MeDiC – Medication-Dispensing Container

Marco Nabacino and Fabio Negretti

Politecnico di Milano

Abstract

The present project aims to help elders in following their medication schedule. This is achieved with a pill dispenser, akin to a vending machine, which can be programmed by the caregiver to deliver the correct pills at the right time.

The goal of the device is to prevent human error by avoiding that the pills are taken outside their designated time window or not taken at all. The dispenser is modular, so that it can be adapted to handle all the needed kinds of pills.

The mechanical implementation of the dispensing system is based on a stepper motor acting on an endless screw which acts as a conveyor. A LED and an active buzzer notify the user when the delivery has occurred, so as to provide an audiovisual feedback.

1 Introduction

For medical reasons, elders are often prescribed a sizeable amount of pills of various kinds: statistics are mixed, but a lower bound for the number of prescription medications in adults over 65 is four, with around 40% of the elders taking five or more [1, 11, 12]. Pill-taking is a sort of everyday ritual and as such requires the so-called *prospective memory*, which consists in "forming a representation of a future action, temporarily storing that representation in memory, and retrieving it at a future time point" [2]. Although evidence is mixed, studies suggest that generally older adults demonstrate difficulty with prospective memory tasks, even when the task has become habitual [3, 7, 13]. As a result, in elderly, polymedicated people, the probability of a medication error occurring is high, and inappropriate administration frequency is among the most widespread errors [4, 12]. A common solution to this problem consists in entrusting the elder to a caregiver who, among other things, also administers this task: however, even when such a figure is present, the process is still susceptible to human error [5].

The work presented herein shows a possible way of facilitating such a process: the idea is to use a dispenser which automatically delivers the pills when they need to be taken, notifying the user in the process. MeDiC is designed primarily for those elders whose access to medications must be restricted, and thus need the help of a caregiver. However, it can also serve as an aid to self-sufficient elders or anyone in need of taking multiple pills per day. In the latter case, the user performs ordinary maintenance on their own, restocking the machine when necessary.

MeDiC uses a timetable, which is submitted by the caregiver, to decide when to deliver the pills. This schedule contains information about which medications are to be taken on each day, how many of them must be taken and at what time. Outside this time window the pills are inaccessible to the elder: this prevents any unwanted and dangerous ingestions.

When the time comes for a pill to be taken, MeDiC issues an alert in the form of a green LED and a buzzer. This way, a visual feedback is provided alongside an acoustic one, so that people with hearing issues can still be notified effectively. The system keeps beeping the buzzer until the user pushes a button, at which point MeDiC delivers the required pills, ready to be taken. Should the pills not be taken after a set amount of time, that daily dose should be skipped rather than postponed. In this case, the delivery button gets disabled and the pills are not issued.

When the slot for a certain kind of pills is near depletion, MeDiC notifies the caregiver: the storage is only accessible to him or her, who proceeds with restocking.

2 Related works

A widespread solution for aiding in complying with the prescribed medications is to use a pill organiser, where each slot is assigned to one day of the week. This method has the advantage of being inexpensive and easy-to-use, but lacks dependability, since it relies heavily on the correct preparation of each slot by the user. The setup process must be repeated periodically and requires that every slot be filled with the correct amount of pills of each type; in order to do so, the user needs to have the weekly schedule at hand. In addition, such a pillbox can often hold just a weekly supply of medications, hence the refilling process turns out to be quite frequent. Finally, most of these devices do not restrict access to the pills in any way, so the risk of taking medications at the wrong time is not mitigated.

A more advanced version of this type of container sees the addition of some electronics which allow the user to specify the time of the day when he or she needs to take the pills: the device then only unlocks when the schedule is met. This way, access to medications is restricted and the user is unburdened of the prospective memory task of remembering to take pills, since these "low-tech" organisers integrate a means to alert the user as well, typically in the form of a buzzer. These devices are otherwise identical to the simple pillbox and as such all other previous advantages and disadvantages carry over. Moreover, they are powered by batteries, which are not required in the previous solution and can prove to be a nuisance.

