
AutoMedic: Framework of Automatic Pill Dispenser System with Human Centered Design Method

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Abstract

Medication non-adherence is a serious problem in Indonesia, with low adherence rates reaching 41.5% in hypertension patients and 78.1% in type 2 diabetes mellitus patients, due to memory loss, complexity of medication schedules, and physical limitations, especially in the elderly population. This study aims to develop an IoT-based automatic pill medicine dispenser to improve medication adherence through a Human Centered Design approach that focuses on user needs. The research methodology uses three stages of HCD: Inspiration through in-depth interviews with users of various ages and health experts, Ideation to design a system concept that integrates ESP32, RTC DS3231, servo motor, and mobile application with Firebase as a real-time database, and Implementation to develop functional prototypes and usability evaluation. The test results show that the system can function well in providing reminder notifications, automatic dispensing, and real-time monitoring of medicine consumption. Evaluation with ten respondents showed good ease of use, although elderly users had difficulty in setting schedules through the application and needed improvements in portability and notification customization. This research contributes user-friendly health technology solutions and an HCD-based IoT development framework to improve medication adherence in patients with chronic diseases.

Keywords:

Automatic Medicine Dispenser, IoT, Human Centered Design, Medication Adherence,

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1. Introduction

Medication adherence is a crucial factor that determines the success of treatment in patients with chronic diseases. The phenomenon of medication non-adherence has become a significant problem in Indonesia, with a high prevalence in various regions. Research showed that 56.3% of elderly people with hypertension in Wangurer Village, North Minahasa Regency, showed an adequate level of compliance, but 43.7% still experienced non-adherence in taking antihypertensive medicine [1]. Similar conditions were also found in areas with a wider population, where the level of adherence to taking medication for hypertensive patients at the Samarinda Lempake Health Center showed alarming results with 41.5% of patients having low compliance, 34.1% moderate compliance, and only 24.4% having high compliance [2].

The problem of medication non-adherence is not only limited to one type of disease, but also extends to various other medical conditions. In patients with type 2 diabetes mellitus, the majority of patients (78.1%) showed a low level of adherence in taking oral antidiabetic medicine, with factors such as the level of knowledge, motivation, and attitude of patients being the main determinants of non-adherence [3]. Another study on

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type 2 diabetes mellitus patients showed that although there was a positive correlation between education level and medication adherence, the distribution of adherence was still dominated by the moderate (52.7%) and low (32.4%) categories [4]. This phenomenon also occurs in the use of antibiotics, where only 50.4% of people show a sufficient level of compliance in the use of antibiotics according to the rules [5].

Medication non-adherence in the elderly population is influenced by a variety of complex interacting factors. The main factors identified include decreased cognitive function with age, memory loss, unwanted medicine side effects, and boredom due to long-term medication [1]. A study on antibiotic use for pneumonia therapy identified that discipline was the dominant factor that most influenced adherence, with disciplined respondents being 4.393 times more likely to adhere to treatment than those who were not disciplined [6]. In addition, socio-demographic factors such as age, gender, education level, and socioeconomic status also contribute to the level of treatment adherence.

The development of Internet of Things (IoT) technology opens significant opportunities to address medication adherence issues through an integrated technology approach. The implementation of IoT technology in the context of elderly health has shown significant potential in improving quality of life through monitoring systems that can be tailored to the specific needs of the elderly population, as has been demonstrated in the development of an indoor air quality monitoring system specifically designed for elderly homes [8]. IoT technology allows the implementation of health monitoring systems that can be categorized into two main classifications: clinical care and remote monitoring, which allows real-time monitoring of patient health parameters at home with data transmission to servers or cloud computing for further analysis by medical personnel [9]. The implementation of this technology has proven to be effective in increasing the accessibility of health services by lowering operational costs, especially in monitoring patients with chronic diseases that require intensive and continuous monitoring of health parameters.

The development of Internet of Things (IoT) technology opens up significant opportunities to address medication adherence issues through an integrated technology approach. IoT technology enables the implementation of health monitoring systems that can be categorized into two main classifications: clinical care and remote monitoring, which allow real-time monitoring of patient health parameters at home with data transmission to servers or cloud computing for further analysis by medical personnel [8]. The implementation of this technology has proven to be effective in improving healthcare accessibility by lowering operational costs, especially in monitoring patients with chronic diseases that require intensive and continuous monitoring of health parameters.

