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Master of Science in Computer Engineering

MEDICINE REMINDER FOR INDEPENDENT LIVING BASED ON RFID TECHNOLOGY

Supervisor: Prof. Giuseppe Pozzi
Assistant Supervisor: Prof. Fabio Salice

Master Graduation Thesis by:
Lorenzo Franzi, Student Id: 820060

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"Senza sacrifici e impegno resterai un burattino di legno!"

Mangiafuoco in Pinocchio

Sommario

L'invecchiamento demografico sta compromettendo la sostenibilità dell'attuale sistema assistenziale: è perciò necessaria una riforma per sgravare il corrente sistema sanitario da una crescente richiesta di interventi. La sfida attuale è quella di prolungare il periodo che intercorre dal momento in cui una persona, invecchiando, passa da una vita indipendente alla necessità di usufruire dell'assistenza di un istituto di cura. Si stanno perciò sviluppando soluzioni alternative che si propongono di aumentare l'autonomia, la sicurezza in se stessi e la mobilità per consentire alle persone più anziane di continuare a vivere nella propria casa. Poichè per molti anziani assumere medicinali è spesso un'esigenza fondamentale, occorre garantire che la loro assunzione avvenga in modo regolare e sistematico, perfino se vivono in casa propria e senza nessuna persona costantemente presente per accudirli.
L'obiettivo di questa tesi è di realizzare un dispositivo elettronico a basso costo ma efficiente e di facile utilizzo in grado sia di verificare che l'assunzione dei farmaci avvenga secondo le prescrizioni dei medici sia di comunicare gli esiti del controllo ai familiari o al personale addetto all'assistenza. Il prototipo costruito utilizza la tecnologia RFID per monitorare la posizione delle confezioni dei medicinali all'interno di un opportuno contenitore e può essere in grado di integrarsi in un'infrastruttura di rete wi-fi preesistente che ne consente la programmazione.

Abstract

Demographic aging is jeopardizing the sustainability of the welfare system: it is therefore necessary a reformation to relieve the current health care system by a growing demand for intervention. The challenge now is to extend the period that elapses from the moment a person passes from independent living to the need to have the assistance of a health institution by getting older. Alternative solutions therefore are being developed to aim the increase of autonomy, self-confidence and mobility to enable older people to continue living in their own home. Since for many elderly the intake of medications is often a fundamental requirement, it should be ensured that their assumption is done in a regular and systematic way even if they live in their own home and without anyone to look after them and always present.
The purpose of this thesis is to provide an embedded electronic low cost device, efficient and easy to use which can both check if the intake of medicines is performed according to the doctor's prescription and to communicate to family members, caregiver or doctors the monitored situation. The prototype is built using RFID technology to know the location of the medical packaging in a proper box and could be integrate into existing wi-fi infrastructure network to be programmed.

Acknowledgements

First of all, I want to express my gratitude to Professor Fabio Salice for his guidance, his advice and his support during this work. His knowledge, passion and expertise has been for me a source of inspiration for this project: his way of analysing problems and find solutions is something I'll never forget.
Heartfelt thanks to Giuseppe Pozzi for giving me the opportunity to work on this project letting me learn a lot about the embedded world: without this project I wouldn't have never discovered all I know about this field.
An important thank you to Andrea Masciadri, Federico Bianchi and Anna Trofimova for sharing their office with me all those months of work and for helping me in the most critical moments. With them I have to be grateful to all the members of the Assistive Technology Group for the friendship.
I will never forget all the knowledges that Paolo Bernasconi taught me.
Finally, many thanks to all my friends and my family members for your support in these months.

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RFID	**R**adio-Frequency **ID**entification
VCC	**V**oltage of **C**ollector - Positive Voltage
GND	**G**rou**ND** - Reference Voltage
UART	**U**niversal **A**synchronous **R**eceiver/**T**ransmitter
RTS	**R**equest **T**o **S**end
CTS	**C**lear **T**o **S**end
SHDWN	**SH**ut **D**o**WN**
TCP/IP	**T**ransmission **C**ontrol **P**rotocol/**I**nternet **P**rotocol
RX	**R**eceive
TX	**T**ransmit
RTC	**R**eal **T**ime **C**lock

To my family

I would like to dedicate this thesis to my parents, Giuseppe and Marisa as a sign of love, respect and gratitude I feel for you. I am grateful to you for teaching me things of real value and for supporting me.
A big thank is for my sisters, Irene and Elisabetta, for being always close to me. A special mention is for my grandmother Giuseppina, always positive and willing to me.
To all the teachers I have encountered in my studies I extend a warm embrace, without you I would not be what I am about to become.
Last but not least, thanks to all my friends, those near and those far away, because you always make me feel like I was in a big family.

Chapter 1

Introduction

Population aging is one of the most important processes going on in industrialized countries. Its effects, already visible even in developing countries, have an impact not only on the structure and composition of the populations, but also on the social, economic and political aspects of the lifestyle.

According to the forecast of the United Nations [1], the total amount of people aged over 60 years will outnumber the children in 2047. In addition, the welfare system at the same time is going to change; its sustainability will probably also be affected by the inequality that will be created among the most productive age population and older segments that, in addition to being economically passive, also involves a cost from sustainability and welfare point of view.

In recent years, especially in European countries, it has been a number of proposals to change the current paradigm of care. Until now, in fact, the care provided for the elderly has been concentred towards the more complex subjects (total dependence, high comfort, reduced life expectancy), focusing on the hospital system and the dissemination of specialized services: the healthy system always left out interventions on the population still able to perform independently their basic functions. Hospitals and nursing homes will not be able to support the growing demand for assistance requiring public and private health care to change.

