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DESIGN AND IMPLEMENTATION OF A LOW-COST STANDALONE MEDICATION-REMINDER SMARTWATCH FOR ELDERLY PATIENTS: PROTOTYPE DEVELOPMENT AND FUNCTIONAL TESTING

BY

AlaaMajeed Raheem[1],Zainab Auday[2],Esraa Makey[3],Marwa Abdulah[4], Nbras Abas[5]

[1,2,3,4,5] *Department of Medical Physics and Radiotherapy, Technical Engineering, College,Sawa University, Almuthana, Iraq*

Abstract

Medication non-adherence is a typical issue in elderly patients who often face challenging dosing schedules, age-induced memory decline, and sensory impairment. Several digital health solutions, like Smartphone apps and commercial smart watches, have been suggested to provide on-time medication consumption. However, these systems are often expensive, technically complex, or require continued internet and Smartphone connectivity, hampering their applicability in older adults in low-resource settings.

In this paper, we propose the concept of an inexpensive and discrete smart watch-like device that provides time-based wrist-worn medication reminders for elderly patients. The proposed system employs an ESP32 microcontroller to provide the timing, a DS3231 real-time clock (RTC) unit to accurately record time, and a little OLED display to display time and calculated dose times and to send vibrational and audible buzzer warnings according to requirements of the user. An interface is simple to use through menus allowing the caregiver/clinic worker or doctor to preprogram numerous times per day's prescribed drug doses without using a Smartphone or cloud connection. A prototype of the smart watch was built and functional bench tests were performed to show the ability to trigger the alarm, accurately time alarms, the brightness display of the timer and the reminder logic response under normal operating conditions.

The initial results of these tests suggest that the device can continuously present visual and auditory cues for the time of drug-intake for all conditions indicated. Although no clinical user test has been undertaken at the moment, the study proves that a low cost standalone medication reminder smart watch for elderly patients is feasible, and forms a base for subsequent usability studies and clinical evaluation of the concept.

Keywords: Medication, Smart watch, Elderly Care, Medication adherence, ESP32 Microcontroller, Reminder device

1. Introduction

An increasing number of older adults globally poses significant challenges to the health care systems across the globe. With an increasingly long life expectancy coming up, elderly patients increasingly live with multiple chronic diseases in complex, long-term drug regimens. Dosing medications, doses, and timing makes it harder to manage because old age often leads to cognitive decline, vision impairment, or reduced manual dexterity.

The risks of disease progression, preventable complications, hospitalization and added cost to health care are serious when medication is not taken as prescribed (WHO, 2003; Brown & Bussell, 2011; UN, 2022). Medication non-adherence is thus acknowledged as a significant issue that prevents optimal therapy in older adults, instead of an insignificant individual condition. There have been various approaches suggested to promote medication adherence. Legacy options such as pill boxes and written schedules and helping the caregivers are not enough for patients who may have memory issues — or who need help with daily routine.

Newer than ever, digital health technologies over the last few years were becoming popular as tool for sending patients personalized and timely reminders. These include SMS reminders, Smartphone apps, electronic pill dispensers, and the use of smart watch alerts. Research on the effectiveness of reminder systems has indicated that reminders can lead to enhanced adherence in multiple patient populations with a significant decrease in missed doses and therapeutic outcome reporting (Vervloet et al., 2012; Santo et al., 2016; Waldman et al., 2018). Nevertheless, the current commercially known ones are not tailored to the circumstances of elderly users especially in resource-constrained environments. Commercial smart watches or sophisticated medication-management platforms are often costly, require constant charging, and require ongoing Smartphone or internet access as well. Their interfaces tend to be more aimed at younger, more tech-savvy users and include complex menus, use of touch gestures and small icons that may not be understood by people with cognitive or visual impairments.

Subscription cost and compatibility with mobile phones can also restrict older adults with low income and low digital literacy the ability to use these systems (Waldman et al., 2018; Lee & Chan, 2019). These limitations are suggestive that simple, affordable standalone technologies that can provide clear medication reminders without Smartphone or cloud service dependency are well worth pursuing. Here we bridge this gap by developing a cheap, intelligent medication reminder device with smart watch aesthetics for elderly patients.