A further step toward smart devices is represented by a dispenser which adds the feature of notifying the caregiver or the relatives if the user does not take the medications on time [10]. Such an alert is issued in the form of an e-mail, automated phone call or text message. The device is structured as an ordinary pill organiser, with several slots containing the doses: the correct one unlocks and starts blinking when needed. As for costs, this product requires no upfront investment, rather a substantial monthly fee is charged: in the long term such a solution becomes therefore very expensive.

Finally, a number of feature-rich smart dispensers [6, 8, 9] can also be found on the market. The key improvement over the previous solutions lies in the restocking method, which is by type rather than by schedule. Precisely, the slots of the machine do not represent the days of the week, rather, they are associated to the various medications: this means that each slot is filled with a single type of pill. The device is then able to assemble the daily dose, consisting of a mix of different pills, using the weekly medication schedule submitted once and for all. This way, the user does not need to consult the schedule every time restocking is needed; moreover, the process becomes much faster and less tedious. Another advantage is that refilling is needed less often, since each slot can keep more than a week's worth of medications; the dispenser automatically notifies the caregiver when one or more slots are near depletion. It should be noted however that, unlike the previous devices, these dispensers cannot handle all types of medications, namely irregular-shaped ones like half-pills are not delivered correctly. Moreover, such products are very costly, requiring either expensive monthly subscriptions or substantial one-time payments.

In conclusion, none of the existing solutions manage to conciliate ease of use and feature-richness with an affordable price.

3 Proposed solution

3.1 System specifications

Functional requirements MEDIC must be able to help elders in managing medications, preventing mistakes related to out-of-schedule taking and composition of the daily dose of pills. In particular, all the pills making up the dose should be dispensed at the right time and the user must be notified accordingly. Access to medications must be restricted at any other time. Finally, the machine must alert the user when it is running out of pills.

Non-functional requirements The device must possess the following characteristics:

AFFORDABILITY The system must be as inexpensive as possible, so as to be available to everyone.

EASE OF USE MEDIC must be intuitive, and interaction with the user should be minimal, ideally limited to the press of a button. This makes the dispenser accessible to anyone, including people with mild cognitive impairments.

FLEXIBILITY The dispenser must be able to deliver as many types of medications as possible: if a pill or tablet can fit, it must be delivered correctly.

Modularity The machine must be expandable to fit the user's needs, and each module is suited to a different pill dimension.

Configurability The user must be able to set the number of pills at which the machine sends a "running out of pills" notification.

Reliability The system must be as robust as possible: no mechanical faults should occur, and MeDiC should keep working even in the event of a power outage.

3.2 Design challenges

If the medications were stored by day, as is the case in ordinary pill organisers, the machine would only need to unlock the correct slot when the time comes. However, MeDiC stores the pills by type, and must therefore be able to correctly assemble the scheduled dose on its own. This means that the dispenser must deliver the correct amount of pills of each type, avoiding any excess or defect in the erogation of the pills. In order to do so, MeDiC needs to be able to dispense one pill at a time: this requires careful planning of the mechanical design choices.

A first possible solution consists in a lock-style erogation: the pills are stored in a funnel which aligns them inside a vertical pipe. At the end of the pipe, a set of two mechanical gates allows single-pill erogation as shown in figure 1. If more than one pill must be delivered, the aforementioned procedure is repeated as many times as necessary.

Such a solution has the advantage of being very user-friendly, since for restocking it is sufficient to refill the funnel, as one would do a regular cup. However, a big disadvantage lies in the lack of flexibility, dictated by two elements: the diameter of the tube and the distance between the gates. As for the diameter there is some leniency, since it must be greater than the size of a single pill but smaller than that of two adjacent pills; thus, it is possible to make an error up to 100% in excess. What actually limits this approach and ultimately makes it unviable is the distance between the gates, which has a really tight margin of error. Indeed, if it is too small, the closing gate encounters the pill and consequently jams, while if it is too large, the erogation system either jams or delivers more than one pill at a time. Since pills on the market come in many different shapes and sizes, it is not reasonable to design an erogation system tailored exactly to each one of them.