1.1 Possible scenarios and new models of healthcare

A possible scenario of a future healthcare system is described by Intille et Al. [2] and it consists of a transition to a health care system focused on keeping people healthy. This outlook requires a strong government intervention that refocuses financial incentives on preventative care.
The new models make use of a different method. Assuming a wider understanding of the aging process, they propose to use a preventive approach to try to intercept the difficulties that people encountered along the entire span of old age. It is therefore necessary work on risk factors and limitations of everyday life of people with possible functional disability, but still encouraging self-help and a better quality of life even in case of difficulties. This type of approach can also allow a more rational use of resources.
In this context we can find the project BRIDGE (Behaviour Drift Compensation for Autonomous and Independent Living) from ATG (Assistive Technology Group) active at the Polo Territoriale di Como of Politecnico di Milano [3]. The project aims to achieve the objectives described in ambient Assisted Living Joint Programme [4]: to increase the autonomy, self-confidence and mobility of elderly to let them be able to continue to live in their own home as long as possible, not worsening the state of health and functional capacity of older people, promoting a lifestyle healthier for individuals with high risk factors, increase security to prevent social isolation, keep the network proximity, provide for the needs of families and those involved in their care, optimize the use of resources devoted to older classes [5]. For this purpose it is encouraged the connection between the person and the social environment (family, network proximity, the third sector) implemented a system capable of providing targeted interventions - in the home and in the structural support for daily activities - resulting from having identified changes in behaviour and to have them interpreted, even with the psychological and sociological analysis support.

1.2 Problem definition

Medications have an important role in the lives of many elderly people. In addition, aged people often suffer from multiple diseases so they are forced to take different kind of drugs, several times a day and even at different times. In such a context, it is understandable how difficult it is for an elderly remember to respect the administration prescribed regularly and systematically. To prove this thesis, it is possible to cite the results of some statistics conducted in the United States [6]:

- 55% of older people do not respect the administration properly prescribed;
- 50% of all prescribed medications are taken incorrectly;
- 26% of errors in medication, according to doctors, are potentially serious;
- 23% of admissions to nursing homes is due to errors in medication, affecting 380000 patients with an estimated annual cost of 31.3 billion dollars;
- 10% of hospitalizations (3.5 million patients) is for the same reason and it costs 15.2 billion dollars a year;
- Errors in the use of drugs cause at least 7000 deaths and at least 770000 injuries every year in the United States [6].

It is already several years that the market, and research, propose products, devices or prototypes, capable of helping the patients and the people who are responsible for their care to respect the time and manner for the assumption of prescribed medications, with the aim of reducing the effects listed above.

1.3 Thesis contribution

Goal of this work is the creation of the prototype of a embedded low-cost device that can control the intake of medicines as part of mutual reassurance for autonomous and independent living [7].

The system is made of a box which has in the bottom a large RFID antenna. This antenna can read RFID tags pasted on the packaging of medicinal products and the software running on a microcontroller, and connected to the antenna, will perform the control of the intake of the medicines.
The device is able to detect when a person picks up and repositions a medicine considering this action like an intake. The instrument checks that the time of this action coincide with a prescription loaded into the system. It can check if the medication is taken correctly, in a wrong moment, if it is not taken or even if it is taken too many times with respect to the medical prescription. Events detected shall be reported to a caregiver or to relatives, even using the wi-fi interface.
It is possible to highlight some of the main features of the device:

- Functionality: it is able to detect the pick up and the repositioning of the single medicine package, supports liquid substances and the dimensional limits are those of the system box: separators can be placed according to the user needs;
- Positioning flexibility: the small size and its "wireless nature" make the device to be positioned (and repositioned) with great flexibility. Can be powered with batteries and the only limitation is the screen: to be visible the box system should be placed in a frequently used place;
- Simple configuration: the configuration interface for managing medicine prescriptions can be easily done using any device with a common web browser (like PC, smartphone, tablet, etc.).

1.4 Thesis structure

Next chapters are structured as follows:

Chapter 2 shows the state of the art of tools that can help people to respect the time and methods for taking prescribed medications. There is also a special attention about devices proposed by the research that use RFID technology.

Chapter 3 describes the RFID technology and the different standards which discipline products; it has been analysed in particular the ISO/IEC standards that has been adopted for the project.

Chapter 4 describes the hardware architecture of the system and also the main hardware components of the prototype: the Seriz II Board, the customized RFID antenna and also the wi-fi module RN-131.

Chapter 5 describes how the medicine manager works. All the solutions to keep track the adherence the therapy by the user are described here.

Chapter 6 summarizes the results obtained and are explains some possible future developments that can be implemented to improve the prototype.

Chapter 2

State of the art

It is several years that the market and research propose products, devices or prototypes, capable of helping the patients and the people who are responsible for their care to respect the time and manner for the assumption of prescribed medications, with the aim of reducing the sides effects like incorrect intake of medicine, errors in using medicines and no respect of the treatment.
The market offers a variety of solutions designed especially to remind patients, during the day, from time to time, which medicines are to be taken. We can divide them in two main categories: physical devices, everything with a body containing medicines, and virtual supporting tool, that are only virtual reminders.

2.1 Physical devices

Physical devices can mainly divided in two categories: Mechanical, they have nothing electronic-based in their structure, and Electronical, they have some parts that are electronic-based.

2.1.1 Mechanical physical devices

The mechanical physical devices are containers of medicines that, thanks to different compartments, allow to manage the intake of medication in a simplified and schematic way.

We will focus only on PillBox from QualiFarma [8] as a representation of this category because all the devices are very similar and the only difference between them is the design and the organization of bins in which user can put medications.
They can be daily (with compartments for each hour of the day to refill daily) or weekly (with a number of fixed compartments for each day - usually 4 - to be recharged weekly). These very simple devices are useful only for the management of medicines, but the absence of electronics as a support do not give the possibility of creating alerts for the user. (As a simple example the situation is: "if the medicines are in the bin I have not yet taken them, if they are not in the bin I have already taken them").
These devices are, very simple, very low-cost, portable, no need of energy, not customizable and without the possibility of alert user if a medication has not taken.