Empirical evidence shows that the use of assistive technology tools can significantly improve medication adherence. Research on the use of daily medicine boxes for tuberculosis patients showed an increase in compliance from the initial condition where 68.8% of respondents had moderate compliance and 31.3% low compliance, to 87.5% of respondents with high compliance after 21 days of intervention [9]. In addition, the development of an IoT-based intravenous therapy monitoring system for the elderly showed a high level of accuracy with an error percentage of only 0.84%, and successfully provided automatic alerts and real-time notifications through a smartphone application [10].

The development of IoT technology for healthcare requires a user-centered approach to ensure optimal system effectiveness. The concept of Human Centered Design emphasizes the importance of understanding users' needs, limitations, and preferences as a foundation in designing technological solutions [11]. This approach is crucial given

the complexity of interactions between technology, users, and context of use in the IoT ecosystem that involves interdependencies between human and non-human actors [12].

The implementation of Human Centered Design principles in the development of digital health applications has shown promising results. Research on the design of a mobile application as a medication reminder system for the elderly using a user experience design approach achieved an average Single Ease Question (SEQ) score of 5.9875 and a System Usability Scale (SUS) score of 82, indicating a high level of user satisfaction [13]. This success was achieved through the application of design principles specific to the elderly, namely interface simplification and enlargement of interaction button sizes, which were adapted to the physical and cognitive limitations of the target population. In addition, the implementation of the Human Centered Design methodology in the design of the user interface of the Android-based attendance application also showed effectiveness in creating a user-friendly interface that suits the needs of users [14].

Based on the analysis of complex medication adherence issues and the unoptimized potential of IoT technology, there is an urgency to develop technological solutions that can bridge the gap between medical needs and patients' ability to manage their medication. The development of an IoT-based automatic pill dispenser using the Human Centered Design method is expected to contribute significantly to improving medication adherence through automation of the dispensing process, smart reminder system, and real-time monitoring of medication consumption. The integration of this technology with the Human Centered Design approach will ensure that the developed system is not only technically feasible, but also user-friendly and suits the specific needs of users, especially the elderly population who are prone to medication non-adherence.

The purpose of the research is to design and develop a functional prototype of an IoT-based automatic pill dispenser that can improve medication adherence through a Human Centered Design approach. Specifically, this research will identify user needs through an in-depth study of patient behavior and preferences in taking medication, design an IoT system integrated with an automatic dispensing mechanism and real-time monitoring, and evaluate the effectiveness and usability of the developed system. The contribution of this research is expected to provide an innovative technological solution to overcome the problem of non-compliance in taking medicine, as well as develop a Human Centered Design methodology framework that can be applied in the development of other digital health technologies.

2. Related Works

Previous studies on IoT-based automated medication dispensers have explored various technological approaches to address the problem of medication non-adherence, particularly in the elderly population and patients with chronic diseases. Philip et al. [16] developed an Automatic Medicine Dispenser system integrating Arduino Uno, NodeMCU, and "MedCare" mobile application with dual-dispensing capability for pill and liquid medicine, achieving effectiveness in real-time notification but limited to 2-3 weeks of medicine storage capacity and dependency on internet connectivity. Meanwhile, Nigade et al. [17] implemented a system with an accuracy rate of 98.6% using ESP32 and Blynk application, showing superior technical performance with a false alarm rate of 0%, but using a conventional development approach that lacks in-depth consideration of usability and user experience aspects. A different approach is shown by Aung et al. [18] who focused on a commercial application for pharmacies with a modular design and intuitive interface, although it still faces challenges in dispensing accuracy stability (~80%) and has not been integrated with IoT technology for remote monitoring.

Significant contributions were also made by Achammal et al. [19] who integrated facial

recognition biometric technology on a Raspberry Pi-based system to improve the safety of medicine dispensation, but this study has not applied the Human Centered Design methodology that can optimize the experience of elderly users. In general, these studies [16,17,18,19] show strengths in the technical aspects of IoT implementation and system accuracy, but have limitations in user-centered development approaches. This gap creates an opportunity for the development of an automated pill dispenser system that is not only technically superior, but also designed with the needs, characteristics, and limitations of the target users in mind through the implementation of a comprehensive Human Centered Design method.

