HEXADRAWERS: MODULAR DRAWERS FOR MEDICINE SCHEDULE MANAGEMENT

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20 February 2021

Abstract: *Nowadays, more and more people take multiple medications a day. Especially for the elderly, it is quite common to forget a medicine or take it more than once in a row. Our device would store different medicines in separate drawers and warn the user when it is time to take their medication, indicating which medicines to take. The reminder stays on until the system confirms that the number of medicines has decreased. On the other hand, if too many doses are taken, a warning message is sent to a caregiver. Additionally, we built a remotely accessible system for scheduling the weekly calendar of the pills and receiving warnings.*
Keywords: *medicine, drawer, pill, modularity, scalability*

1. INTRODUCTION

In Italy 1.3 million people (11.3% of the population) take 10 or more different medicines a day. If we focus our attention on the elderly, 55% of people aged between 75 and 84 years old must remember to take between 5 and 9 medications a day, while 14% take even more doses.

Our project is modular and highly scalable, consisting of a variable number of hexagonal prismatic cells each hosting a drawer devoted to the storage of a single type of medicine and including the computational power required to process the data from the sensors. One of the cells, called master cell, also takes care of the communication with the users.

In order to manage the schedule remotely (for example a grandchild can remotely set up the drawers and keep the schedule updated for a grandparent) we need a WiFi connection. Therefore, the master cell connects to the WiFi network to receive the schedule and information about the medicines in the drawers. It also receives from the other cells the actual number of doses inside each drawer and takes decisions based on this information. To warn the user when they need to take one or more specific medicines, the master tells the corresponding cells to light up: the lights turn off only when the relative drawer has been opened and closed and the system confirms that the number of medicines has decreased. The interaction with the system is carried out through a Telegram bot with a simple and intuitive series of commands in a chat-like interface. If the user took more than one dose, the system sends a warning message to the authorised Telegram accounts. Moreover, if one or more drawers have been left open for more than a certain amount of time the master warns the user through an acoustic signal that persists until all the drawers are closed.

Inside each hexagonal prism, the actual drawer consists of a parallelepiped divided into a different number of compartments based on the kind of medicine stored: for example, two columns and seven rows for pills and one column and seven rows for sachets.

To determine whether the medicine is present or not in each compartment there is a vertical hole which goes from the bottom to the top of the structure and an IR laser beam going through it. To understand which compartment the laser signal is referring to at any time, we keep track of the position using an incremental encoder consisting of the following sequence: a magnet for each side, a magnet on the left, a magnet on the right.

Since the only components not in the casing are the magnets, we can easily clean and sanitise the drawers.

Lastly, the modularity of the product makes it easily adaptable to the user's needs and makes it possible to build a system only as big as needed, limiting costs.

2. RELATED WORKS

Nowadays the most common solution for the weekly management of medicines consists of a simple box divided into some compartments, each one devoted to a single day. This extremely simple solution allows to transport medicines around during the day and to always have at one's fingertips an organised medicine drawer: however, this product does not give the opportunity to divide the pills according to the time slot in which they should be taken, which increases the risk of mistaking one pill for the other.

A first improvement has been obtained by partitioning each compartment into four sub-compartments corresponding to the four main segments of the day: morning, afternoon, evening and night. Even though this object gives us a rather simple control on the timing, there is an important disadvantage: for instance, if we need to take a medicine at 3 pm and another one at 5 pm, they are both stored in the afternoon compartments, therefore they can be taken by mistake.

In order to avoid this issue altogether, digital medicine dispensers have been designed: they memorise the exact hour in which the pills should be taken and warn the user when the time comes.

These devices usually have a single compartment for all the pills of the same medicine: therefore, there is no way to keep track of the number of doses inside the drawer.

We focused our attention on the devices intended for the daily medicines of old people who most likely do not have to travel: therefore, the mobility requirement is not a key point.

Within this scope, one of the most relevant solutions is HERO, a smart product suitable for personal and home use that stores, dispenses, and manages pills. It is a non-moveable machine that can contain up to 10 kinds of pills. It is also lockable and password protected. HERO's main drawback is its cost: currently, it is rented at a monthly cost of 29.99$.

However, all these kinds of devices are not modular at all, very expensive and difficult to adapt to your needs.

3. PROPOSED SOLUTION

3.1. System specifications

The system must be capable of storing and managing medicines: it must keep track of the number of doses of each kind of medicine, remind the user to take their medicines at the right time and check if the dose has been removed from the cabinet. The system should require as little interaction as possible from the final user: a part time caregiver or family member periodically restocks the cabinet and the same person, or even a third involved person, remotely updates the schedule. Therefore, the system must have an internet connection to update the schedule but it must also be able to save the data locally and preserve them in case it gets powered off and on.

