Smart Cup for a Smart Pill Dispenser for Verification of Pill Consumption

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***Abstract*— This research paper describes the design of a device that can assist seniors or people with physical or cognitive limitations to take their prescribed medications that are in the form of pills on time while verifying that such pills have been actually consumed. The design consists of a portable smart pill dispenser that will rest on a base, allowing it to dispense pills into a smart cup. The smart pill dispenser uses a stepper motor to rotate to a desired pills based on a specific time slot/day of the week. The smart cup attached to the pill box uses an accelerometer, gyroscope, and an IR proximity sensor to detect if a user is taking the medication by how much the smart cup is lifted and tilted. The smart cup will inform the smart pill dispenser if the pills are properly consumed or not, thus, allowing the device to potentially aid the patients to have a healthier life.**

Keywords*— Accelerometer, Gyroscope, IR proximity Sensor, Wireless Charging, Portable, Assistive Technology, Arduino RP2040 Connect, LSM6DSOX IMU

I. Introduction

Technological advancements are made for the benefit of people in their everyday life. One area essential for the well-being of human beings is that of medical technology as our quality of life is highly dependent on ensuring that we retain a healthy body and a healthy lifestyle. Medical technology has the goal of enabling the users of such technology to receive medical attention, medical services, or medical products in an efficient manner. Such technology also includes facilitating the proper delivery of prescribed medications to an individual by a healthcare provider.

In this specific area of products that specialize in the delivery of prescriptions, there exists many devices that allow for the automated scheduling and dispensing of prescriptions to a user of the device. Typical users of such devices are seniors and people with physical movement or cognitive limitations. Thus, such automatic pill dispensers have the ability to significantly increase the quality of life of the users by ensuring that they are receiving their prescribed medications on time. However, current products are limited to only the dispensing of the medications. They include methods and sensors to ensure that the prescriptions are properly dispensed at a timely manner, however, there is no method to verify if the pills have actually been consumed by the user or not.

The goal of this work is to introduce a mechanism that can detect if the user of a small pill dispenser has likely consumed the pill. We describe the design and evaluation of a “smart cup” which is a device to be used in conjunction with an automated pill dispenser. The smart cup also includes sensors and signal processing capabilities to act as a method of confirming that the pills dispensed have been consumed by the user. The overall goal of such a system is to ensure that users, expected to be seniors or people with disabilities, to take their medication and pills on time and, as appropriate, inform healthcare providers of missed medications.

This work describes three versions of a smart cup design. Each version uses a different complement of sensors (accelerometer, gyroscope [3], and IR proximity sensor) and each version is designed to overcome specific limitation of prior versions. We also conducted experiments with all three versions to evaluate its accuracy at detecting movements indicative of the consumption of a pill. The main contributions of this paper are: 1) three designs of a smart cup using different combinations of sensors for detecting pill consumption, and 2) design of evaluation experiments to systematically measure the accuracy of such smart cup systems.

II. Related Work

Rajan et al. [1] describe a smart pillbox that is based on an Arduino. Their system sends reminders to the users with a smartphone app. Zeidan et al. [2] describe the design of a medicine box to monitor the consumption of multiple pills. The main focus of their system is safety and security, i.e., keeping the medication out of the reach of non-users by locking medicine box after pills are taken. Kanhasinwattana et al. [4] describe a smart pillbox system that includes an application to set up medication reminders and collect feedback from the pillbox if the medication was taken with the prescribed time. Abdul Kader et al. [5] developed a smart medicine box to remind seniors and hospital patients to take their prescribed medicines on time. The focus of their work was in reminding users with sound and LED lights when the time for medication arrives. Vasil Moise et al. [6] use an ATmega328PB microcontroller, two solenoids, a stepper motor, two microswitches, one buzzer, a real time clock module, and an LCD display to implement a smart pill dispenser. Ransing et al. [7] describe how a smart home can be built using different types of sensors to make it suitable for elder care. Huang et al. [8] describe improvements to pill dispensers to make them more suitable for elders. Somewhat different from these systems, Chang et al. [9] describe a smart eyeglasses-based pill recognition system to make pill dispensing systems safer to use by visually impaired people.

III. System Design

A. Device Configuration

The smart pill dispenser will be designed to have several slots where each slot represents the medications or pills needed to be taken at a specific time or day of the week (Figure 2). The smart pill dispenser will rotate to the specific slot, based on the specific information obtained from a database of users of this device, and dispense the medication and pills of the day into the smart cup. Following this, the smart cup will detect if the user consumes the pills dispensed at that time and inform the smart pill dispenser of the completion of the consumption of the pill.