The relevance of previous studies [16,17,18,19] to the development of IoT-based automatic pill dispensers using the Human Centered Design method is substantial, especially in providing a foundation for IoT system architecture, selection of appropriate hardware components, and insight into the technical challenges that need to be overcome. However, this research will fill the methodological gap by integrating Human Centered Design principles that include user research, iterative design, and usability testing to ensure the developed system is truly accessible, user-friendly, and suits the specific needs of users with technological limitations and diverse physical abilities.

3. Proposed Method

The research uses the Human Centered Design method to provide a primary focus on experience and comfort with user involvement in every development process, from needs identification to operational evaluation of the tool. This method consists of 3 main stages, namely 1) Inspiration, 2) Ideation, 3) Implementation.

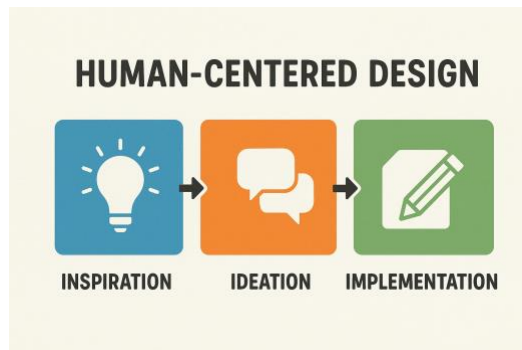


Fig. 1 Research Stage

3.1 Inspiration

Inspiration is the first stage in the Human Centered Design methodology which is the initial foundation in designing an IoT-based automatic pill dispenser. In this phase, researchers conduct in-depth exploration to understand the needs, problems, and expectations of users that will form the basis of system development. The Inspiration phase is crucial because Human Centered Design is human-centered, so a comprehensive understanding of the user is the key to success.

To obtain comprehensive data, the researcher conducted interviews with 10 respondents, including 7 users and 3 health experts. Interviews with users focused on three main groups, including 2 elderly (≥ 60 years old), 1 adult (25-59 years old), and 2

adolescents (15-24 years old) to understand the needs and challenges in consuming medicine from various age groups. In addition, interviews with health experts including 3 respondents, including 2 nurses and 1 pharmacist were conducted to obtain medical perspectives, including aspects of patient education, compliance monitoring, pharmacology, and potential medicine interactions. This approach ensures that the design of the IoT-based automatic pill dispenser not only meets the needs of users, but also meets the standards of safety and medical effectiveness. Table 1 displays user interview questions of the study.

Table 1: User Interview Questions of the study

| No | Question | Stakeholder |
|----------|--|-------------------------------|
| A | Current Medication Taking Routine | User (Elderly/Adult/Youth) |
| 1 | Do you or your family take medicine every day? What kind of medicine? | |
| 2 | How many times a day do you usually take your medicine? What time of day? | |
| 3 | How do you remember to take your medicine now? | |
| 4 | What is the biggest difficulty with taking medicine? | |
| B | Problems Encountered | |
| 5 | Have you ever forgotten to take your medicine? How often? | |
| 6 | What happens if you miss or forget to take your medicine? | |
| 7 | Have you ever taken the wrong medicine (dose, type, or time)? Tell us about your experience. | |
| 8 | Who usually reminds you if you forget to take your medicine? | |
| C | Solutions that Have Been Tried | |
| 9 | Solutions You've Tried What are some ways you've tried to avoid forgetting to take your medication? | |
| 10 | Have you ever used a reminder or alarm app? How did it work out? | |
| 11 | Did you use a special medicine box? Did it help? | |

Table 1: List of User Questions.

Table 2: Health expert interview questions

| No | Question | Stakeholder |
|----------|---|------------------|
| A | Patient Medication Adherence Experience | Nurse/Pharmacist |
| 1 | Based on experience, how often do patients not adhere to taking medication as prescribed? | |
| 2 | What are the main causes of medication non-adherence that you often encounter? | |
| 3 | In which disease states is medication non-adherence the highest risk? | |
| 4 | What clinical impact have you seen due to medication non-adherence? | |
| B | High-Risk Patient Population | |
| 5 | Which patient group most often forgets or takes medication incorrectly? | |
| 6 | Are there any special characteristics of patients who find it difficult to manage medication schedules? | |
| 7 | How to manage patients with multiple medications (polypharmacy)? | |
| 9 | What are the special challenges in geriatric patients in medication management? | |
| C | Current Monitoring System | |
| 10 | How do you monitor patient adherence to medication? | |
| 11 | How often do patients report problems related to medication use? | |
| 12 | How do you communicate with the patient's family regarding medication? | |

Table 2: List of Expert Questions.