(a) Daily Pillbox from QualiFarma

(b) Weekly Pillbox from QualiFarma

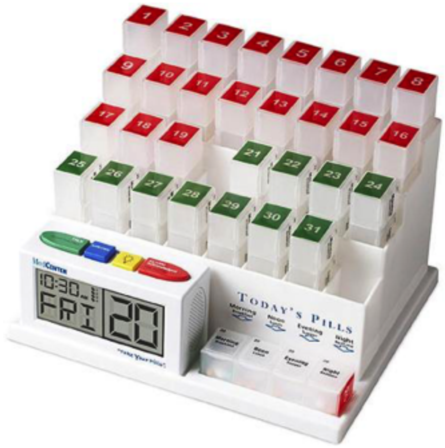
(c) Another example of Weekly Pillbox

FIGURE 2.1: Different examples of Mechanical Physical Devices

2.1.2 Electronical physical devices

The electronical physical devices are equipped with electronic-based components and this allows the possibility to do a lot of operations: some are very simple like reminding user to take the medications at a scheduled time - a sort of alarm clock - and other are more complex operations such as notify to a relative of the user

(a) Example of Weekly Alarm Clock Pill Box



(b) Example of Monthly Alarm Clock Pill Box

FIGURE 2.2: Different examples of simple Electronical Physical Devices

the failure in taking a medicine via SMS or email. We see this variety of devices in more detail by classifying them according to the amount of electronics used.

Alarm Clock Pill Box (weekly)

Alarm Pill Box offers a light and sound reminder that ensures patients take the medication on time. It is a digital alarm clock, an audio alarm and an LED light alarm all in one [9]. Usually are color coded to make it easy to set. They need batteries to work.

31-Day MedCenter with talking interactive alarm (montly)

The MedCenter medication management system is a monthly medication management system. The Medication Cassettes with Talking Interactive Alarm Clock organizes medications by day of the month with up to four dosage periods per day [10].
It has a friendly reminder that notifies to the user the time, date, and which daily dose to take. The user must press the Alarm Acknowledged Button to confirm compliance.
It also have the data verification: user can check the matching between the visual dates on the pill cassette and the clock with audible alerts. The number on the pill cassette is green or red: in the first case the pills are to be taken, in the second case the day is in

the past so the pills have been already taken. This helps to assure accuracy.
It is also easy to setup and easy to use.

MedMinder (weekly)

Now we look into a more advanced pill box that is sold in United States and has a lot of advanced features and services. It has a montly fee to be paid. The most advanced one has also an alert (similar to a clock or a necklace) for the user. Let's see something more detailed.
MedMinder pill dispensers [11] remind the user to take their medications with a series of optional visual and/or auditory alerts. The reminders occur in 30-minute intervals. First the compartment will flash, then the pill dispenser will beep, then the user will receive a phone reminder. If the user still has not taken their medications, then all caregivers will be notified via phone, email and/or text message. Of course, if the medications are taken on time, there will be no reminders nor notifications.
The locked pill dispensers are for those at greater risk for taking the wrong medication at the wrong time. All compartments are locked and only the specified compartment will unlock at the right time. The dosage compartments can be setup to un-lock or re-lock in wider windows, before or after the scheduled dosage, to allow more flexibility for the user. With the push of a button the pill dispenser will open a two-way voice channel with the medical alert professionals at the UL certified monitoring center. The wireless pendants are waterproof, feature 800 feet of transmission range, a long-life battery, and have a necklace and a male or female watch band design.
MedMinder pill dispensers have an internal cellular modem that communicates with the MedMinder remote system. There is NO NEED for a phone line, computer, cell phone or Internet access. The pill dispenser uses a built-in micro cell phone to connect with our monitoring station. MedMinder pill dispensers can be filled for several weeks, depending on the number of dosages per day.
Two Dosages Per Day: The pill dispenser holds two weeks of

medications. The first 2 rows become WEEK ONE and the second 2 rows become WEEK TWO. One Dosage Per Day: The pill dispenser holds four weeks of medications. (The limitations are because it has 28 compartments).
Refill trays make refilling the pill dispenser more convenient and reduces the possibility of medication errors. Refill trays can be filled ahead of time by family members, a pharmacist or caregiver and placed directly into the MedMinder medication dispenser.
Caregivers can record voice messages on the MedMinder portal and our pill dispensers will play them so the user will hear a familiar voice. Custom greetings can be set as medication reminders, positive feedback, or even one-time personalized messages for special occasions. Caregivers can also type a personalized message that MedMinder converts to voice format.
MedMinder allows user to have as many caregivers as needed. And if there is the need to add more caregivers, it is possible to do it from the website and add the additional caregiver(s) information, who will then be able to set their own notifications preferences.

Dispensers

The most common Electronical Physical Device in the market is composed by dispensers. They are objects that contain medications in small boxes that have to be refilled weekly or monthly. The difference with respect to the solutions shown above is that

FIGURE 2.3: Medminder Devices with clock and necklace

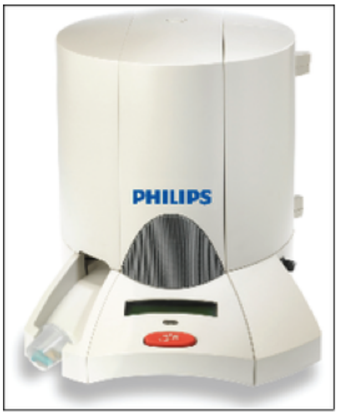


FIGURE 2.4: Philips Dispenser

in this case the dispenser releases only the medications that are in the corrispondent box. So in this case the dispenser is capable of delivering, to the user's request or automatically according to the programmed dosage, the medicines previously loaded in the compartments. In the market there are a lot of dispensers. Here a list of them.

Philips Medication Dispensing Service This dispenser produced by Philips [12] is easy to set up and even easier for seniors to use. Typically it's a caregiver who loads the machine with the single-dose pill cups and contacts Philips to program the dispensing schedule. Then, when it's time for a dose, the machine will sound a reminder. Then you can simply press the release button to dispense the dose and take your pills. If you haven't pressed the button after 90 minutes, your caregiver will get a phone call so they can step in and help.

TabSafe TabSafe [13] is an easy-to-use, effective solution for managing medications that can accommodate even the most complex schedules. This medication management system reminds the user, dispenses medications, alerts caregivers before a dose time is missed, and monitors adherence. TabSafe improves medication adherence to over 96%, leading to better health outcomes and avoids preventable costly emergency visits and hospitalizations. The security features and online reporting provide peace-of-mind for users and their caregivers.