Several design considerations were taken into account in the design of the smart cup. The design considerations were based on the limitations of different sensors. We implemented three versions of a smart cup design in this work. These are:

V1: with an accelerometer to measure the axis of orientation of the smart cup,

V2: with a gyroscope added to the accelerometer to measure angular orientation of the cup, and

V3: with an IR proximity sensor to measure the height of the cup while the user is interacting with the smart cup.

Figure 1 show the prototype of the feedback system to be attached to the smart cup. Figure 3 shows the block diagram of the smart cup design. The sensors consist of the integrated IMU model LSM6DSOX, for the accelerometer and gyroscope, and Sharp GP2Y0A21YK0F for the IR proximity sensor. The gyroscope, accelerometer, and IR proximity sensors are attached to the smart cup via an Arduino RP2040 Connect to serve as the feedback system of the cup that will eventually send such information to the smart pill dispenser. The microcontroller collects the readings from the sensors, and then sends this information to the smart pill dispenser. As the smart cup will be lifted by the user, we will implement a wireless rechargeable power supply. Figure 4 is the design for the smart cup and its desired motion when the user interacts with it when taking the pills dispensed from the smart pill dispenser.

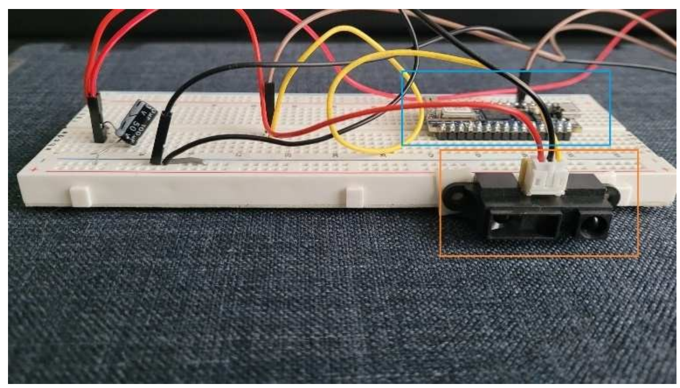

Fig. 1. In blue box: RP2040 Arduino connect board with accelerometer and gyroscope. In orange box: IR proximity sensors.

IV. Evaluation and Results

A. Procedure

To assess the ability of the three versions of the smart cup to detect the consumption of pills by the user of the smart pill dispenser, we conducted several experiments where we systematically performed different types of actions with the smart cup and evaluated its ability to correctly detect the action. The different actions are designed to include situations in which a false positive could occur, i.e., where the user does not complete the action of consuming the pill but the system incorrectly identifies a completed action.

