RAPID - Reliable Autonomous PIll Dispenser

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1 INTRODUCTION

In a society with an increasing elder population[Hobbs 2001] combined with traditional non-reliable forms of medicine intake control solutions, our society is faced with the growing problem of wrong medicine administration by frequent users that rely on traditional methods.

The Italian average for medicine consumption is 1.5 pills a day, with this value climbing to 10 (3 doses a day) for people over 65 [Zito et al. 2021]. Following the medication, schedule requires “prospective memory” [Nabacino and Negretti 2020][Crystal and George Wilson 2015] which is a specifically hard task for people suffering from dementia or Alzheimer’ syndrome, and in general for elder people. The introduction of caregivers to administer the medicine intake marginally solves the problem, being reliable to human error and resulting as very time-consuming.

Our objective consists of designing a safe, reliable, cost-effective smart solution based on previously proposed solutions, improving and resolving their main issues: "HexaDrawers"[Marco Faverzani 2021], "MeDiC"[Nabacino and Negretti 2020] and "Med-Drop"[Pike et al. 2021]. The final desired product includes a seamless pill intake procedure in which any non-fundamental action from the user is performed by the system.

Reliability and safety are the most important factors for our design, followed by cost (to enable more users) and intrinsic modularity. In the hopes of reducing pill intake errors, introducing more tranquillity for the families or caregivers, our design doses with high degrees of autonomy medication to patients who are unable to assert their pill intake schedule.

The project is highly scalable through 3D printing, with every module consisting of a pill magazine and a reliable delivery system, in order to overcome the risk of overdosage. Multiple modules can be stacked side by side, organized in a master-slave configuration with the master module connected to the internet for remote control of the delivery schedule and to communicate via notification/email with the caretaker.

The master module is tasked with notifying the caregiver about any deviation from the user schedule or from the system regular operation. Such messages include warnings when a pill is not delivered or taken properly on schedule; reminders when storage is almost running empty.

For optimal operation, the physical dimension of the pill determines the "type" of magazine needed; the pill is dispensed from the magazine through a sliding compartment and a load cell check the correct operation of the sliding mechanism; a photo-interrupter sensing system verifies and counts the number of pills dispensed for each individual module to ensure the correct operation of the pill selection system. Finally, each module emits a sound when it’s ready for the user to intake and lights a green LED to signal which medicine needs to be taken.

2 RELATED WORKS

The first and still most common approach to improving medication adherence are pill organizers, simple containers divided into compartments to group different pills [Pike et al. 2021].

The most advanced of such devices can lock or unlock the various compartments on a time-based schedule set by the users [Marco Faverzani 2021], while also reminding the patient which pill has to be taken. Even if the risk of assuming wrong medicines during a day is mostly mitigated, the organizer requires frequent refilling by a caregiver or relative of the patient.

One advantage of schedule-based organizers is portability, being battery-based, making them a valid solution for users that roam often during the day [LiveFine 2019]. Our project however, focuses on people who are mainly located at home, either by ageing issues or mental or physical disabilities. Self-contained units are already present on the market [Health 2020][Philips 2004][PharmRight 2020], equipped with smart features.

The main drawback is the high cost of such units, not to mention their lack of modularity and scalability. To solve this issue, we are basing our design on different prototypes [Nabacino and Negretti 2020][Marco Faverzani 2021], all while keeping cost as low as possible. Here’s a list of some of the solutions discussed above and other similar products.

2.1 HexaDrawers prototype[Marco Faverzani 2021]

A highly modular setup made of hexagonal drawers that communicate through a magnetic interface, using an innovative method through a Telegram bot in a master-slave configuration. In this way a single ESP32 micro-controller manages the whole system, keeping the prototype price as low as 20€. It however requires pre-sorting the pills by schedule, leaving such important tasks to the user or caretaker.

2.2 MeDiC prototype[Nabacino and Negretti 2020]

Due to the very simple mechanical design, this prototype shows high reliability and precision, and it’s open to further implementation for modularity. However, the refilling process is time-consuming. Additionally having a higher medicine capacity would require a very large and impractical device.

2.3 Med Drop[Pike et al. 2021]

This design was implemented to aid nurses to distribute medications in-home visits to VA (Veteran Affairs) patients; it is a fully mechanical device used as both a sorting tray and a pillbox, an attempt to solve the intrinsic problem of schedule based pill dispensers.

It is a great solution for its intended use but presents itself as a fully passive device with no smart related features. The announced cost of the prototype is 19.89$.