FIGURE 2.5: TabSafe Dispenser

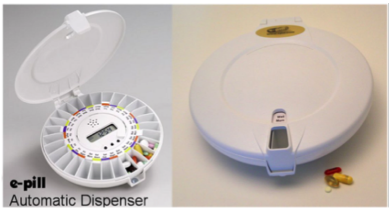


FIGURE 2.6: E-Pill Dispenser

The fee for using TabSafe is monthly because it offers the refill from a specialized person and a constant service of monitoring.
TabSafe is programmed on the website www.tabsafe.com. Enter all scheduling information for medication cartridges and messages and download to the TabSafe.

E-Pill Automatic dispenser Med-Time Med-Time XL [14] is a device for dispensing medicine, reminding the user when medicine shall be taken, and making the correct dose available. Alarm will sound and pills rotate into position. Lift up device, turn the dispenser upside down to allow the pills to fall into the hand. All other medicine is inaccessible. Alarm stops by turning device upside down (or after 60 minutes).
Load the pills in the medication tray. Set the alarm clock (from 1 up to 28 alarms per day). Tray has 28 compartments, each can hold several pills. Early dose feature allows patient to access medications up to 30 minutes before scheduled medication time.
It costs around 500$ but no further services are provided.

Livi Livi [15] is a highly advanced, dependable and remarkably easy-to-use home medication dispenser.

FIGURE 2.7: Livi Dispenser

Livi prompts users when and how to take their meds via audible and visual alerts.
It automatically dispenses a 90-day supply of up to 15 different pills and supplements. If a dose is missed, Livi alerts caregivers via text message or email. Livi uses a cloud-based application that makes scheduling and real-time monitoring of meds easy and convenient. Livi retains the user's medication history and adherence data, which can be shared with physicians and other caregivers.
Getting started with Livi is easy. All medication orders are entered using the cloud-based application from mobile devices or web browsers. Once the med order is entered, Livi's container can easily and quickly be configured to handle the specific pill size and shape. After that, simply pour the contents of a pill bottle into one of Livi's containers and follow the set-up prompts on the display. Repeat for up to 15 different meds or supplements. Livi will then begin dispensing the right medication at the right time, in the right quantity with the right instructions.
Livi can also provide reminders for refrigerated items, creams, liquids and other medications. Livi is dependable and accurate thanks to advanced engineering and smart technology, which are far more reliable than manually sorting large amounts of medications and supplements. If a dosage is skipped or missed, Livi immediately alerts caregivers via text message or email. Medications and dosages can be adjusted in real-time using LiviWeb.

FIGURE 2.8: Lumma Dispenser with the application to configure it

Livi securely holds a 90-day supply of up to 15 different medications or supplements. As medications reach re-order levels, Livi alerts both users and caregivers via text and email. Once a prescription is re-filled, the meds can be added to the assigned, on-board container and Livi will continue to dispense the medication at the right time, in the right quantity with the right instructions.
There is no need to pre-sort medications when using Livi!
Livi was designed inside and out to be easy to use. Users will find large buttons, a bright, crisp display and an easily-accessible cup that holds dispensed medications. Caregivers will encounter an easy-to-navigate web application, simple set-up fields and the peace of mind that comes with a fully automated medication dispenser. The design, engineering and technology inside are what make the device so innovative and reliable.

Lumma Lumma Dispenser [16] is very similar to Livi. It has also its own App to access statistics, preferences, scheduling and other stuff. It is under development and raised funds thanks to Kickstarter.com [17].
Like Livi, the most powerful thing it can do is to automate sorting and dispensing all the pills.

Tamper-Resistant Pill Dispenser The prototype device of a tamper-resistant dispenser was designed mainly with painkillers in mind [18]. In fact in this dispenser, medication is added by the pharmacist via a lockable opening in the bottom – the pharmacist has a key to that opening, but the patient doesn't. At the same time that the container is filled,

FIGURE 2.9: Tamper-Resistant Pill Dispenser

the patient's fingerprint is also scanned and matched to the device.
When they're subsequently supposed to take a pill, the patient holds their finger pad to the dispenser's scanner. As long as the print matches and the proper amount of time has elapsed since their previous dose, this causes a disc to rotate within the device, picking up a pill from a loaded cartridge and dropping it into an exit channel.
In its present form, the dispenser is made mainly from a "super-tough steel alloy," and can hold up to 60 tablets at once.

Memo Box

Memo Box is a device designed to replace the familiar plastic seven-day pill boxes that works in conjunction with a smartphone app to ensure users take prescribed medication at the right time, and in the right dose [19].

> "The team likens their device to a central nervous system, with the Memo Box system consisting of a "brain" (cloud computing servers), "sensors" (hardware which tracks the user's access to its contents), and "nerve fiber" (wired and wireless technology which seamlessly syncs information across the hardware, companion app and server).
> Tiny Logic points out that no sensor can yet determine whether someone has actually swallowed their pills or not, so it chose to focus on giving Memo Box the ability to learn. Algorithms allow the Memo Box to learn the

FIGURE 2.10: Memo Box Dispenser

> user's intake habits and with occasional feedback from said user, Memo Box becomes more intelligent over time and makes smarter decisions.
> For example, it figures that if you haven't opened the box, you haven't taken your pill. And based on your habits and feedback, it also works out the odds of whether you may have opened the box by accident."

There's also a double dose alert that detects when your Memo Box has recently been opened and asks whether you've already taken that dose. Memo Box will even notify you when you forget to bring your medication with you after leaving the house.

> "A handy feature is the remote family monitor, which lets you keep an eye on medication dosing for other people. If your kids need to take medication while at school, or your elderly parents miss a dose, Memo Box comes to the rescue again with a message on your smartphone, such as: "James, your mom might have forgotten to take her pills, would you like to call her?"."

The battery life is estimated to last a year with typical use.
Tiny Logics was founded in Cambridge, United Kingdom by Shan Lu and Meichen Lu, two college students who wanted to help their parents overcome problems with taking medication. They raised funds on Kickstarter.com [https://www.kickstarter.com/projects/661527809/memo-box-smart-companion-for-your-pills-and-vitami/description] but till now they are testing prototypes.