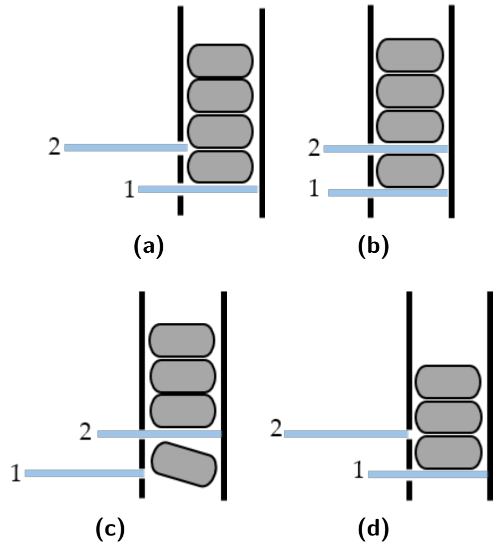


Figure 1: Working principle of the lock

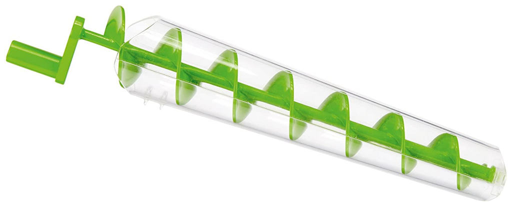


Figure 2: Endless screw used in the prototype

The opted solution makes use of an endless screw which acts as the auger of a screw conveyor, reported in figure 2. The screw is restocked manually by inserting one pill in each slot; in order to facilitate the restocking process, the auger would ideally be shaft-less. The screw is connected to a stepper motor, which allows to deliver a single pill through a complete revolution, as if it were a vending machine.

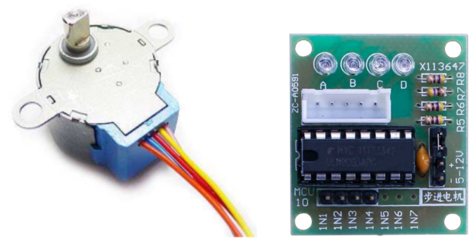
One of the main advantages of such a solution is being virtually fault-free: as long as a pill fits, it is delivered correctly. This eliminates the need of any sensors which would detect whether the pill has been correctly issued. Moreover, such an approach is very flexible, since a wide array of pills of any shape can be used in combination with the screw. For example, small pills can still be correctly delivered even by a large-pitch screw, even though this solution is suboptimal in terms of spatial efficiency: by decreasing the pitch, it would be possible to fit a bigger amount of pills over the length of the screw. This leads to the possibility of adopting a modular system, for which a rough distinction between pills is made with regards to their size; each class of pills will be then be associated to a screw of appropriate pitch.

Another advantage brought by the combined use of the screw with the stepper motor is the possibility of knowing exactly how many pills have been delivered so far, by simply counting the revolutions of the motor. This knowledge allows MeDiC to alert the user when the screw is running out of pills. Another way of doing this would entail the use of some kind of sensor, such as a proximity sensor, to detect the presence of a pill, or lack thereof, in a specific slot of the conveyor. The sensor would point to a slot and detect the signal during a turn of the screw. By comparing this signal with the known signal produced by the empty slot, it would be possible to know whether the examined slot contains a pill. Supposing that the sensor is mounted to investigate the third-to-last slot, the system would issue an alert when that slot is empty, saying that only two pills are left. Such a solution however lacks configurability, since the user would not be able to choose the pill threshold at which being notified. This problem can be solved by mounting several sensors, each on a different slot: such an approach is however a costly one. On top of that, some pills are so thin that their detection can be very troublesome.

None of the mentioned issues arise if instead sensors are forgone in favour of counting the revolutions of the stepper motor. In this case, if in restocking not all slots are filled the alert system could fail; in order to solve this problem, the screw is kept visible, albeit inaccessible, at all times.