The design features an ESP32 microcontroller, a DS3231 real-time clock (RTC) module, small OLED display with both vibration and audible buzzer alert to accommodate different sensory preferences. We make two contributions towards each of these: the first focuses on a hardware and software architecture that allows us to program multiple daily reminder time schedules with a straightforward interface, and the second we report test results for initial functional bench tests against timing accuracy, time-for-reminder triggering, and general usability of the prototype under normal operating condition. The goal is to establish a practical context for future usability studies and clinical assessment of inexpensive, wrist-worn medication reminder tools for elderly care.

2. Literature Review

2.1 Medication adherence in elderly populations

Adherence to medications is a critical factor in treatment outcome and this is especially relevant in elderly populations who are often diagnosed with multiple chronic conditions and complex drug regimens. In Brown and Bussell (2011), medication adherence is an inherently complex behaviour that is affected by various clinical, social and behavioural variables and is linked with unstable disease control, increased patient complications and greater utilisation of healthcare. In ageing populations, these risks are compounded by cognitive decline, visual limitations, and functional impairments that render elderly patients less able to recall and organise medications on a daily basis.

Demographics the presence of aging population on a global scale also emphasise the need to engage adherence in an older population. By 2050, the projected number of adults age 60 years and older will exceed 1.5 billion, according to UN (2022). Healthcare systems will continue to suffer the adverse consequences of non-adherence, with preventable admissions to hospital and rising costs, as the proportion of older adults rises. According to the World Health Organization, long term therapy adherence stands at around 50% in chronic diseases, further reflecting that non-adherence is not an exception but part of a common, serious issue (WHO, 2003). These results offer a sound foundation to create practical interventions to encourage day-to-day medication adherence in elderly people.

2.2 Electronic reminder interventions

Since forgetfulness is one of the most frequent causative reasons for unintentional medication non-adherence in older adults, electronic reminder systems have gained significant interest as a means to ensure timely medication adherence. Vervloet et al. (2012)

conducted a systematic review on interventions using electronic reminders and concluded that such systems can improve adherence in various chronic diseases, particularly in the short term. Their analysis determined that reminders sent through basic electronic cues could help patients to remember doses, as long as those reminders are clear and embedded in everyday routines. As mobile technologies spread, mobile phone–based interventions have developed as a prominent intervention. Santo et al. (2016) evaluated the use of mobile phone interventions for improving adherence in adults with chronic disease and concluded that SMS messages, app notifications, and other mobile reminders can promote better adherence if they are consistent and individualized to the patient's schedule. Still, such interventions usually depend on ownership and regular use of a mobile phone along with a fundamental understanding of mobile apps and notifications—factors that might not necessarily be satisfied in older, less tech literate populations.

2.3 Electronic reminder systems for older adults

Numerous studies have concentrated more on electronic reminder systems for older adults. Lee and Chan (2019) performed a systematic review of electronic reminders and medication adherence interventions in the elderly and found that several of them had a positive impact on adherence. Their work suggests that electronic reminders might be especially useful when they are simple to use, give clear alerts, and are adjusted for age-related sensory and cognitive impairments. Simultaneously, they said some of the systems are too complicated or too difficult for routine practice by elderly patients, particularly when there are multiple steps involved, small screens, or intricate menus. One evidence of a device that is designed for aging people is the medication reminder watch tested by Waldman et al. (2018).

Among older adults enrolled in their randomised controlled trial, the adherence rates increased from 68% to 92% when a reminder timepiece was worn, proving a simple, wrist-worn device can greatly impact the regular use of medication. The watch provided clear alerts at scheduled times, an interaction that allowed for easy interaction. This study supports the view that wrist-worn, watch-style reminders can be a form of communication that is acceptable and can be used with older users if the interface and features of the watch are convenient.

2.4 Identified gap and motivation for the present work

While the literature demonstrates that electronic and wearable reminder systems may facilitate medication adherence, various limitations persist when including these electronic and wearable reminders in practice for the general population of elderly patients. Most mobile phone–based interventions assume that patients have constant access to a Smartphone and that they could be easily manipulated through apps and notifications (Santo et al., 2016). Similarly, some of these electronic reminder systems studied among older adults still have a relatively complex interface or more expensive infrastructure that is either not accessible or not very affordable in low-resource health care contexts (Lee & Chan, 2019). But even successful wearable solutions like the reminder watch examined by Waldman et al. (2018), these are frequently commercial products, and their price, proprietary nature or connectivity needs may stifle widespread implementation. The findings suggest a big gap: the simple, inexpensive, and standalone devices can provide easy to use, wrist-worn reminders for medicine without relying entirely on smart phones, internet connections, and complex user interfaces. Based on systematic reviews of electronic reminder interventions (Vervloet et al., 2012; Lee & Chan, 2019), and the successful outcomes of reminder watches on use among older adults (Waldman et al., 2018), this study aims to provide evidence of the design, development and implementation of a novel, personalized, low-cost smart-watch-type device designed for medication adherence in older patients with simple visual and auditory reminders.