3.2 Ideation

Ideation is the second stage in the Human Centered Design method that aims to develop solutions based on user needs and challenges identified in the Inspiration stage. Researchers started by formulating the design concept of an automatic pill dispenser system that emphasizes ease of use, reminders of medication time, and real-time monitoring capabilities. From this concept, an IoT-based solution was developed that integrates hardware and software systems, and is connected to a mobile application to support user compliance in medicine consumption.



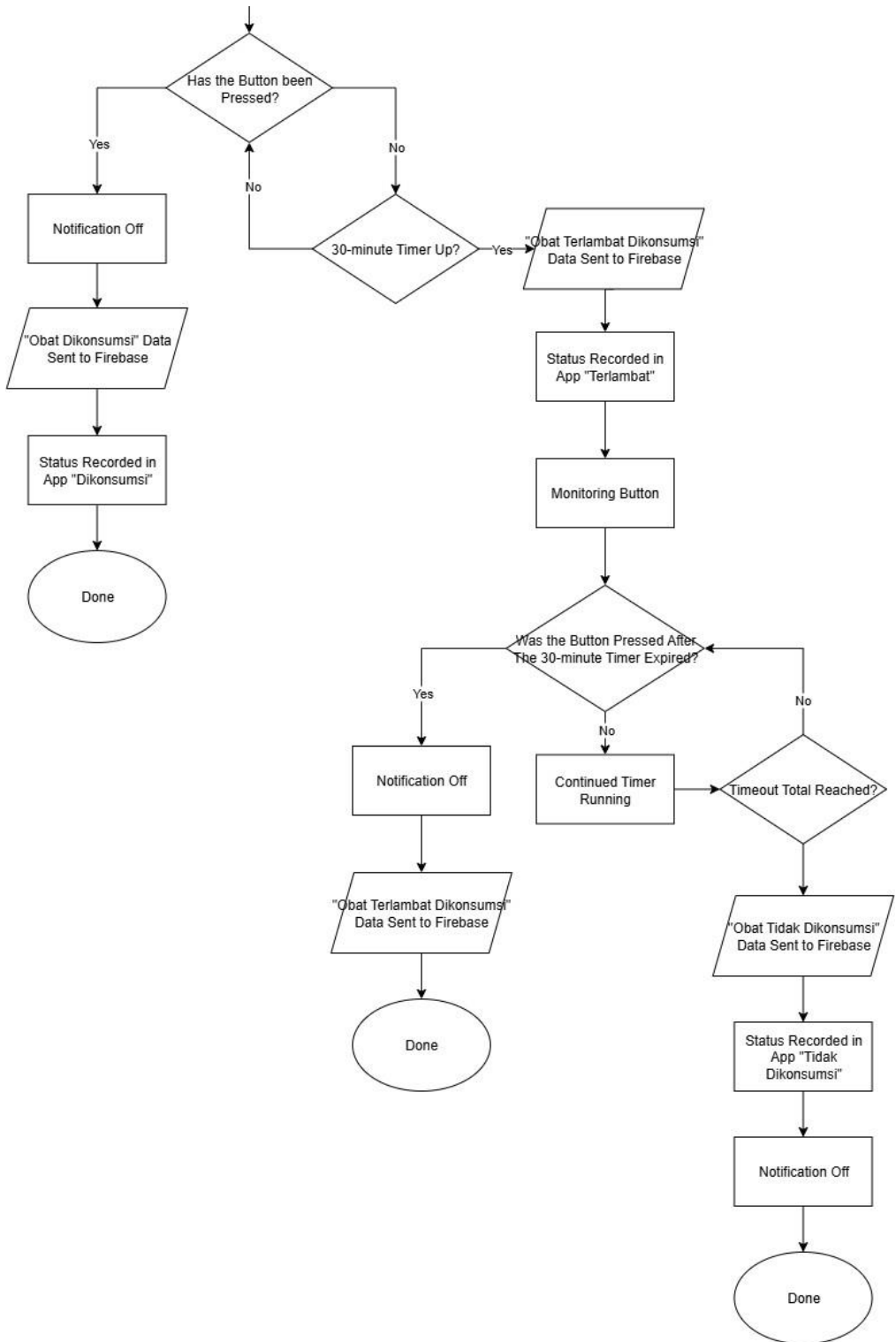


Fig. 2 Flowchart of System Workflow

The concept is visualized in the form of a system workflow flowchart that shows the process from ESP32 initialization, internet connection checking, schedule retrieval from Firebase, to medicine dispensing by servo motors when drinking time arrives. The system is equipped with indicators in the form of LED lights and buzzers, as well as a confirmation button that records consumption status into Firebase. If not confirmed, the system will mark as “Not Consumed” and send a notification to the app, ensuring the user gets immediate feedback and the system remains functional under various operational conditions.