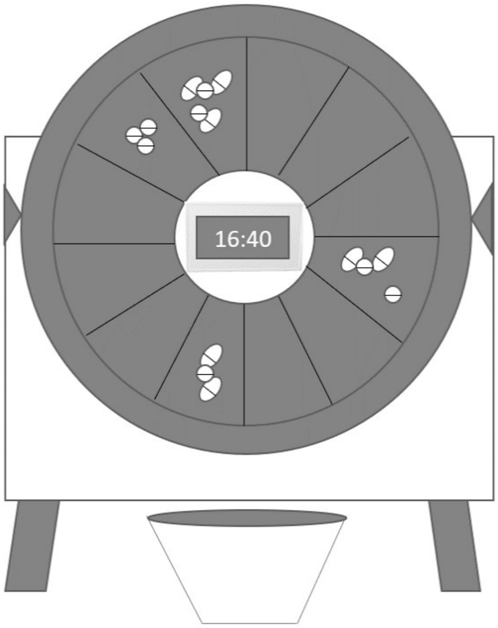

Fig. 2. Prototype of Smart Pill dispenser with Smart Cup

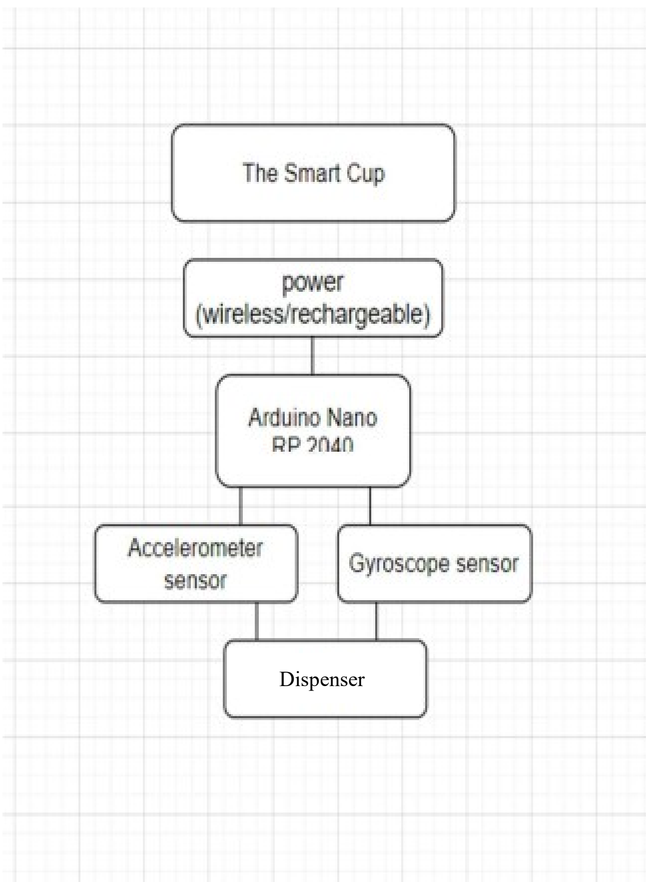

Fig. 3. Block diagram of the design

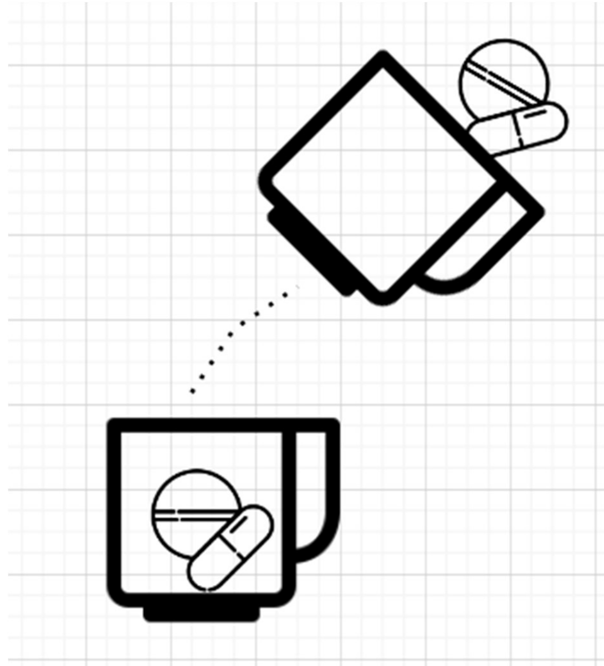

Fig. 4. Design for the smart cup.

The first experiment consists of performing the action of consuming the pills in the ideal form as illustrated in figure 4. The purpose of this experiment is to evaluate the ability of the system to detect the user performing the typical action after the pills that have been dispensed. The second experiment covers the case where the action of consuming the pill has been interrupted. This is to consider situations such as the user begins to consume the pills but gets distracted for various reasons and does not complete the activity. The purpose of this experiment is to evaluate the ability of the smart cup to identify such interrupted actions and detect that the pills have not been consumed. The third experiment consists of performing no action. The purpose of this test is to verify the system's ability to identify that the pills have not been consumed and no attempted to consume them have been performed.

In addition to these three experiments, we measured different movements of the cup to evaluate three specific movements that are key to the proper consumption of the pills. These three movements are (1) the lifting of the cup, (2) the tilting of the cup, and (3) both actions performed in sequence. These movements were performed in each of the aforementioned experiments in order to potentially create a false positive, and visualize if the cup is able to identify these scenarios and accurately inform the smart pill dispenser if the pills have been consumed or not. Each test was performed three times for each movement. As there are three different versions of the smart cup, these tests were repeated two additional times, for a total of 81 measurements.

B. Results

Tables 1-3 show the results of the evaluation experiments conducted with the three versions of the smart cup. The data in the tables indicate the number of successful detections of the user performing the movement associated with lifting the smart cup and consuming the pill after it was dispensed by the pill dispenser. Table 1 includes the data corresponding to design V1 of the smart cup – with only an accelerometer used to confirm the proper action on the cup. Table 2 includes the data collected from design V2 of the smart cup. This version includes both an accelerometer and gyroscope for data collection. Table 3 includes the data obtained from design V3 of the smart cup which includes an accelerometer, gyroscope, and an IR proximity sensor. Each version seeks to mitigate the shortcomings of the previous version in its ability to avoid false positive values obtained from the sensor measurements.

Note that we evaluate different types of movements in these experiments. The first movement measured in these tests corresponds to a complete pill consumption action performed with the smart cup. Thus, a successful detection corresponds to the system detecting that that the pills were consumed. For the second movement, the action of the smart cup is only partially performed corresponding to a case where the pills are not consumed. Thus, successful detection of movement two is the system *not* providing a positive response to the lifting of the smart cup. In the third movement, both actions are performed in sequence and successful detection of this sequence by the system indicates the user correctly consuming the pill. Additionally, given that each test performed on each type of movement was conducted a total of 3 times per test, these measurements are averaged, one time for each test on each movement, and one final time to calculate the average per test.