3. Materials and Methods

3.1 Hardware design and electronic components

The proposed medication-reminder smart watch was designed as a compact, low-power embedded system that can be worn comfortably on the wrist while providing clear visual and auditory alerts. The hardware architecture is built around a microcontroller board, a display module, an alert module, user-input buttons, a real-time clock (RTC) module, a rechargeable power supply, and basic prototyping materials used during initial assembly and testing.

Microcontroller board – ESP32 / Arduino Uno
The ESP32 microcontroller board is the nucleus of the system, chosen for the fact that it provides enough processing ability, power saving, and integrated communication interfaces in-house, ready for further scaling. It also has multiple GPIO pins for the display, alert modules, buttons, and RTC link. An Arduino Uno board was used for initial circuit testing and code prototyping as well during the early development phase due to its ease of implementation and stable quality. After the logic had been confirmed, the design was moved to the ESP32 platform using the smaller form factor and better capabilities.

Display module – OLED 0.96″ / LCD 16×2
A 0.96-inch OLED display was chosen for the final design because its high contrast and brightness make the time and reminder information easier to read for elderly users. The compact size of the OLED module also fits well within a smart watch-style enclosure. For early prototyping and debugging, a 16×2 character LCD was additionally employed, as it is inexpensive, widely available, and easy to interface with microcontroller boards. Both display options were tested to ensure that basic time and message rendering worked correctly before finalising the hardware configuration.

Alert module – buzzer or vibration motor
To deliver medication reminders in a way that accommodates different sensory needs, the device includes an alert module that can be configured as either an active buzzer, a vibration motor, or a combination of both. The buzzer generates a clear audible tone at scheduled times, while the vibration motor provides a tactile cue that can be perceived even in noisy environments or by users with mild hearing impairment. Both components are low-power and require minimal wiring, which supports a simple and reliable integration into the overall design.

User-input buttons
There are multiple push buttons which make for a simple, menu-based interface to set and acknowledge reminders. With these buttons, a caregiver or healthcare provider can set the current time, schedule one or more daily medication schedules, scroll through other items on the menu, and verify their choice. To lower cognitive load and allow elderly users who do not know the complexities of digital interfaces, the button layout and interaction sequence were intentionally kept simple.

Real-time clock module – DS3231
Accurate timekeeping is essential for any medication reminder system. The DS3231 real-time clock (RTC) module was selected because it offers high accuracy and temperature-compensated timing, ensuring that scheduled reminders remain aligned with actual time over extended periods. The module communicates with the microcontroller via an I^2C interface, which simplifies wiring and keeps the design organised. The RTC retains time information even when the main system is powered off, thanks to its onboard backup battery.

Power supply – Li-Po battery and charging module
To enable one's wrist-worn device to be portable, it is operated by a rechargeable lithium-polymer (Li-Po) battery with a capacity in the range of 500–1000 mAh. This capacity is adequate for daily use without frequent recharging, depending on alerts and display use. A TP4056 charging module is incorporated in the design to allow safe charging of the Li-Po battery via a standard USB connection, making it convenient for patients or caregivers to recharge the device when needed.

Prototyping materials – wires and breadboard
During the initial development stage, jumper wires and a breadboard were used to connect the microcontroller, display, alert modules, RTC, and power components. This prototyping setup made it possible to iteratively test and refine the wiring, pin assignments, and code logic before transferring the final circuit to a more compact and robust configuration suitable for enclosure in a smart watch-style case. Functional checks were performed at each step to ensure that all modules operated correctly in combination before final integration.