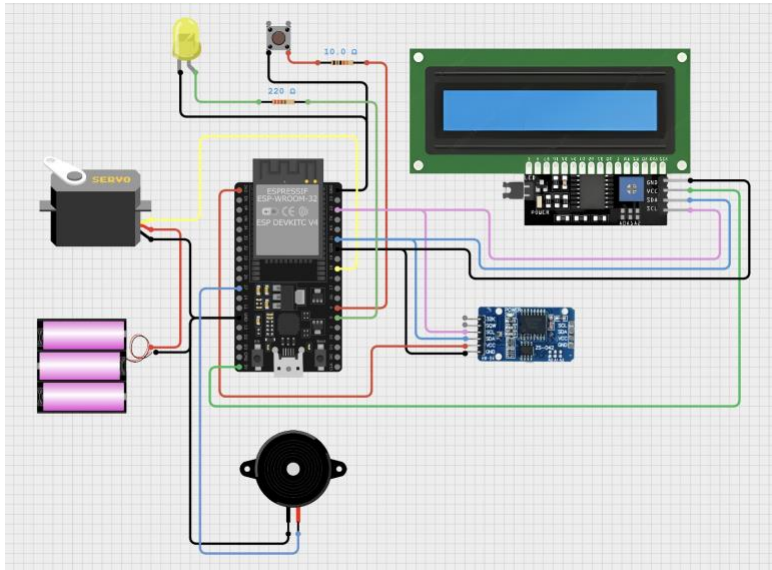


Fig. 3 IoT Component Set

To support the performance of the system, researchers designed a series of IoT components that incorporate ESP32, RTC DS3231, servo motor ES08MA II, I2C 16x2 LCD, buzzer, LED, and button. All components are efficiently organized by considering signal stability and power efficiency. The system architecture is divided into three main parts, namely hardware, software, and IoT communication. The ESP32 acts as the controlling center, while the Android app serves as the user interface connected to Firebase for data management. Real-time communication between the device and the app ensures accurate data synchronization and a responsive usage experience.

3.3 Implementation

Implementation is the final stage in the Human Centered Design method. In this phase, researchers realized the design of the IoT-based automatic pill dispenser system into a functional prototype. The process began with the assembly of prototype components including ESP32, RTC DS3231, servo motor, LCD I2C, buzzer, LED, and button, then continued with software development to integrate the mobile application with the prototype dispenser through Firebase connection. Afterwards, the prototype was tested by three groups of 1) elderly (≥ 60 years old), 2) adults (25-59 years old), and 3) teenagers (15-24 years old) to evaluate the ease of use, reliability of the notification, and its impact on medication adherence. The evaluation was conducted qualitatively and quantitatively, generating feedback that was used as the basis for further improvements to the design and system to better suit the real needs of users. The success indicators of the tool are seen from the ease of the mechanism for setting the medicine schedule, the ease of the mechanism for storing medicine, the effectiveness of notifications, and the

ease of the mechanism for taking medicine.

4. Result and Analysis

At the Implementation phase, researchers realized a functional prototype of an IoT-based pill dispenser. This medicine dispenser uses ESP32 as a microcontroller, RTC DS3231 as a timer, ES08MA II Analog Servo for medicine dispensing mechanism, 16x2 LCD, LED, and buzzer as visual and sound notifications, and pushbutton as a mechanism to turn off the alarm, dispense and record medicine status. The workflow of the medication dispenser system starts with the user setting up the medication consumption schedule through the mobile application on the Add Schedule page to select the date, time, and type of medication. After that, the device will initialize the ESP32 and check the internet connection. If successful, the system retrieves the schedule from Firebase and enters monitoring mode. When the time to take medicine arrives, the servo will dispense the medicine along with a notification. If the user presses the confirmation button according to the schedule, the system records the status as “Consumed”; if late, it records “Late Consumed”; and if not, it records as “Not Consumed” and a notification is sent to the app. The Consumption History page then displays this information chronologically, making it easier for users and health workers to monitor adherence to the medication schedule.



