joining us today. Could you please share your experience using our medication management system?

Patient 2: Well, I must say I encountered quite a few challenges with the system. Firstly, the mobile app interface was not very user-friendly for someone like me with limited vision. The buttons were too small, and the text was difficult to read even with the screen reader.

Interviewer: I see, I apologize for the inconvenience. Were there any other aspects of the system that you found particularly challenging?

Patient 2: Yes, definitely. The Augmented Reality feature in the app didn't work consistently for me. Sometimes it would take multiple attempts to scan the medication box, and even then, the audio instructions weren't always clear or accurate.

Interviewer: Thank you for sharing your feedback. We'll take note of these issues and work on improving the app's accessibility and Augmented Reality functionality. Is there anything else you would like to mention?

Patient 2: Well, the medication cabinet itself was also a bit difficult to navigate. The servo motors were quite slow in opening the doors, and I found it hard to distinguish between the different compartments. It would be helpful if there were tactile markers or some other way to identify the chambers more easily.

Interviewer: Understood, we'll explore ways to enhance the navigation and accessibility of the medication cabinet. On a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the system?

Patient 2: I would say around a 4. While I appreciate the effort put into developing the system, it still needs significant improvements to be truly useful for someone with visual impairments like mine.

Interviewer: Thank you for your honest feedback. We'll prioritize addressing these issues to improve your experience with the system.

Appendix 4: Interview Transcription: Patient 3

Interviewer: Thank you for agreeing to speak with us today. Could you please share your experience using the medication management system we've developed?

Patient 3: Of course. Well, overall, I found the system quite helpful in managing my medications. The Augmented Reality feature in the mobile app made it easier for me to identify my medications using audio cues, which was especially useful since I have difficulty seeing.

Interviewer: That's great to hear. Were there any specific aspects of the system that you found particularly useful or challenging?

Patient 3: Yes, the medication cabinet with the servo motors was a fantastic addition. It made it much easier for me to access my medications independently, as I didn't have to rely on someone else to help me open the doors. However, sometimes the audio instructions didn't play clearly, so I had to listen carefully or ask for assistance.

Interviewer: Thank you for sharing that feedback. We'll definitely look into improving the clarity of the audio instructions. Can you tell us if there were any features or functionalities you wished the system had?

Patient 3: Well, it would be helpful if the app could provide reminders for when it's time to take my medications. Sometimes I forget, and having a reminder would ensure I stay on track with my medication schedule.

Interviewer: That's a valuable suggestion. We'll explore incorporating medication reminders into the system. Lastly, on a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the system?

Patient 3: I would say around an 8. While there are areas for improvement, I do appreciate the convenience and assistance the system provides in managing my medications.

Interviewer: Thank you for your feedback. We'll continue to work on enhancing the system to better meet your needs.

Appendix 5: Interview Transcription: Patient 4

Interviewer: Thank you for joining us today. We'd like to hear about your experience with the medication storage and retrieval aspect of our system. Can you share your thoughts?

Patient 4: I'm afraid I didn't find it very user-friendly, to be honest. The process of storing medications in the cabinet was quite complicated for me. The instructions provided in the app weren't very clear, and I struggled to scan the medication boxes accurately.

Interviewer: I see, that sounds frustrating. Were there any specific challenges you encountered when trying to retrieve medications from the cabinet?

Patient 4: Absolutely. The servo motors in the cabinet were slow to respond, and sometimes they would get stuck halfway through opening the doors. This made it difficult for me to access my medications when I needed them, which was quite concerning.

Interviewer: Thank you for sharing your experience. We'll take note of these issues and work on improving the instructions for storing medications and the reliability of the cabinet's servo motors. Is there anything else you'd like to mention?

Patient 4: Well, I also found it confusing to navigate the app's interface when trying to retrieve medications. The process seemed overly complicated, and I often felt overwhelmed by all the steps involved. Simplifying the user experience would definitely make a big difference.

Interviewer: Understood, we'll work on streamlining the process for retrieving medications in the app. On a scale of 1 to 10, how satisfied are you with the medication storage and retrieval aspect of the system?

Patient 4: I would say around a 3. It needs some improvement to be more user-friendly and reliable for individuals like me with visual impairments.

Interviewer: Thank you for your honest feedback. We'll prioritize addressing these issues to enhance your experience with the system.

Appendix 6: Interview Transcription: Patient 5

Interviewer: Hello, thank you for taking the time to speak with us. Can you tell us about your experience with the medication storage and retrieval functionality of our system?

Patient 5: Unfortunately, it wasn't very positive. I struggled with both storing and retrieving medications using the system. The app's interface was confusing, and I found it difficult to understand the instructions for scanning medication boxes and entering data.

Interviewer: I'm sorry to hear that. Were there any specific issues you encountered when trying to retrieve medications from the cabinet?

Patient 5: Yes, quite a few. Firstly, the servo motors in the cabinet were quite noisy and slow to respond. This made the process of opening the doors feel cumbersome and inefficient. Additionally, the audio cues provided in the app weren't always clear, making it hard for me to locate the correct chamber.

Interviewer: Thank you for sharing your experience. We'll look into improving the responsiveness of the servo motors and enhancing the clarity of the audio cues. Is there anything else you'd like to mention?

Patient 5: Well, I also found it frustrating that there was no tactile feedback or other means of identifying the different chambers in the cabinet. As someone with visual impairments, it's important for me to be able to navigate the system independently, and the lack of tactile markers made that difficult.

Interviewer: Understood, we'll explore incorporating tactile markers or other accessibility features into the cabinet. On a scale of 1 to 10, how satisfied are you with the medication storage and retrieval aspect of the system?

Patient 5: I would say around a 2. It definitely needs significant improvement to be more user-friendly and accessible for individuals like me.