2.1.3 RFID-based

In recent years, RFID systems have been adopted in many areas demonstrating the potentiality and the advantages of this identification technology.
RFID technology makes it possible to uniquely identify objects, people and animals. To them it is necessary to apply the labels (also called tags or transponders) able to communicate with radio frequency (therefore without physical contact, neither mutual optical visibility) with a reader. An information system connected with the reader, starting with the identification codes of the tags, allows to carry out search operations, localization, tracking.
In hospitals the technology is already widely used to monitor patients, drugs and medical devices. The small size of the RFID transponder and low costs, have led the research to propose solutions to be applied in the domestic sphere.

RMAIS - EMBC10 It is a prototype of a marketable Radio-Frequency Identification (RFID)-based Medication Adherence Intelligence System (RMAIS) that can be conveniently used at a residential home by ordinary patients [20]. RMAIS is designed to maintain patients' independence and enable them to take multiple daily medicine dosages of the right amount at the right time. The system is patient-centered and user-friendly by reminding a patient of the prescribed time for medication and dispensing it in a fully automatic and fool-proof way. This is achieved due to a scale, an RFID reader and the rotation platform. In addition, this system has an Internet-based notification function that is used to alert the patient when it is time to take medicine as well as report deviations from the prescribed schedule to the primary care physicians or pharmacists.

RFID Medication Dispenser In this case the project [21] is very simple and very rough but it is effective in teaching how to build a homemade dispenser using RFID reader programmed with Arduino [22]. It's very rough and without any programmable reminder or security system (it could be further work on that). This instructable was created in fulfillment of

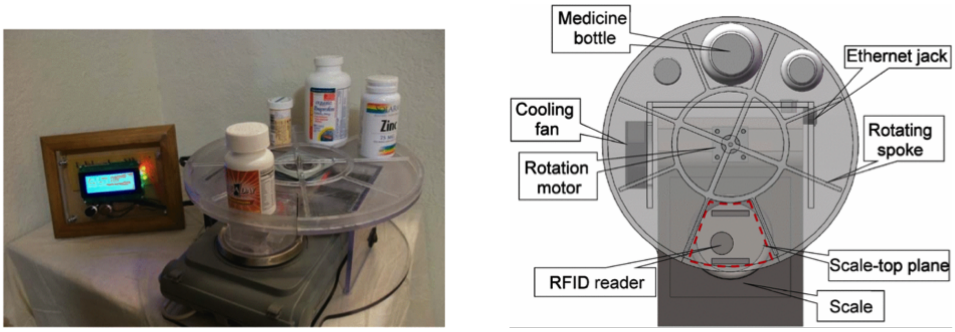


FIGURE 2.11: RMAIS Device Prototype different views

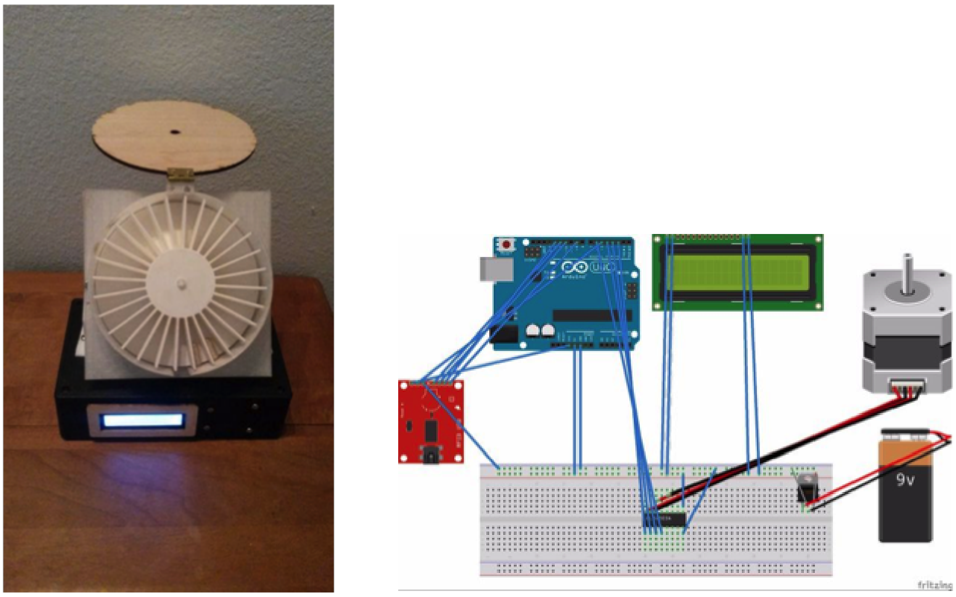


FIGURE 2.12: RFID Medication Dispenser with Arduino

the project requirement of the Makecourse at the University of South Florida [23].

A low-overhead ubiquitous system for medication monitoring

This device, proposed by Fishkin and Wang [24], consists of a floor on which to place the drugs and by a scale. For each container of the medicinal product is applied to an RFID transponder, in this way, a reader, placed below the floor, is able to detect when a medication is removed and subsequently repositioned. The scale, selected with an accuracy of 100 mg is used to determine how many pills have been taken.

The device is completed by a power board and a radio communication system that transmits the measurements to

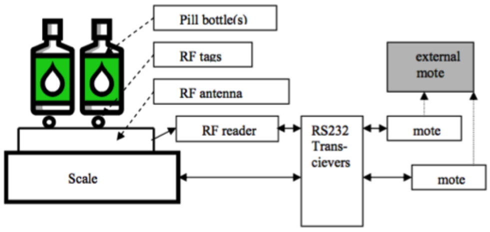


FIGURE 2.13: RFID Device Prototype and its schema description

the central unit of the system, that is concerned to verify the correctness of assumptions and to provide, through a web page, useful information to the user, including:
- The list of drugs to be taken in the coming hours;
- When a package is lifted from the ground, the display shows how many pills should be taken;
- When a pack is placed back on the floor, the display shows any further therapies that have to be done after the assumption of the medication (such as eating, avoid sun exposure, etc.).
The programming of the system, such as the details of the therapy that the user must follow, is not made via the same interface, but using the particular colored card (command card) on which is applied a RFID transponder. Placing the medicine with the charts of command you can instruct the system on how many pills should be taken, how many times a day if the number of pills is compelling and should be understood as maximum or minimum and if it is necessary to alert someone if you fail intake.
In conclusion the platform of medicines is only a measuring instrument; In fact we must add to it the central control unit and the wireless communication system owner. In addition, the programming method appears syntactically limited (it is not possible to establish the time periods of employment) and a little bit complicated. The cost of the solution, using high-quality components such as precision balance and radio modems, could represent an element of disadvantage.