2.4 Phillips Medication Dispenser[Philips 2004]

The product can only be rented through a monthly subscription fee of 59.95$ with no initial cost, though it requires a phone line to issue alerts to caregivers of any important warning. It contains an internal backup battery and can take up to 40 days of 6 different medications.

2.5 LiveFine Automatic Pill Dispenser [LiveFine 2019]

It's the simplest commercial solution, consisting of 28 compartments that can be unlocked on a time-based schedule. Given its plastic construction, it's prone to breaking or unlocking if dropped or abused. It lacks all sorts of connectivity and we can consider it competitive only for its price tag of 89$.

2.6 Livi automated medication dispenser[PharmRight 2020]

The Livi Medication Dispenser offers a 90-day reservoir for 15 different pills with time-programmable reminders and alarms. Based on the medication size, the user is required to assemble the specific reservoir to ensure better functionality.

The device works with main power, backed up by a battery that guarantees 8 hours of continuous operation. It's not state of the art but still very capable. However, it's the most expensive solution, requiring a first 49$ instalment followed by a monthly fee of 99$, which amounts to 2,425$ over a 2-year span.

2.7 Hero[Health 2020]

With a 90 day reservoir of up to 10 medications and a fully functional and integrated app to control the device, the Hero pill dispenser can be considered the market reference point when designing a pill dispenser.

It combines all of the main desirable features such as schedule customization with reminders, fully automated pill sorting and delivery, notifications and warnings for caregivers, relevant data visualization in an easy-to-use package, all coupled with smart connectivity.

All its features come at a hefty price for extended use: a 99$ first instalment, followed by a 29$ monthly fee (795$ in a 2-years use interval).

3 PROPOSED SOLUTION

3.1 System Specification

The main goal of this design is to facilitate the management of the pill intake regime and by consequence increasing the user's pill adherence. To achieve that it must autonomously store and dispense medicines, organizing them into a set amount of pills of different types and dosages, following the medical schedule of the patient.

It must be highly reliable as the pill-taking procedure is a sensitive part of the user's life and requires the correct amount and type selection of pills from the storage compartment, only then it can improve pill adherence concerning other traditional methods that rely on "prospective memory [Crystal and George Wilson 2015]".

To adapt to various patient routines, it requires internet connectivity, through which the schedule can be uploaded, while also storing some data locally to ensure temporary backup even in the case of a power outage. If patients are highly impaired, caregivers are given the role of refilling the system's storage and remotely setting the medication schedule.

Smart connectivity is required from the RAPID system, which includes notifications and warnings for both the user and the caretaker. Through the use of alarms and LEDs, it signals to the user, and through the use of email notifications, it can inform the caretaker. When it is time to ingest a medicine a buzzer sound will remind the user to take the pill and LEDs signal which module is being activated. On the other hand, warnings are sent to the caregiver in case of a missed pill, failed pill delivery or tilting of the device or short supply of pills.

Another important requirement is a low production price, as many of the available smart all-in-one solutions roam in the order of the thousands of dollars after 2 years of use, our solution aims to be affordable to a larger public, staying below the 80$ mark.

To make RAPID more customizable, a side-by-side modular configuration has been adapted, with every container reserved for a single medicine type. The mechanical coupling between modules is achieved through perimetric magnets, while the electrical connection is achieved through a multi-pin magnetic connector.

3.2 General Architecture

The minimum configuration is comprehensive of a master cell connected to the first dispenser module, and all the other modules required can be added side by side; the master cell manages all the computation required through an Arduino Nano IoT 33 microcontroller, and the email service is achieved through an ESP8266 module. Aside from storing the medical schedule of the patient and driving the mechanics of the device, the microcontroller Arduino Nano IoT 33 manages the notification system for both the user and the associated relative or caregiver.

The pills are stacked one above the other in a vertical cylindrical container, which is closed by a bottom gate controlled by an Sg-90 servo motor. A 28BYJ-48 stepper motor controls an arm one pill height above the first pill. By synchronizing the rotation of the servos, the dispensing action is performed in 4 stages. First, the higher servo motor displaces the above pill until it touches the wall of the device, locking it in place and blocking the whole column. Then by opening the bottom gate a single pill falls while the others are held by the locking arm. The gate closes after a short period of time. The locking arm is released by activating the servo motor again, unlocking the pills that can slide down, putting the second pill just above the bottom gate and the cycle can be repeated.

After leaving the gate, the pill passes through a photo-interrupter that serves a double purpose: a counter to keep track of the dosage of medicines (in case that multiple doses are required) and as a check sensor, to ensure the correct functionality of the device.