Table 1: Specifications of the stepper motor

28BYJ-48 Stepper Motor	
Rated voltage	$5\,\mathrm{V}$ DC
Number of phases	4
Speed variation ratio	$1/64$
Stride angle	$5.625°/64$
Frequency	$100\,\mathrm{Hz}$
DC resistance	$50\,\Omega \pm 7\%(25\,°\mathrm{C})$
In-traction torque	$> 34.3\,\mathrm{mN\,m}$
Self-positioning torque	$> 34.3\,\mathrm{mN\,m}$
Friction torque	$600 \div 1200\,\mathrm{gf\,cm}$
Pull-in torque	$300\,\mathrm{gf\,cm}$



(a) 28BYJ-48 stepper motor

(b) ULN2003A driver board

Figure 3: Stepper motor and driver board

3.3 Components used

The prototype uses an Arduino UNO board as the microcontroller which handles all the logic and provides the control signal to the motor through its driver board.

The motor used is a 28BYJ-48 stepper motor powered by $5\,\mathrm{V}$ DC, shown in figure 3a and whose specifications are reported in table 1. This is a unipolar motor: a bipolar one would be able to generate a higher torque, but it would also be more difficult to drive and more expensive. Since the chosen motor generates enough torque to turn the fully-loaded screw, it is completely adequate. In addition, this application does not require high precision, therefore the stride angle could in principle be relatively high. The motor operates at 15 RPM, which means that delivering a pill takes at most four seconds. A higher speed would be nice to have, however it would require a more expensive motor: the attained erogation time is in line with the existing solutions and represents a good trade-off between cost and performance.

The motor is powered and controlled through a driver board which mounts a ULN2003A chip, reported in figure 3b. The board allows to operate the four phases of the stepper motor through a set of transistors. The four LEDs inform which phases of the stepper motor are active.

3.4 General architecture

In its final form, MeDiC would be made of several modules, each of them consisting of one screw driven by its stepper motor. The motors would all be driven by the same control signal, and a set of relays would power only the needed ones. The number of modules is at the user's discretion, depending on the number of the prescribed medications. The modules would come equipped with screws of various pitches, ranging from very small ($\sim 0.5\,\mathrm{cm}$) to large ($\sim 3\,\mathrm{cm}$), so that they can best fit the size of the pills. Only one of the modules has been developed in the prototype, which is shown in figure 4.

Figure 5 shows the schematic of the circuit used. Pins 10 through 13 on the Arduino UNO are con-

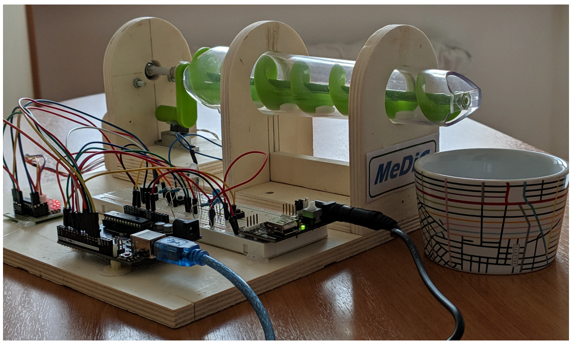


Figure 4: Prototype developed

nected to the ULN2003A driver board and provide the motor-driving signal. The wires in the lower part of the breadboard are dedicated to the calibration of the initial position of the screw, as explained in section 3.5.

1. As a first step, the device needs to be filled, starting from the slot closest to the collection tray and proceeding backwards. Once the screw has been filled, pressing the refill button (the blue button in figure 5) confirms that the system is ready to dispense the medications.

2. As long as no pills need to be delivered, the system is idle. In this state, the RGB LED is red and pressing the delivery button (black in figure 5) does nothing.

3. When the time comes for a medication to be issued, the device beeps the active buzzer and turns the RGB LED green. Pressing the delivery button while in this state mutes the buzzer, turns the RGB LED yellow and issues one pill. If instead the delivery button is not pressed before a certain amount of time, it gets disabled.

4. The system then returns in the idle state. If few pills are left in the screw, the blue refill LED turns on. The device keeps working normally while the refill LED is on, and can be refilled at any time. When doing so, the blue button should be pressed, at which point the refill LED turns off.

Note that the system can be refilled at any time, even when the screw is not running out of pills; one should just make sure to press the refill button after.