In order to allow the sanitisation of the drawers, no electrical or mechanical elements should be included within the drawer: therefore, all these components are to be placed in the casing. Since this product is intended for a domestic environment, it must also be affordable.

The system manages a very delicate aspect of the user's life, therefore it must be highly reliable.

Energy efficiency is not a main constraint since the device is not to be moved and can therefore be constantly plugged in.

3.2. General architecture

The cabinet is composed by a master cell connected to a varying number of additional cells. All the cells are hexagonal prisms that can be stacked and new cells can be added later based on your needs.

The master cell contains the microcontroller which receives data from the other cells, processes and stores them and activates the visual and acoustic warnings for the user. Since the schedule and the settings are controlled remotely, the microcontroller in the master cell must be WiFi enabled: therefore, we use an ESP32 microcontroller. Moreover, the master cell contains the buzzer which is enabled whenever a drawer has been left open or a medicine has to be taken.

Each secondary cell contains a rectangular prismatic drawer and the sensors that monitor its content. Some computational power is required to interpret those signals and for lack of custom components an Arduino can be used, even if it is way more than what is needed.

In all cells, two IR beam-breakers are placed above and below the drawer guide while two Hall sensors are placed on the two sides of the guide, triggered by a set of magnets encased in the drawers. Two LEDs are located on the front of the cell and they light up when it’s time to take the medicine.

Given a fixed design of the casing, it is possible to design different drawers that can store different types of medicines. For example, in the case of pills the drawer can be partitioned into 14 compartments arranged in two columns and 7 rows: each compartment contains a single pill and presents a hole on the bottom which lets the signal of the IR beam-breaker pass through. Long sachets, instead, could be hosted in drawers with a single column of compartments corresponding to two pill compartments each. In this case both beam-breakers will measure the same compartment. Each cell has been designed so that it is easier to collect the medicine: cells for pills have a paraboloid-like shape while cells for sachets have a wedge shape.

Hereafter we will implicitly refer to the drawer configuration and counting algorithm for medicines in the form of pills: as previously said, different drawers for sachets are also compatible with the same casing.

The communication between the master cell and all the others is carried out through the RS-485 protocol. The architecture, shown in Figure 1, consists of a vertical bus (black in figure) passing through a column of cells piled up on the master cell and some horizontal busses (white in figure) that connect each row of cells to the one placed above the master cell. Therefore, each cell also contains two RS-485 transceivers, one for the horizontal bus and one for the vertical bus: the master cell acts as master for the vertical bus while the master cell and all the other cells piled up on it act as masters for the corresponding horizontal busses. The cells are kept in place by magnets that also align the pins of the connectors.

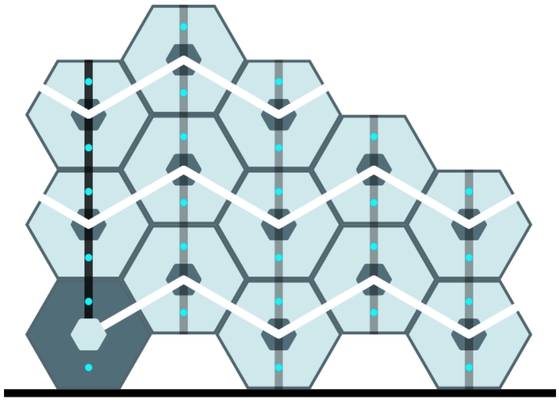

Figure 1: cabinet and busses scheme

The connection phase begins when the caregiver selects the “Update cabinet” command in the Telegram bot. Hereafter, the master cell starts sending connection requests on both busses. All other cells, when physically connected, power on and automatically go into connection mode on both busses. If a cell establishes a vertical connection, it takes the role of master for its horizontal bus while still propagating the vertical connection signal. If, instead, the cell establishes a horizontal connection, it takes the role of horizontal propagator and disables the vertical bus. When a cell is connected, the corresponding LEDs light up: once all the physically connected cells are lit up, the user can switch off the connection mode in the Telegram bot. To get started only a master drawer is needed, to which secondary cells can be added later: these cells are designed so that they can be placed either in a horizontal V bus or Λ bus configuration.

To communicate with the device, we designed a Telegram bot with specific reply keyboards that, through a chat-like interface, allows the caregivers to see and manage the contents of the cabinet. To start the bot, the caregiver can search inside the Telegram app the bot ID written on his cabinet or simply scan the corresponding QR code. At the first interaction the bot will ask for a code, reported on the documentation of the master cell. After the code has been sent the caregiver's Telegram ID will be added to the list of the allowed Telegram IDs that the bot will respond to. The main menu shows a list of possible commands: "Manage drawers", "Opened drawer alarm", "Connect new WiFi", "Update cabinet".