For the system modularity, every magazine features 2 connectors on its sides, thus allowing the daisy-chaining of the various compartments required by the medical necessities of the patient. Each module shares the same working mechanism, but the dimension of the single container depends on the size of the medication that has to be dispensed. Following the Capsule Size Guide[International 2018], the dispensers are designed to serve the most consumed pills. To calibrate the module, the user is required to turn an adjusting screw to correctly set the height of the locking servo-motor to allow exactly one pill in between the bottom gate and the servo locking arm.

The whole enclosure for the device should be made through 3D printing only, thus to keep the prototyping cost as low as possible; its design should not limit the flexibility of the dispenser regarding the size of the medicines, so a simpler rectangular enclosure is chosen.

3.3 Relevant System Characteristics

Arduino Nano IoT 33 is the board chosen to perform the sensor data analysis and to manage the main signals. Via the magnetic connector, the board is connected to the 2 motors (driven by their specific board) and to the photo-interrupter, while at the same time being connected to the internet. The connection is achieved by an ESP8266MOD-12-F microcontroller in the form of a NodeMCU V1.0 board, which guarantees a solid 2.4GHz Wifi connection and lets the system communicate via email with the user.

To verify the correct delivery of the number of pills a counter was designed using a strong light source pointing to a Light Dependent Resistor (GL5516) in a pull-up configuration, where the Arduino Nano IoT 33 analog input pin reads the photovoltage, sensing the obstruction of the light beam as a pill passes by, adding 1 to the counter's sum. The latter is also used to keep track of the number of pills inside the container, given the information of the amount inserted into the storage.

4 EXPERIMENTAL RESULTS

4.1 Prototype

A 28BYJ-48 5V stepper motor was used as the pill locking mechanism, driven by a ULN2003 stepper driver, an SG90 servo motor as the gate opening operator. A KY-008 laser and an LDR gr-5516 in a pull-up configuration were used to create our own fast photo interrupter (140 checks per second in its fastest configuration), detecting the passage of even the smallest of pills when calibrated.

The motors arms and supports were designed on Autodesk Fusion 360 (personal use) and printed on a GHOST 4 3D printer with PLA filaments, with overall low production cost prototyping.

Small machine screws and glue were used to join all the components together on the prototype's structure, which was created from wood scraps. This was chosen to keep the environmental impact as subtle as possible. The module selectors were realized with LEDs, diodes and transistors, to respond to only the unique identifier of each slave module, most components used, came from the Arduino starter package, together with relays, buzzers, buttons, resistors and transistors to complete all the required functions.

The computational load is handled by an Arduino Nano IoT 33 board, which became necessary due to its higher dynamic memory and its real-time clock module to keep track of time (embedded in its SOC). However, for accuracy purposes, we sample and update the current time with an NTP Server (Network Time Provider), which receives the Unix time stamps from the web. That was necessary given that the internal RTC of the Arduino Nano IoT 33 SAMD architecture deviates from the actual time up to 20 minutes a day.

The code converts the epoch timestamp into useful data, such as date, weekday and time information to run the pill dispenser schedule. As the prototype implements emails as system alerts and notifications for the caregiver, an ESP8266 board was used to accomplish that task, decreasing the load from the Arduino Nano IoT 33 and adding no more than 6€ to the prototype. This however would be removed in future developments.

The match between schedule data and real-time data is performed by the Interrupt Service Routine, which ensures the verification of this condition at all times, signalling to the main loop when to trigger the dispensing of pills (motors, photo interrupter check, buzzer operation and module selection for the dispensing). After such operation, an insertion sort algorithm organizes the schedules in chronological increasing order for the enabling of the ISR check of the closest alarm from the current time.

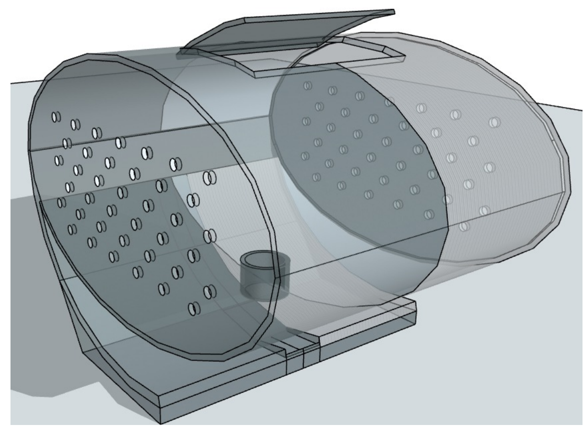

Fig. 1. 3D render of a possible design of the RAPID

4.2 Calibration and testing

As the dispenser required to be calibrated, it was interfaced with the software, through "test functions" to diagnose and solve every issue before testing the complete model, easing the future maintenance and debugging of the machine.