3.5 System characteristics

In order to correctly deliver the pills, the screw should end its rotation when the slot closest to the delivery tray is fully contained inside the cladding. This ensures both that the pill is correctly contained by the last blade and does not accidentally fall onto the delivery tray, and that the just-delivered pill gets pushed out by that same blade. In the prototype, this position of the screw corresponds to having the crank completely downed. Exploiting this fact, a magnet is attached to the crank, which hangs over a magnetic relay. When the crank is downed, the magnet activates the relay and a circuit gets closed, so that the system knows that the screw is in the correct position. Should this not be the case, the screw rotates backwards until the right position is reached.

Since the screw only makes full revolutions, in principle it should never lose the correct alignment. However, if a power outage were to occur while the system is delivering a pill, the screw would get set to an incorrect position. Even if this issue is taken care of by the aforementioned solution, it is nevertheless advisable to have a double power supply system, so that the erogation is not stopped at all. MeDiC should feature both a wall plug connection and an internal rechargeable $9\,\mathrm{V}$ battery. Measuring the currents powering both the microcontroller and the motor, the power consumption of the device has been calculated: assuming that the dispenser delivers 30 pills in one day, the prototype requires about $850\,\mathrm{mAh}$ to work for 24 hours, where $840\,\mathrm{mAh}$ (98.8% of the total charge) are drawn by the idle Arduino. Seeing as the prototype only uses a fraction of its computational power, in order to limit power consumption the final product should swap out the Arduino in favour of a tailored microcontroller which is more energy-efficient.

4 Use cases

John needs to take a pill in the morning, at 8 AM At 8 AM John is notified by a sound and by a green LED. He presses the delivery button and collects the pills from the plate.

John feels the need to take a pill outside the prescription window He gets to the dispenser, the LED is red and no pill is ready. There is no way to collect the pills.

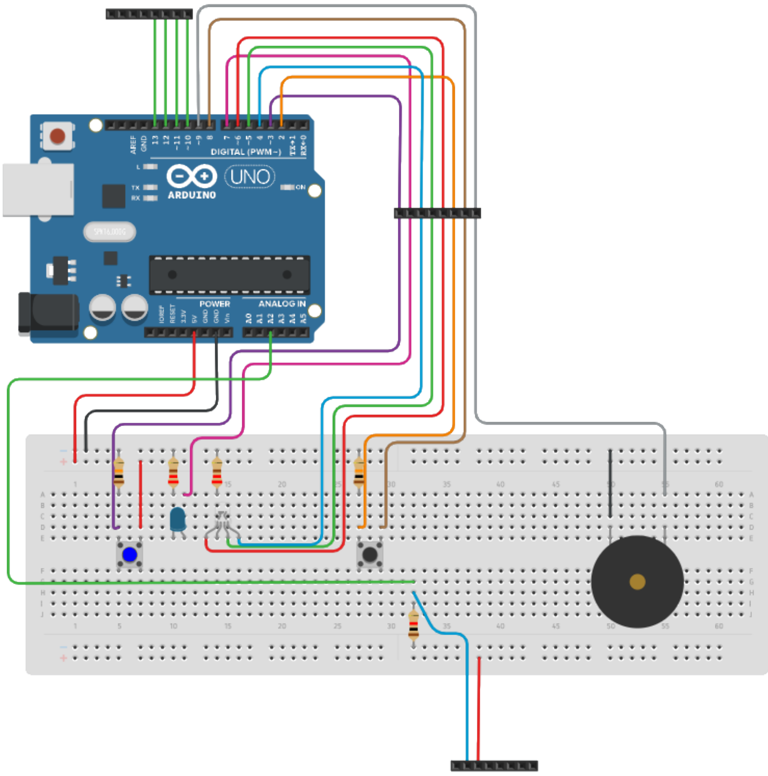


Figure 5: Sketch of the circuit

John needs to take a pill but he forgets. He arrives at the dispenser slightly late MeDiC is still beeping and the LED is green. John presses the delivery button and collects the pills, with no issues.