3.2 Working logic and system flow

The medication-reminder smart watch has a well-defined sequence of simple interconnections between the internal clock, stored medication schedules, and alert modules. Once power is turned on, the microcontroller initialises the RTC module, display, buttons, and alert hardware. Its time is read from the DS3231 and updated on the OLED screen, so that the user can confirm and verify the device. Caregivers or healthcare staff can create one or more daily medication times using push buttons, and these are saved into the microcontroller's memory. Normally, the firmware uses a loop to repeatedly compare the current time from the RTC and the programmed medication times. When the time that the RTC received corresponds to that of a scheduled time within a given tolerance window, this routine of reminders is engaged. In this routine, the smart watch starts the buzzer and/or vibration motor and a clear message on the screen declares it is time to take the medication. The alert is up for a set time until the user clicks a button to acknowledge the reminder. This logic enables reminders to remain on the wrist at the appropriate moments, without the need for a Smartphone, internet connection, or any other device. Such reminder systems have the potential to lead to fewer missed doses, by supplying a consistency of easily recognised cues tied to pre-arranged medication schedules, as evidenced from past works on electronic reminder interventions (Vervloet et al., 2012). This control flow was applied and validated at the prototype level for the current implementation prior to functional testing. The key steps of the medication reminder cycle from schedule settings to alert acknowledgement are illustrated in Figure 2.

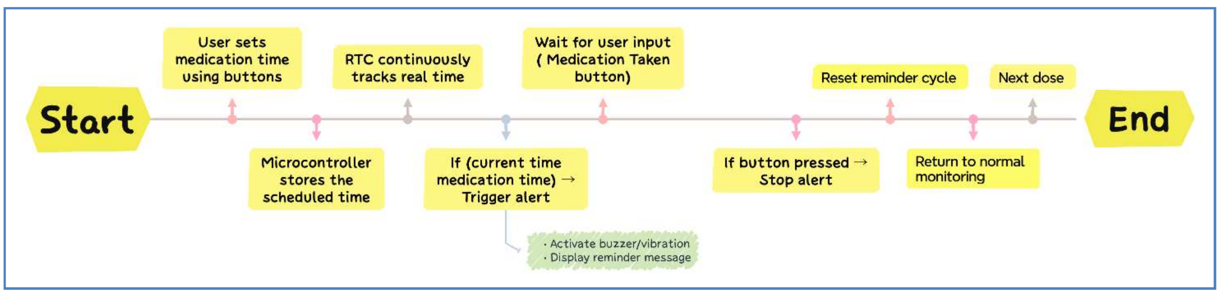

Figure 2. System flow of the medication-reminder smart watch.

4. Results

After assembling the prototype of the medication-reminder smart watch on a breadboard and then placing the main components inside the plastic enclosure, a series of functional bench tests was carried out to evaluate the basic performance of the system. Several reminder times were programmed using the buttons, and the behaviour of the microcontroller, RTC module, display, and alert components was observed under different operating conditions.

The primary objectives of these tests were to verify that:

1. reminders are triggered at the correct scheduled times;
2. alerts are clearly noticeable for the user;
3. the device responds correctly when the confirmation button is pressed; and
4. the system remains stable during prolonged operation, low-battery conditions, and light mechanical movement.

Table 1 summarises the main test cases, the expected and actual behaviour of the prototype, and the overall outcome for each scenario.

Table 1. Functional test cases for the medication-reminder smart watch prototype

Test case	Expected behaviour	Actual behaviour	Status
1. Single reminder at 10:30	Buzzer and visual reminder activate exactly at 10:30	Alarm activated on time; display showed medication message	Pass
2. Reminder at 14:00 after several hours of operation	RTC keeps correct time and alarm triggers at 14:00	Time remained accurate; alarm triggered at 14:00 with no noticeable delay	Pass
3. User presses “Medication Taken” during alarm	Alarm sound stops and display returns to normal screen	Buzzer stopped immediately; display returned to normal monitoring mode	Pass
4. Two reminders scheduled on the same day (morning and evening)	Both reminders are triggered at the programmed times	Both alarms were triggered correctly; no reminder was missed	Pass
5. Operation under partially low battery level	Device continues to trigger alarms and show text, with possible slight reduction in brightness	Alarm worked normally; display became slightly dimmer after many hours but remained readable	Pass
6. Light shaking to simulate daily handling	Device remains stable without resetting or losing time/settings	Time and reminder settings remained correct; no reset occurred during gentle movement	Pass

The results in Table 1 show that the prototype reliably triggered alarms at the programmed times and maintained accurate timekeeping throughout the test period. The buzzer provided a clear audible signal, and the display messages remained readable for older users under normal indoor conditions. The confirmation button behaved as intended by immediately stopping the alarm and returning the system to its monitoring state, supporting an intuitive interaction cycle for elderly users.