The proposed software is made just to show the features of the system or to troubleshoot, it has been designed to be extremely close to the possible commercial product (despite it being an alpha prototype, only lacking the accompanying app as the main user interface for remote setting) thus including a user-friendly menu built within the Arduino Serial monitor that requires only the input of the medical schedule to be inserted in a guided process by the final user or caregiver. All insertions are followed by a carefully designed error checking algorithm embedded in the code, reducing the risk of software failures.

From the main menu various functions can be initiated:

1. Display all the routines: shows the user all the current medical routines.

2. Edit schedule routines: Entering the second menu: EDIT menu, the user is guided through a simple process where new routines can be added, deleted or changed. Routines can be either daily or weekly based in this first implementation.

3. Display WiFi configuration: to correctly check the internet connection. 4. Refill modules: let the user/caregiver refill 1 or more modules by asking the number of pills inserted and the name of the medicine refilled.

5. Dispense test: for maintenance purposes, the machine can dispense 1 pill to check for mechanical issues (stuck pills, motors failures, ect).

The prototype successfully dispenses the correct amount of pills when the user schedule matches the current date and time and recognizes when no pills were dispensed, or when the Stepper locking mechanism fails (forcing an electrical disconnection for case test). Additionally, it correctly sends the email notification to the caregiver in our extensive testing in case of the latter. If the amount of pills is correctly dispensed, the system also recognizes that case by the use of our photo-interrupter.

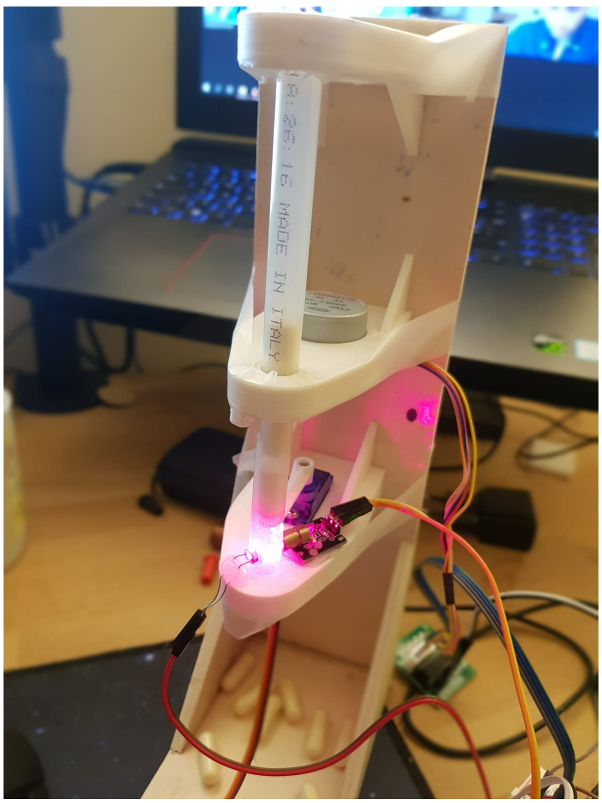

Fig. 2. Picture of the alpha prototype

REFERENCES

Jonathon D. Crystal and A. George Wilson. 2015. Prospective memory: A comparative perspective. *Behavioural Processes* 112 (2015), 88–99. https://doi.org/10.1016/j.beproc.2014.07.016 SI: Tribute to Tom Zentall.

HERO Health. 2020. HERO.

Frank B Hobbs. 2001. The elderly population. *US Census Bureau Population Profile of the United States, http://www. census. gov/population/www/pop-profile/elderpop. html* (2001).

Adinath International. 2018. Capsule Size Guide.

LiveFine. 2019. Automatic Pill Dispenser.

Fedele Pisani Marco Faverzani. 2021. HEXADRAWERS: MODULAR DRAWERS FOR MEDICINE SCHEDULE MANAGEMENT. (2021).

Marco Nabacino and Fabio Negretti. 2020. MEDIC – Medication-Dispensing Container. (2020).

PharmRight. 2020. Livi pill dispenser.

Philips. 2004. Lifeline.

Cole Pike, Taylor Morris, Christopher Bruni, and Jose Gomez. 2021. Med-Drop Pill Dispenser. (2021).

Simona Zito, Filomena Fortinguerra, Andrea Pierantozzi, Fabio Ambrosino, Giuseppe Traversa, Francesco Trotta, Roberto Da Cas, and Agnese Cangini. 2021. L'uso dei farmaci in Italia. Il Rapporto Nazionale OsMed 2020. *Recenti Progressi in Medicina* 112, 10 (2021), 659–667.