Fig. 4 Medicine Dispenser Prototype.

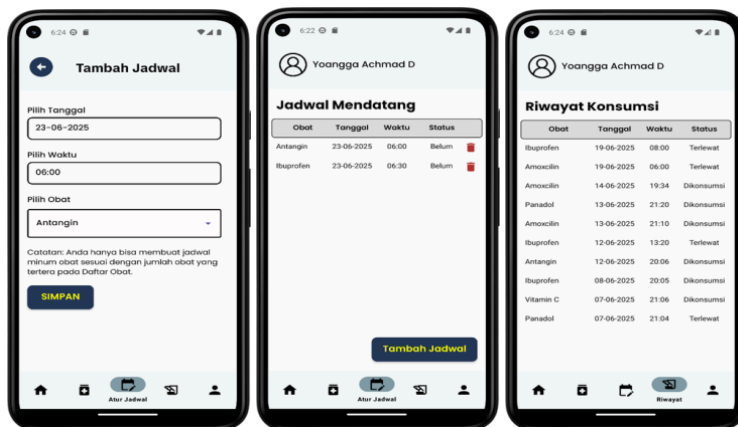


Fig. 5 Medicine Schedule View, Add Schedule & Consumption History View

The integration process of the medicine dispenser system with the mobile application utilizes Firebase as a real-time data storage platform. Schedules set by the user including medicine name, initial status “Belum”, value taken = false, and date and time will be stored in the Schedule Consumption collection. The IoT device periodically accesses Firebase Realtime Database to check the active schedule. If there is a suitable schedule, the alarm will turn on and wait for user confirmation. When the user has pressed the confirmation button and the taken value turns true, the schedule will move to the Riwayat Consumption with the status of “Consumed”, and the medicine stock will be automatically reduced. However, if the button is not pressed within 30 minutes, the schedule is still recorded with taken = false. This flow is designed so that the system can work automatically but still pay attention to user interaction, to ensure that the medicine is consumed on.

4.1 Prototype Testing

After the prototype of the IoT-based automatic pill dispenser was successfully developed and integrated with the mobile application through Firebase, the researchers continued the trial phase with potential users. The test was conducted by demonstrating how to use the medicine dispenser, starting from setting up the medicine consumption schedule, arranging the medicine into the dispenser tube, reminder notifications, to retrieving the medicine when the specified time arrives. The test results show that the system can generally function well and the features run according to the flow that has been designed. However, some obstacles and shortcomings were found, especially in elderly potential users. Although they were able to operate the device well, some of them still experienced difficulties in arranging the medicine in the order of the schedule, as well as obstacles in managing the consumption schedule through the application due to limited understanding of smartphone use. This finding is an important input for improving the application interface and tool design to make it more friendly for users with certain limitations. Table 3 displays prototype test results with respondents.

Table 3: Prototype Test Results with Respondents

| Respondent | Medication Dispenser View | Set Schedule | Store Medication in Tube | Notification | Medication Retrieval | Feedback and Suggestion |
|------------|---|--|--|---|--|---|
| R1 | The size is just right, suitable to be placed at home or boarding house | Very easy to use, very easy to understand and no obstacles | It is easy to organize the medicine and there are no obstacles | Helpful in reminding you to take your medication, but the alarm sound can be a bit jarring. | It's easy to take medicine and there are no problems | Improvements to the notification alarm to make it more pleasant to hear |

| | | | | | | |
|----|--|---|---|---|---|---|
| R2 | The size is not right, because it is too big and not portable enough to carry anywhere and the power is not practical. | Easy to use, quite easy to understand and no obstacles | It is quite easy to organize the medicine and there are no obstacles | Helpful in reminding you to take your medication, but the alarm needs to be snoozed so that notifications can be repeated when overdue. | Easy to take medicine and no obstacles | Addition of snooze to notification alarms so that notifications can repeat when late |
| R3 | The size is right, the size is not too big and does not take up space to | Easy to use, easy to understand, but there are obstacles in using | It is quite easy to arrange the medicine, but has a little problem | Very helpful in reminding the schedule of medicine consumption | It is quite easy to retrieve medicine, but there are problems in the | Improvements to alarm notifications so that alarm sounds can be customized according to taste |
| | be stored on tables, shelves and cabinets | the tool due to age factors | in arranging the medicine because it is confused about the order of the medicine. | ion, but the notification alarm needs to be made easy to customize. | mechanism of retrieving medicine due to lack of understanding in the operation of electronic devices. | |