5. Discussion

The results of functional testing demonstrate that, even with small prototypes at an early stage, the smart watch fulfills its basic function as a stand-alone medication-reminder device for elderly patients. This system was able to provide accurate time during several hours of continuous operation, notify users about single- and multiple-daily doses, and respond to user acknowledgment appropriately. These behaviours are the baseline requirement of any reminder technology to prevent unintentional non-adherence driven by forgetfulness.

While the tests did highlight a number of practical limitations of the current prototype. For users with more severe visual impairment, especially in brightly lit environments, the screen size and brightness may not be adequate. Because it’s a solitary system without access to external software, it cannot preserve long-term medication history, or inform caregivers through automated alerts of missed doses. Further, internal wiring is based on jumper cables and breadboard connections, this is adequate for bench testing but needs to be solved for daily use with a dedicated printed circuit board (PCB). Taken on a larger scale, thus, overall these findings could be considered a reasonable and cost-effective design point from which the future would come more advanced and more user-friendly wearables for medication reminders. Next versions will need to include better display readability, adjust the physical enclosure, perhaps even enable remote monitoring and support for optional connectivity to maintain the simplicity expected of older users.

6. Future Work

In the current study, we explored the design, development and functional bench testing of a low-cost, affordable medication reminder smart watch for elderly patients. A few possibilities for further work could be found with the reference of this prototype. A systematic usability test of older adults is necessary to examine how older adults actually use the device under real-life conditions. For such a study, perceived ease of use, clarity of alerts, comfort with daily use and barriers to its uptake (e.g., vision, hearing or manual dexterity) may be evaluated. Second, clinical or home trials could possibly be performed to analyze how the smart watch is related to participants' medication-taking behaviour. Monitoring missed doses before and after the use of the device can assess its impact on adherence and identify patient subgroups with the best ability to benefit the most. Third, the hardware and enclosure may be improved further.

The next version may include, for example in line with what they have done, a custom printed circuit board (PCB), an improved ergonomic use of the wristband, improved water and dust resistance or higher contrast for more visually impaired users to use. Fourth, optional connectivity and data recording elements could be pursued (e.g., Bluetooth and/or Wi-Fi modules that sync with a Smartphone or caregiver dashboard). The extensions would offer extended monitoring of adherence over time and offer an off-the-shelf ability to trigger reminders, while essential reminder functions would still work offline. Lastly, additional cost efficiency analyses to compare the proposed smart watch to commercially available commercial reminders or Smartphone-based apps could hopefully offer a little information on potential use of the device in larger medication management schemes, particularly amongst under-resourced healthcare systems.

7. Conclusion

The work provided a description and design of a low-cost standalone smart watch device for elderly patients' medication reminders. It supports an ESP32 microcontroller, as well as a DS3231 real-time clock module, an OLED display, and buzzer- or vibration-based alerts in a small, wrist-worn design, enabling it to do everything a Smartphone, internet connectivity, or complex user interface would not.

The hardware and software design was chosen to be simple, affordable, and usable by elderly patients with low digital skills. Functional bench testing indicated that the prototype can retain accurate timekeeping, automate alarms at desired medication times, manage multiple daily alerts, and respond appropriately to the user's acceptance of the alarm. These results show the device works dependably with its core reminder functions, and provide initial evidence suggesting a dedicated, low-price wearable platform would be possible in this context. But the objective of this paper is prototype development and functional testing.

No clinical evaluation or user study of elderly patients is reported, and the device does not contain any long-term adherence logging or communication with caregivers. For this reason, future work will concentrate on a usability study with older adults, enhancing the physical design and enclosure for everyday use, and exploring optional connectivity and data-logging features, while still maintaining the convenience and low price. In conclusion, we recommend that using the proposed smart watch as a foundation not only serve the elderly's medical needs, but also pave the way for the development of medication reminder devices in a resource-constrained way among the elderly population, in the form of accessible, wrist-worn devices, by providing potential for subsequent usability and clinical investigations.

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