The "Manage drawers" command allows you to manage the content of the drawers: first of all, it shows information about the medicines stored in each drawer and allows you to edit one of the drawers or to clear one. If you want to edit a certain drawer the system asks for the name of the drawer, the kind of medicine (pills or sachets), the next time when the medicine must be taken and the repetition period. In the end it asks if (and how many doses ahead of time) you want to be warned by a Telegram message that the medicine is running out. When you are editing a pre-existing drawer there is also a "Leave unchanged" option for each field. The "Opened drawer alarm" command allows you to set the time after which the buzzer should warn the final user that one or more drawers have been left open. This is necessary since the counting process occurs only during the closing phase. The "Update cabinet" command tells the system to initiate the connection of new cells. The "Connect new WiFi" command lets the caregiver save a new WiFi network. For testing purposes, there is also a hidden main menu command that resets all the data and re-initialises the memory.

To detect whether the pill is inside the compartment or not, we mainly considered PIR sensors, sonar modules or break-beam sensors: we chose the latter since they are the best compromise between performance and cost. Indeed, compared to PIR sensors, beam-breakers are faster and more directional, and, compared to sonar modules, they are less expensive. In addition, the need of both an emitter and a receiver is not constrictive for our purposes: the infrared break-beam sensor works by having an emitter placed on one side of the guide that sends out an IR laser beam, and a receiver placed on the opposite side. When the hole in the compartment aligns with the two pieces, a signal should be measured; if not, it means there is a pill in that compartment.

In order to determine the row in which the beam-breaker's measurement is taking place, we use two Hall sensors located in the casing and a set of magnets encased in the drawer between two adjacent compartments. Each position is marked by one of the three possible configurations: a magnet on each side, only a magnet on the left, only a magnet on the right. These configurations are periodically repeated.

To avoid any possibility of confusion for the final user we decided not to use RGB LEDs and have only one colour available: therefore, we opted for a buzzer to catch the attention of the user and two simple monochromatic LEDs placed on the front of the cells to indicate which one to open.

3.3. Relevant characteristics of the system

The internet connection is provided by the built-in 2.4 GHz WiFi module. Up to three WiFi networks are stored in memory and can be forgotten or added by using the Telegram bot: upon reboot, the device cyclically tries connecting to all stored networks, starting from the most recently used. Since communication with the bot can occur only while the drawer is already connected to a WiFi network, the initial configuration is achieved by setting the WiFi router on a mobile phone to the individual first configuration SSID and password of the specific device: these values are reported in the documentation and can't be changed. After this temporary connection has been established, the user can easily connect the device to the actual WiFi network through the Telegram bot.

By using the incremental encoding, we are able to distinguish between the two possible directions, opening and closing. For example, when the last magnets state is a single magnet on the left, if the new magnets state is a single magnet on the right we are opening the drawer while if the new magnets state is two magnets we are closing it. When the same configuration is repeated, it means that we changed the direction and we came back to the same position. Some exceptions had to be taken into consideration such as when the direction changes while a magnet is being measured. Only the measurements taken during the closing phase are saved, while the ones taken in the opening phase are cross referenced to those stored in memory: since the state cannot change when the drawer is closed, if we detect a changed value it means something is not working properly. In such cases an error message is sent to the developer, eventually with some diagnostic data.

When the system boots up, it loads the settings and cabinet data from the memory, connects to the internet and downloads the current time from an NTP server; it also checks for skipped occurrences and updates them until they are in the future.

3.4. Possible future developments

The use of a Telegram bot also allows OTA updates to the sketch in order to add new functionalities or fix bugs. This function, together with the possibility to receive diagnostic data from the devices, makes it possible to optimise the cell occupancy recognition over time.

Since medicines need to be stored at a certain temperature, a software update could make use of the built-in temperature sensor in the ESP32 microcontroller to monitor the temperature in the cabinet and send a message when it gets too hot.

In the master cell we could insert a backup battery in order to make the device perform its basic functions even when the power is temporarily down. To make the battery last longer, the device could enter deep sleep mode setting the wake-up timer for just before the next medicine has to be taken. Once it checks that the user has removed the dose, it goes back to deep sleep mode with an updated wake-up timer.

In the future the Telegram interface could be replaced by a custom mobile application. This would also make it possible to achieve the WiFi configuration traditionally through the app and a temporary Bluetooth or WiFi connection of the drawer to the phone. Moreover, since the elderly often do not have a WiFi connection available at home, we could include a GSM cellular data module in the master cell.