Table 1: Accuracy of design V1 of smart cup (accelerometer)

Number of true positives			
Measurement	**Test 1**	**Test 2**	**Test 3**
Movement 1	3	3	3
Movement 2	0	0	0
Movement 3	3	0	3
Accuracy	67%	33%	67%

Table 2: Accuracy of design V2 of smart cup (accelerometer and gyroscope)

Number of true positives			
Measurement	**Test 1**	**Test 2**	**Test 3**
Movement 1	3	3	3
Movement 2	3	0	3
Movement 3	3	0	3
Accuracy	100%	33%	100%

Table 3: Accuracy of design V3 of smart cup (accelerometer, gyroscope, and IR proximity sensor)

Number of true positives			
Measurement	**Test 1**	**Test 2**	**Test 3**
Movement 1	3	3	3
Movement 2	3	3	3
Movement 3	3	3	3
Accuracy	100%	100%	100%

C. Analysis

Table 1 shows that design V1 of the smart cup (which uses only an accelerometer to detect the proper movement of the smart cup) results in many false positive cases in the detection of whether a user has taken the pills at the moment the action is performed, specifically in the tilting action of the cup, which is represented in movement two on the table. This indicates that if the user had the intention of not taking the pills, they could falsely indicate to the cup that the pills had been taken by partially doing a tilting motion from the cup, and the V1 design of the cup would incorrectly inform the smart pill dispenser that the pills had been consumed. Additionally, as there is no method to measure the distance moved by the cup or to indicate whether the cup had been correctly lifted, these movements could be mimicked at different heights, different from the ideal height (i.e., at the level of the user's mouth), and still result in a false positive measurement of the cup.

Design V2 addresses these issues by collecting data from the smart cup with an accelerometer and gyroscope. The gyroscope measures the angular velocity of the movements performed by the cup in each test. By using this information, the smart cup is able to not only measure the axis of orientation of the cup but also its angular orientation. The results in Table 2 indicate that design V2 of the smart cup is able to identify when the cup has been lifted and tilted properly, which are tests 1 and 3 of the tables. However, even though the results in Table 2 show an increase of accuracy from 67% to 100% in tests 1 and test 3, the design is still unable to avoid the false positive result that comes from lifting the cup partially and tilting it to have the pills fall out of the cup (test 2). This is because this design still does not consider the height of the cup itself.

To address these shortcomings, V3 of the cup includes an IR proximity sensor to sense the position of the cup and its height after its interaction with the user of the smart pill dispenser. Results shown in Table 3 indicate the accurate performance of the system at detecting if the motions have been correctly completed; thus, detecting if the pills have been consumed by the user or not. The mean accuracy of all three tests for all three movements is 100%

V. Conclusions

This work described the design and evaluation of a smart cup to be used in conjunction with a smart pill dispenser. The purpose of this additional smart cup is to identify if a dispensed pill has actually been consumed by the user. The smart pill dispenser will handle the scheduling and selection of the necessary prescriptions and pills for each day and time in which the user needs to consume these medications and pills, and the smart cup will verify that these medications are consumed. We designed and evaluated three versions of a smart cup. Version 3 of the smart cup showed the greatest accuracy in indicating whether the user has completed the action of consuming the pills or not. This design is not only capable of detecting that the appropriate actions are performed by the holder of the cup (i.e., the lifting and tilting of the cup), but it is also able to determine if such actions are performed in sequence. Thus, this design is able to detect a partially complete action which indicates that a user began the movement indicative of consuming the pill but did not actually consume the pill. This capability is essential to a health provider in order to be able to take the necessary actions that may be necessary in a critical situation resulting from the failure of taking medications.

VI. Future work

The main focus of this work was the smart cup that would be used in conjunction with a smart pill dispenser. We are currently developing a design for a smart pill dispenser. The complete design of the system will use a smart cup in conjunction with the smart pill dispenser to dispense pills at a scheduled time into the cup; the cup will awake from its standby mode and will wait for the user to interact with it to consume the pills. As the smart cup will have to function wirelessly, it will require a wireless power source. Future work related to the smart cup is the inclusion of a wireless power source, as shown in Figure 3. Additionally, in order to reduce the number of times that the user may need to replace batteries of the device, given that these users may be elderly or have issues in performing these tasks, the power source will be implemented using wirelessly rechargeable batteries. We will also add the ability of the smart cup to go into a power-saving sleep or standby mode in order to not only conserve its power level, but also to reduce the utilization of its sensors and thus prolonging the longevity of the sensors and the system as a whole.

Acknowledgement

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