2.1.4 BarCode-based

Devices based on barcodes have been replaced by RFID technology because it has no need to have the visibility of the Unique IDentifier (sometimes the barcoded is taken off from medicine box by pharmacists, sometimes it is difficult to read the barcode).
This technology is still used by big machines and from specialized people to let some mechanical systems work properly. Let's see two examples:

Omnicell M5000 It is the first pharmacy automation system that fully automates the fulfillment of multimed blister cards. The M5000 [25] is capable of producing 40-50 filled, sealed, labeled, and audited cards per hour. The M5000 can accommodate an extensive formulary with the ability to store 300 different medications on the machine. The design of the M5000 eliminates the need for specific calibrated cassettes saving time and offering great flexibility.
How it works: The user goes to the pharmacy with a barcode identifying his schedule for medicine assumption, in the pharmacy the robot reads the barcode and extends its arm toward bins holding 300 different pills. Tiny fingers pick pills from some of the containers, using lasers to detect the size, shape and color of each. The robot drops the pills it has selected into 28 small plastic "blisters" embedded in a page of cardboard. There are four blisters for each day of the week.
The result of this operation is a simple list of blister containing each the medicine scheduled for the assumption.
Since the technology used for this machine is very complex, the cost is very high (only a pharmacy that does this operation a lot of time each day can invest on it) but the resulting blisters are perfect and there are no errors.
At the moment there are no researches about best performances (considering both precision and time) than specialized workers, but it helps specialized people to focus on patients and not on filling blisters with medication.

Intelligent cart, fully computerized An intelligent cart [26], fully computerized, which recognizes places, patients and drawers

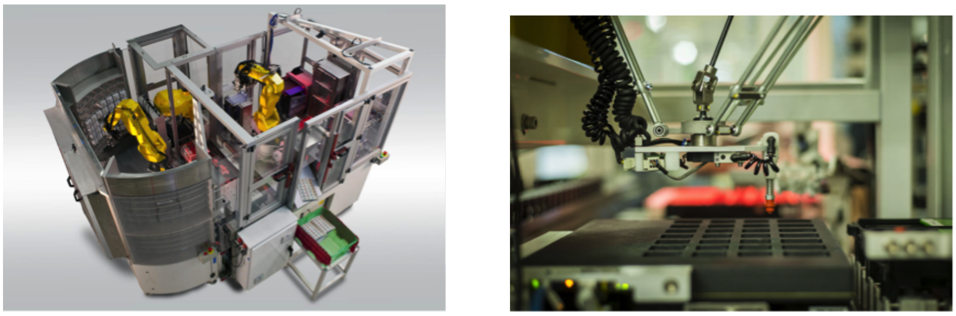


FIGURE 2.14: Omnicell M5000 3D image and when it is filling medicine

to ensure a drug delivery foolproof.
This solution is adopted by ASL TO 2 in RSA Valgioie, the first home for the elderly in Turin, with 44 beds for elderly dependents.
A success, according to the results: the reset of all the risk factors, the reduction of the consumption of drugs and the diminution of nursing time per month dedicated to the activity for drug dispensing.
In practice the cart, thanks to a system of optical recognition and a patented radio frequency identification, guide the nurse in charging the cart with the necessary drugs for the administration. It automatically recognize the room where it is and drive the nurse in finding the right drug, also highlighting the possible opening of a wrong drawer.
With those intelligent cart is handled the entire process of drug therapy, from the administration to inventory management: in addition to the recognition systems, the carts are equipped with touch-screen for simple and intuitive use and thanks to Wi-Fi technology all the informations are available in real time and on the move.

2.2 Virtual supporting tools

In addition to physical tools described before, there is a wide range of purely virtual tools that allow you to be alerted at certain times or in certain situations for the intake of medicines. The growing number of these solutions is due to the great easiness of

use and to the convenience that such devices are always with the user.
However, they have generally a big problem: they can not check whether the user has actually taken the notified medicine, and above all there is no control about the correctness of the assumption of the medicine. The user can unconsciously take a wrong medicine and not the notified one.

2.2.1 App

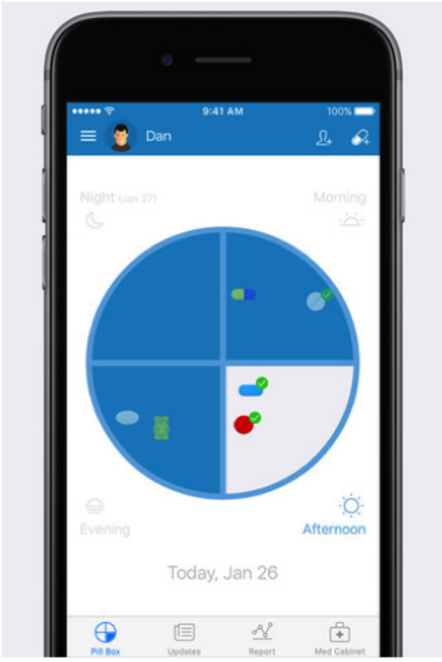
Applications for Smartphones, Smartwatch and Tablets are becoming widely used also as a reminder for taking medicines and managing the assumption of them. We will focus on those who have something interesting for us

MediSafe [27] (Android, iOS, Amazon devices)