| | | | | | | |
|----|---|---|---|---|--|--|
| R4 | Size fits, needs to be made more portable so that it can be carried anywhere and stored in a bag or pants pocket. | Very easy to use, easy to understand and no obstacles | It is quite easy to organize the medicine and there are no obstacles | Very helpful in reminding the schedule of medicine consumption, but the notification alarm needs to be able to add the voice of a familiar person to the alarm sound. | It's easy to take medicine and there are no problems | Adjustments to a more portable size, so that it can be carried anywhere and stored in a bag or pants pocket, as well as improvements to the alarm notification so that the alarm sound can be added to the alarm sound of a familiar person. |
| R5 | The size is just right, can be placed anywhere such as rooms, living rooms and kitchens | Quite easy to use, quite easy to understand, but there are obstacles in using the tool due to age factors | Unable to store medication in tubes due to constraints in arranging medication according to a schedule due to age | Quite helpful in reminding medication consumption schedule, but the alarm notification sound needs to be | It's easy to take medicine and there are no problems | Add notifications other than alarm sounds, flashing lights and text on the screen. If possible, it could be a wristband with notifications. |
| | | | | improved and other notifications other than alarms, flashing lights and writing on the screen are added. | | |

| | | | | | | |
|----|---|--|--|---|--|--|
| R6 | The size fits well, but the size can be enlarged so that it can accommodate large-sized medicines | Easy to use, easy to understand and no obstacles | It is easy to organize the medicine and there are no obstacles | Very helpful in reminding medicine consumption schedules, but additional notifications on smartphones should be added. | Easy to take medicine and no obstacles | Increased size that needs to be enlarged so that it can accommodate medicine with larger sizes, added notifications on smartphones, and added reminders for other types of medicine such as liquid medicine. |
| R7 | The size is just right, but the power is less practical because it is not fully using batteries yet | Very easy to use, easy to understand and there are no obstacles, but it is necessary to add a schedule setting mechanism directly on the tool, not only through the application. | It is quite easy to organize the medicine and there are no obstacles | Very helpful for reminding medication consumption schedules, but it is necessary to add an alarm sound volume setting, as well as a larger screen size. | Easy to take medicine and no obstacles | Improved power to fully utilize rechargeable batteries, added a schedule setting mechanism directly on the device, not just through the app, added alarm sound volume settings, and enlarged screen size. |

| | | | | | | |
|-----------------------|---|---|---|--|--|--|
| R8 (Health Expert) | The size is right and ideal, but the design needs to be made unclear so that the medicine is not exposed to direct sunlight, and the appearance of the device is not visible. | Very easy to use, easy to understand and no obstacles, but not suitable for elderly users who are less skilled in using technology and require a caregiver. | It is easy to arrange the medicine and there are no obstacles, but it is necessary to adjust the storage tube so that it does not look clear, so that it is not exposed to direct sunlight, the storage is made airtight, and there is no moisture. | Very helpful in reminding me of my medication schedule | Easy to take medicine and no obstacles | Adjustments to the appearance of the medicine dispenser by not making it clear, adjustments to the storage tube that is not made clear so that it is not exposed to direct sunlight, airtight and not humid. |
| R9 (Health Expert) | Fit and ideal size | Very easy to use, easy to understand and no obstacles, especially for lay people | It is easy to organize the medicine and there are no problems, but it is not recommended to store the medicine without the package for a long time. | Very helpful for reminding medication consumption schedules, but need to adjust the notification that should not be on for 30 minutes, just 10 - | It is easy to take medicine and there are no obstacles, but it is necessary to adjust the mechanism for missed medicine and not be consumed when the next medicine | Adjustments need to be made to notifications so as not to waste power, as well as adjustments to the medicine retrieval mechanism for missed schedules. |