John needs to take a pill but he forgets. He arrives at the dispenser really late MeDiC has stopped beeping and the LED is red, notifying that John is too late. Pressing the delivery button does nothing.

John gets to the dispenser to retrieve a pill and sees that there are only 2 pills left of that kind The machine automatically notifies John via a blue LED. The caregiver then proceeds in refilling said slot.

There is a power outage and John will need to take his pill shortly The internal battery allows MeDiC to keep functioning correctly for the following 24 hours. When power is restored, the battery recharges.

5 Conclusions and future works

In this paper, a way to help elderly people to take their medications has been presented. This has been achieved through the development of an automatic dispenser, which delivers the correct pills when necessary. The prototype is robust, since it manages to dispense pills without mechanical faults, and versatile, due to the variety of pills it can handle. Another notable feature is reliability, achieved with the introduction of a calibration system of the initial position of the screw.

In order to improve this aspect, a further iteration of the prototype could feature a double power supply system (wall plug + rechargeable battery), which would guarantee the functioning of the device even in the event of a power outage.

Another possible future refinement could be the development of a mobile application dedicated to sending notifications to the caregiver and the relatives. Notifications could be sent when the medications are ready to be collected, when pills are running out, when taking is skipped and when tampering of the device occurs. The latter could be achieved with the introduction of sensors such as accelerometers, allowing to detect when the dispenser is tilted or flipped upside-down. Indeed, tampering may interfere with the way pills are stored in the screw and may lead to an incorrect erogation.

References

[1] Christina J. Charlesworth et al. "Polypharmacy Among Adults Aged 65 Years and Older in the United States: 1988–2010". In: *The journals of gerontology. Series A, Biological sciences and medical sciences* (2015). DOI: 10.1093/gerona/glv013.

[2] Jonathon D. Crystal et al. "Prospective memory: A comparative perspective". In: *Behavioural Processes* (2015). DOI: 10.1016/j.beproc.2014.07.016.

[3] Gilles O. Einstein et al. "Habitual Prospective Memory and Aging: Remembering Intentions and Forgetting Actions". In: *Psychological Science* (1998). DOI: 10.1111/1467-9280.00056.

[4] L. C. Fernández Lisón et al. "Errores de medicación e incumplimiento terapéutico en ancianos polimedicados [Medication errors and non-compliance in polymedicated elderly patients]". In: *Farmacia hospitalaria: organo oficial de expresion cientifica de la Sociedad Espanola de Farmacia Hospitalaria* (2006). DOI: 10.1016/S1130-6343(06)73991-5.

[5] Noha Ferrah et al. "Systematic Review of the Prevalence of Medication Errors Resulting in Hospitalization and Death of Nursing Home Residents". In: *Journal of the American Geriatrics Society* (2017). DOI: 10.1111/jgs.14683.

[6] *Hero Pill Dispenser, Medication Manager, & Pill Organizer*. URL: https://www.herohealth.com.

[7] Matthias Kliegel et al. "Complex prospective memory: development across the lifespan and the role of task interruption". In: *Developmental Psychology* (2008). DOI: 10.1037/0012-1649.44.2.612.

[8] *Livi Smart Pill Dispenser for the Home*. URL: https://www.liviathome.com.

[9] *Automatic Pill Dispenser for Seniors & Loved Ones – MedaCube*. URL: https://www.medacube.com.

[10] *Top-Rated Pill Dispenser for the Elderly | MedMinder*. URL: https://www.medminder.com.

[11] Lucas Morin et al. "The epidemiology of polypharmacy in older adults: register-based prospective cohort study". In: *Clinical Epidemiology* (2018). DOI: 10.2147/CLEP.S153458.

[12] Virtudes Perez-Jover et al. "Inappropriate Use of Medication by Elderly, Polymedicated, or Multipathological Patients with Chronic Diseases". In: *International Journal of Environmental Research and Public Health* (2018). DOI: 10.3390/ijerph15020310.

[13] Melanie Zeintl et al. "The role of processing resources in age-related prospective and retrospective memory within old age". In: *Psychological Aging* (2007). DOI: 10.1037/0882-7974.22.4.826.