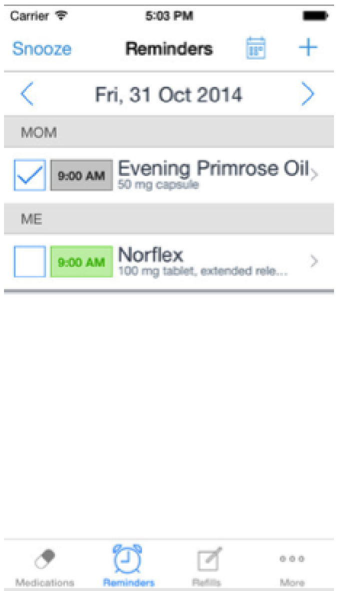
It looks the most complete, customizable and friendly user application for smartphone.
Here a list of strenght points:
+ very nice and easy interface
+ Research of medications (name in english)
dose and units
+ person (can be for someone else - different statistics are generated) pill reminder can be activated as needed (frequency, times, period). The alarm is on a specific time. If deactivated is considered a "if needed medication"
+ refill reminder can be activated as needed (can be fixed date or a period of time)
+ function snooze
+ statistics on medical adherence
Something should be improved like:
- There is no possibility to set "take this medicine after meal or after another medicine or far from another medication" (can only be written a note)
- Research of medicine is done only for US medication

Pill Reminder [28] (only on iOS devices)

Here a list of functionalities of the app (what is missed is not

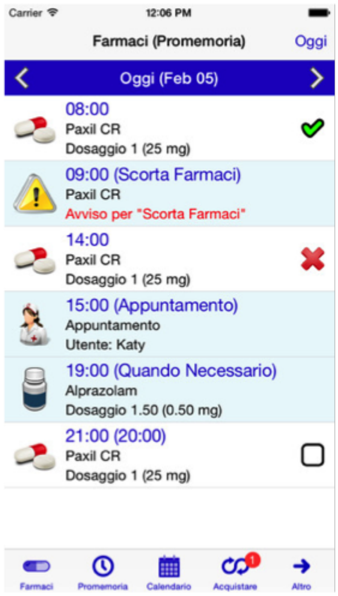


(a) MediSafe App



(b) Pill Reminder App

(c) MedHelper App



(d) Farmaci Promemoria App

FIGURE 2.15: Different examples of mobile applications for managing medicines

a feature of the app):
+ Research of medications (name in english)
+ notes
+ person (can be for someone else)
+ pill reminder can be activated as needed (quantity, frequency, times, period). The alarm is on a specific time.
+ refill reminder can be activated as needed (can be fixed date or a period of time)
+ function snooze
+ calendar with past and future events

Farmaci, Promemoria con Allarme e Calendario [29]
In this simple application there are a lot of useful infos to be inserted that in other app are missing like "Expiration Date".
The design is a little bit rough.
It is simple and intuitive to organize medication and other appointments all together.

MedHelper [30] (Android and iOS devices)
Pros:
+ Can be setted a lot of infos on prescription
+ Can be created multiple profiles so it can manage more people with one app
Cons:
- Design not so intuitive

2.2.2 Other SW

ICareHealth icareHealt

They provide a large variety of solutions that can mainly divided in two categories:

- Software (thanks to partnership with Microsoft, based on Microsoft services).
  Collaborative initiatives with Microsoft allows iCareHealth to

provide residential and home care providers with the technology, software, services and devices that can deliver tangible benefits. The system incorporates a variety of user interfaces that can be accessed via a configuration of devices including desktops, laptops and mobile devices – depending on operational requirements.

- Products
  In products they can provide there are both Home Care Manager (Easy to use tools that enhance the delivery of home care) and Medication Management (Designed to simplify medication management and administration, medication profiles and reporting interactions with pharmacists).
  The programs are proprietary but they provide something similar to a tablet that can run the program and can be used by users.

2.3 Mixed solutions

The following solution is very similar to what we are interested in. It is based both on hardware and on software technologies. It uses: a Web-Server, a Mobile Application on a Smartphone, a Smartwatch, a Home Gateway and a Cabinet detecting RFID on medications containers.

2.3.1 An Intelligent Medication System Designed to improve the Medication Adherence

In this case described by Rodrigues, Silva and de Lucena [31] are considered two scenarios: one scenario is at the physician's office where prescription software is used to register the patient treatment and makes them available through a web service that is responsible to send the data to patient's smartphone, which will alert the patient about the intake schedule. The second scenario is based on a patient's mobile device, be it a Smartphone or a tablet; in this scenario the mobile device receives the prescription data and generates the alarms, based on prescription data and on patient data localization. If the patient is at home, the home gateway sends the alarms to all home devices - for example a TV.

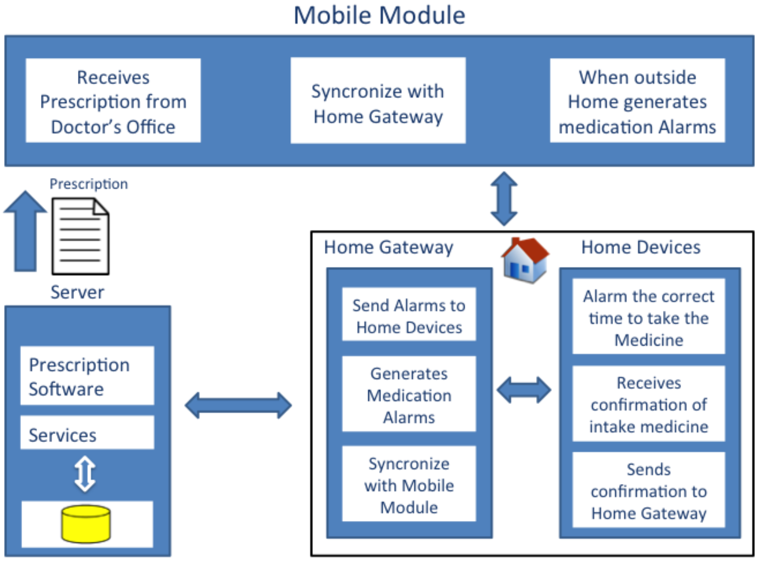


FIGURE 2.16: Structure of the system

It is composed by four parts:

- **A Prescription Software (PS)**
  The PS is where the physician can make the prescription and see the patient medicine intake confirmation. This software is intended to provide an interface for the physician to give the prescription. This program is hosted on the web and once the prescription is finished the patient smartphone will receive the prescription data through an app. It's also responsible for generating alerts to the doctor, the patient's caregiver or some relative, if the patient does not inform the correct intake of the drug.

- **A Mobile Application**
  The mobile receives the prescription in the Doctor's office, and once the patient registers the first take of each medicine listed on the prescription, while still away from home, it generates the medication alarms; it's also responsible for synchronizing its data with a home gateway when the patient is at home.