To prevent an error from corrupting the counting system until reboot, we could use a third Hall sensor placed on the guide in the position of the last magnet when the drawer is closed: this way, each time the drawer is closed, the counting algorithm starts again from the closed configuration; therefore, a counting error remains restricted to one single opening and closing step and does not propagate. In a nutshell, this can be seen as a hardware checkpoint for the counting system.

To avoid dirt, such as pill debris, from getting stuck in the holes and obstructing the laser beam, the hole should be filled with an IR transparent material.

4. EXPERIMENTS

4.1. Prototype

For our prototype we used the ESPRESSIF ESP 32 – WROOM – 32 microcontroller (approx. 8€), the Adafruit 3mm IR Break Beam sensor (approx. 4.50€ for 2 sensors) and the AZ-Delivery Hall effect KY-003 sensor (approx. 4.70€ for 2 sensors). We designed the 3D models of the casing and of the drawer with AutoCAD 2021 and we printed them with a CoLiDo DIY 3D printer using PLA filament (approx.

3€ of filament used). The total cost has been approximately 20€.

We glued a custom-built beam-breaker holder to each beam-breaker hole in the guide and then we placed the sensors there. We placed a Hall sensor on each side of the guide and we inserted 7 neodymium magnets in the holes left in the printed drawer for this purpose. We connected all the wires to a breadboard which is connected to the microcontroller. The microcontroller was plugged into the wall or to a PC. The software was developed in C using Arduino IDE. We put together the front panel and the guide without the lateral surface to test the system; after we confirmed that each component individually was working properly, we covered them all by adding the lateral surface.

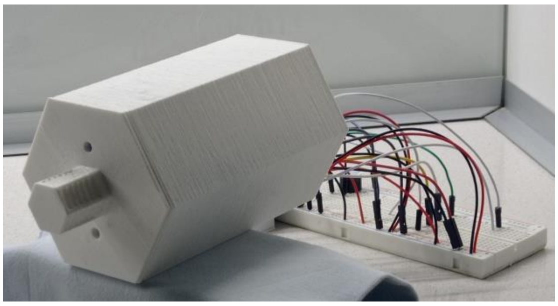

Figure 2: prototype

4.2. Experiments

First of all the device was connected to different WiFi networks and the Telegram bot was tested using different accounts.

After we assembled all the printed components and we placed the sensors, we wrote some auxiliary code to check that all the components were still working properly and that they were placed correctly. Using this code we made sure that the magnets were strong enough to trigger the Hall sensors through the plastic wall but not such that the fields generated by two neighbouring magnets would overlap. Then, we checked that the beam-breaker transmitters and receivers were aligned. At this point, we uploaded the complete version of the code and checked all the functionalities: the LED reminder system, the counting system, the message warnings, etc.

For this purpose, we set a schedule and simulated many scenarios: receiving a LED reminder and taking a pill, forgetting one, taking too many, leaving the drawer open…

5. CONCLUSIONS

The designed system provides a good trade-off between cost and performances: buying all the pieces in bulk, the estimated cost of the materials is under 13.50€ for the master cell and under 8€ for each additional cell, while still having good detection quality.

Moreover, our solution is not limited to a certain medicine format and dimension: different drawers can host pills, sachets and more.

In this paper we have therefore presented a flexible device that can improve everyday life, especially for the elderly: the final result is an easy to use, affordable product that allows you to take care of your loved ones by being warned in case of low stocks, skipped doses or overdosage.

6. REFERENCES

[1] A comparison of IoT-connected, automated pill dispensers, available at: https://medium.com/@medipense /2017-the-year-of-the-iot-automated-pi lldispenser-ca1d41f0592b, accessed Dec. 2020.

[2] Automatic Pill Dispenser & Medication Manager | Hero, available at: https://h erohealth.com, accessed Dec. 2020.

[3] IR beam-breaker sensor, available at: https://www.adafruit.com/product/217 and https://thepihut.com/products/ir-br eak-beam-sensor-3mm-leds.

[4] Hall sensor, available at: https://www.a z-delivery.de/en/products/hall-sensor modul-digital?_pos=1&_sid=b445225 65&_ss=r.

[5] Arduino Telegram bot, available at: https://core.telegram.org/bots/api and https://github.com/witnessmen ow/Universal-Arduino-Telegram-Bot.

[6] Ibox: Smart Medicine Box With Iot Application, Nur Zulaikhah Nadzri et al., European Journal of Molecular & Clinical Medicine, Volume 07, Issue 08, 2020.