Interviewer: Thank you for your feedback. We'll work on addressing these issues to improve your experience with the system.

Appendix 7: Interview Transcription: Patient 6

Interviewer: Hello, thank you for taking the time to speak with us. Could you please share your experience using our medication management system?

Patient 6: Hello, it's my pleasure. Overall, I found the system to be quite helpful in organizing my medications. The augmented reality feature in the app made it easier for me to understand which medication I needed to take and when.

Interviewer: That's great to hear. Were there any aspects of the system that you found challenging or difficult to use?

Patient 6: Well, sometimes I had trouble scanning the medication boxes with the app's scanner. It took a bit of practice to get the hang of it, especially since my vision isn't very clear. Additionally, the servo motors in the cabinet were a bit noisy, which could be bothersome at times.

Interviewer: Thank you for sharing that feedback. We'll work on improving the scanning functionality and see if we can minimize the noise from the servo motors. Is there anything else you would like to see added to the system?

Patient 6: It would be helpful if there was a feature to track my medication refills and remind me when I need to order more. Sometimes I run out unexpectedly, and it would be nice to have a reminder so I can avoid missing doses.

Interviewer: That's a great suggestion. We'll look into incorporating a medication refill tracking feature into the system. On a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the system?

Patient 6: I would say around a 7. While there are some areas that could be improved, I do appreciate the assistance the system provides in managing my medications.

Interviewer: Thank you for your feedback. We'll continue to work on enhancing the system to better meet your needs and improve your overall experience.

Appendix 8: Interview Transcription: Caregiver 1

Interviewer: Thank you for participating in this interview. Could you please share your experience using the mobile application to add medications for your patient?

Caregiver 1: Certainly. Overall, I found the process quite straightforward. The interface was intuitive, and I appreciated the step-by-step guidance provided in the app.

Interviewer: That's great to hear. Were there any specific features of the app that you found particularly useful or challenging?

Caregiver 1: One feature that I found particularly useful was the ability to easily input all the necessary details about the medication, such as the name, dosage, schedule, and any special instructions. However, I did encounter some challenges with uploading images of the medication boxes, as the process was a bit finicky at times.

Interviewer: Thank you for sharing that feedback. We'll look into improving the image uploading process to make it more user-friendly. Is there anything else you would like to mention about your experience using the app to add medications?

Caregiver 1: I appreciated the convenience of being able to access and update the medication details from anywhere using the app. It made it much easier for me to keep track of my patient's medications and ensure they were receiving the correct dosage at the right times.

Interviewer: That's good to hear. On a scale of 1 to 10, how satisfied are you with the overall usability and effectiveness of the app for adding medications?

Caregiver 1: I would say around an 8. While there were some minor issues with the image uploading process, overall, I found the app to be quite useful and effective for managing medications.

Interviewer: Thank you for your feedback. We'll continue to work on enhancing the system to better meet your needs.

Appendix 9: Interview Transcription: Caregiver 2

Interviewer: Thank you for taking the time to speak with us. Could you share your experience with adding medications using the mobile application?

Caregiver 2: Of course. To be honest, I found the process quite cumbersome and confusing. The interface of the app wasn't very intuitive, and it took me a while to figure out how to input all the necessary details for each medication.

Interviewer: I see. Can you elaborate on what specifically made the process confusing for you?

Caregiver 2: Well, for starters, there were so many fields to fill out for each medication - the name, dosage, schedule, instructions, and more. It felt overwhelming, especially since I had to repeat the process for multiple medications. Additionally, the instructions provided in the app weren't very clear, which made it hard for me to know if I was entering the information correctly.

Interviewer: Thank you for sharing that feedback. We'll take note of these issues and work on improving the app's usability and clarity of instructions for adding medications. Is there anything else you'd like to mention?

Caregiver 2: Yes, I also encountered some glitches and bugs while using the app. Sometimes it would freeze or crash unexpectedly, which was quite frustrating. It made the already challenging task of managing medications even more difficult.

Interviewer: Understood. We'll investigate these technical issues and work on improving the stability of the app. On a scale of 1 to 10, how satisfied are you with the experience of adding medications using the mobile application?

Caregiver 2: I would say around a 3. There's definitely room for improvement to make the process more efficient and user-friendly.

Interviewer: Thank you for your honest feedback. We'll prioritize addressing these issues to enhance your experience with the app.

Appendix 10: Interview Transcription: Caregiver 3

Interviewer: Hello, thank you for speaking with us. Can you share your thoughts on using the mobile application to add medications?

Caregiver 3: Sure. Overall, I found it quite frustrating and time-consuming. The app's interface was cluttered, and it wasn't very clear how to navigate through the different screens and options.

Interviewer: I see. Were there any specific aspects of the app's interface that you found particularly confusing?

Caregiver 3: Well, for starters, the process of adding medications felt overly complicated. There were too many steps involved, and I often felt like I was getting lost in the menus. It would have been helpful if the app had a more streamlined and intuitive interface.

Interviewer: Thank you for sharing your feedback. We'll take note of these usability issues and work on simplifying the process of adding medications. Is there anything else you'd like to mention?

Caregiver 3: Yes, I also encountered some issues with the app's performance. It was quite slow and laggy at times, which made the task of adding medications even more frustrating. I had to constantly wait for the app to respond, which slowed down my workflow.

Interviewer: Understood. We'll investigate these performance issues and work on optimizing the app for smoother operation. On a scale of 1 to 10, how satisfied are you with the experience of adding medications using the mobile application?

Caregiver 3: I would say around a 4. There's definitely room for improvement to make the process more efficient and user-friendly.

Interviewer: Thank you for your feedback. We'll prioritize addressing these issues to enhance your experience with the app.

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