| | | | | | | |
|---------------------|--|---|--|---|--|--|
| | | | | 15 minutes to save power. | schedule arrives. | |
| R10 (Health Expert) | The size is quite fitting and ideal, but to store the medicine, it is recommended to keep it wrapped in its packaging. | Easy to use, easy to understand and no obstacles, but adjustments need to be made for elderly users | It is easy to arrange the medicine and there are no obstacles, but it is necessary to add a schedule separator label and directions for rotating the tool to make it easier to arrange the medicine, as well as a tube holder that allows storing the medicine using the medicine packaging to make it more sterile. | Very helpful in reminding me of my medication on schedule | It is easy to take medicine and there are no obstacles, but the size of the medicine dispensing hole needs to be enlarged so that some types of large-sized medicine are not easily stuck and the addition of labels for the medicine retrieval mechanism. | Adjustments to the mechanism for organizing schedules to make it easier for elderly users, adding schedule separator labels and rotation directions to make it easier to arrange medicine, and increasing the size of the medicine dispensing hole, so that some types of large-sized medicine are not easily stuck. |

4.2 Evaluation

The IoT-based automatic pill dispenser prototype developed based on the Human Centered Design approach has shown good functional compliance with user requirements. The integrated IoT system can support the automatic dispensing mechanism with real-time monitoring in accordance with the research objectives. Key

features such as setting medication schedules, reminder notifications, and compliance monitoring have functioned well in supporting the improvement of users' timeliness in taking medication. The integration of the IoT device with the mobile application allows users to digitally monitor their medication consumption history, which contributes to increased awareness and compliance in taking medication according to a predetermined schedule. The usability evaluation showed that users from various backgrounds, ranging from the elderly, adults, teenagers, to health professionals such as nurses and pharmacists, can operate the dispenser with relative ease. The ease of use is reflected in the intuitive interface and simple medication retrieval process.

Based on user feedback obtained through an in-depth study of patient behavior and preferences, several areas for improvement were identified. Users suggested the addition of a mechanism for setting the medication schedule directly on the dispenser without relying on a smartphone, a more compact size of the device to improve portability, and an increase in medication storage capacity. In addition, users also suggested improvements to the medicine output hole that needs to be enlarged, the addition of clear labeling of rotation and storage directions, and instructions on how to take medicine. Feedback related to improving customizable voice notifications and a larger screen with more complete information are also important considerations in further development. The evaluation from a healthcare professional's perspective provided specific recommendations related to the safety and quality standards of medicine storage. Experts emphasized the importance of non-transparent storage to protect medicines from direct sunlight, as well as hygienic, airtight and moisture-proof design. These recommendations are in line with Human Centered Design principles that prioritize safety and effective use.

From the researcher's perspective, an in-depth analysis of the prototype revealed some technical shortcomings that need to be optimized. The dualism of energy sources (battery and electricity) needs to be optimized with a single battery system to improve energy efficiency. The prototype's oversized dimensions reduce portability, while the not-fully-airtight medicine storage tube could potentially affect medicine quality. The too-small medicine dispensing hole makes the retrieval process difficult, and the non-customizable alarm system reduces the flexibility of reminders according to users' individual preferences. In addition, the lack of labeling or turn-by-turn instructions and the button-pushing dispensing mechanism are not intuitive, especially for elderly users. The transparent storage tube also presents a risk of sun exposure that could degrade the quality of the medication, while the unappealing visual design could potentially affect user acceptance of the product. These findings provide a comprehensive framework for the development of Human Centered Design-based digital health technologies, where each aspect of improvement identified can guide the development of more innovative and user-centered health technology solutions.

5. Conclusion

This research aims to develop an IoT-based automatic pill dispenser to improve medication compliance through a Human Centered Design approach centered on user needs. The research method uses three main stages, namely Inspiration to identify user needs through in-depth interviews with various age groups and health experts, Ideation to design integrated IoT system solutions with mobile applications, and Implementation to realize functional prototypes which are then tested and evaluated by users. The

developed prototype successfully integrates ESP32, RTC DS3231, servo motor, and other supporting components with mobile application through Firebase, enabling schedule setting, automatic notification, and real-time monitoring of medicine consumption.

The evaluation shows that the system functions well and can be operated by users from various backgrounds, but still requires improvements in aspects of portability, notification customization, and medicine storage safety standards according to user and health expert feedback. The contribution of this research is to provide innovative technological solutions that can help overcome the problem of medication non-adherence, especially in the elderly population, while developing a Human Centered Design methodology framework for digital health technology development. Future research is recommended to optimize the energy system with a single battery, improve the portability of the device, develop an airtight and anti-transparent storage tube, and add notification customization and schedule setting features directly on the dispenser to improve accessibility for users with technological limitations.

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