- **A Home Gateway**
  This component is responsible for generating and sharing the intake reminders to other in-home devices as well as receiving confirmations from these devices and synchronizing with the Mobile Application.
- **A Smart Watch Application**
  This application is responsible for indicating if the patient is at home or not and delivering alarms to the patient.

In this project is very smart the use of a smartwatch to detect the person and differentiate from another one. The system can know who take medicines from the cabinet. The alarm are shown both on the Mobile Application and on TV since it is common in elderly people. The cabinet is not portable and must be placed in a fixed position.

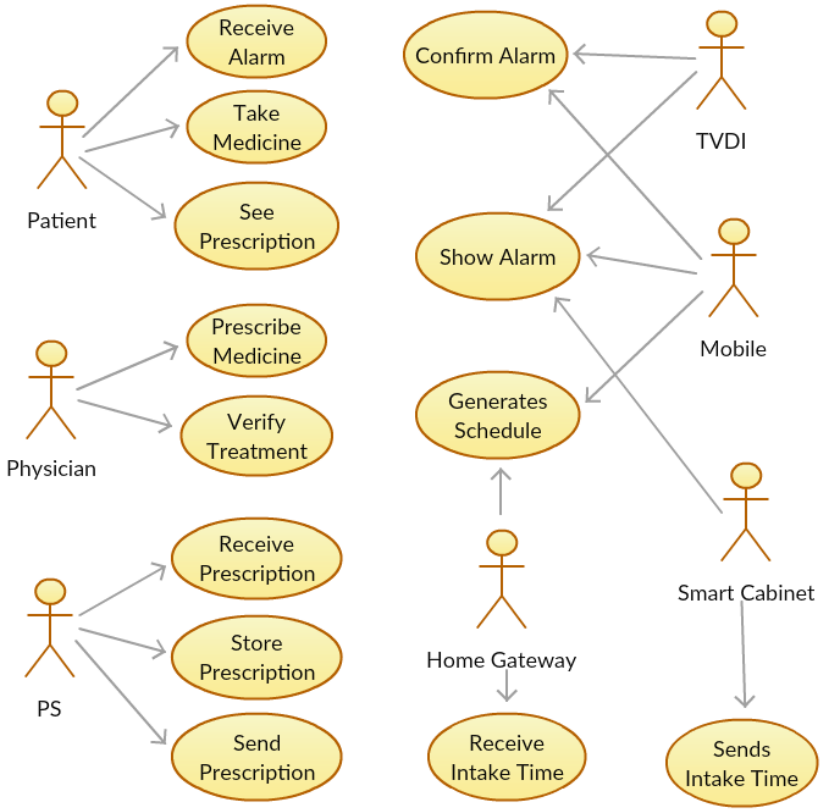


FIGURE 2.17: UML diagram of the system

The patient actor has three activities which are: receive reminders, take drugs and view prescriptions. In this case, it is observed that the actions of the patient depend on the feedback alarms and revenues from the gateway and the smartphone. The Medical actor prescribes the drugs through prescriptions subsystem and monitors the treatment of patients.
The prescription system, represented in the diagram by actor PS, is responsible for generating prescriptions and sending them to the gateway and to the smartphone for treatment and scheduled and the actor mobile generates schedules for taking drugs, also showing reminders.
The smart cabinet sends data on medicines intake to the residential gateway and shows the data taken through warnings and alarms, while the gateway creates schedules, receives intake times and reports the data to the doctor to assist in decision taking on medical treatment.
The iDTV actor is responsible for presenting the alarms of taken medication to the patient and confirming the alarms to be sent to the residential gateway.
Thus, the integrated system with wireless networking and internet technologies, allows health teams to track the prescriptions and schedules, enabling the doctor to be notified, for example, in cases of medication deviation or medicines taken at incorrect times.
A prototype for a prescription monitoring scenario was developed through applications embedded in iDTV, smartphone and residential gateway, in order to verify the systems integration and improve adherence to medications.
The gateway was implemented on a Mini PC. The other devices at home are represented in our implementation by a Digital TV because it's very popular among elderly people.
The PS (prescription software) is implemented in JSF Java and hosted on the web through a Tomcat Apache Server. The Mobile Module is implemented using the Android platform. In the mobile module it is possible to see all medical prescriptions, register the time of first intake of each medicine, and see the in-take times registered by the patient. Based on prescription data the alarm

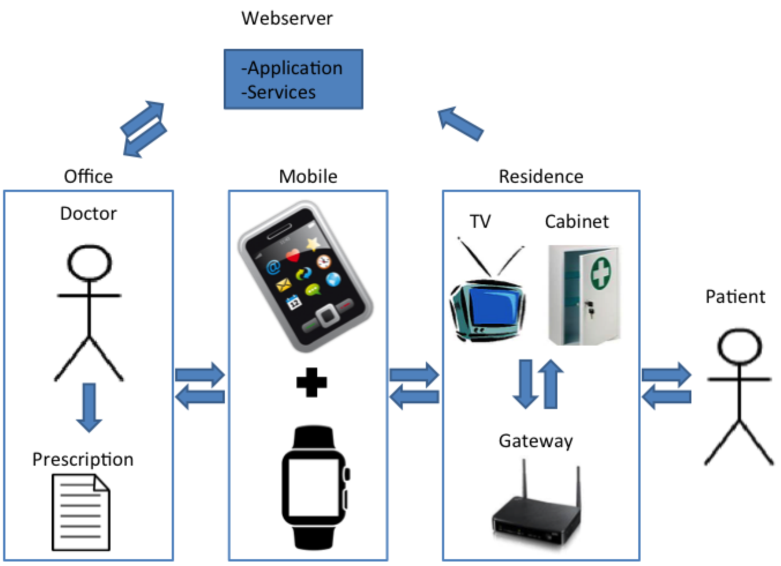


FIGURE 2.18: Overview of the implementation of the system

module generates the agenda for next doses of medication.
The communication between the Gateway and the TV was implemented using a communication infrastructure that enables the creation of a residential automation application using the Brazilian interactive Digital TV System and diverse electronic devices. This system may be extended to any other Digital TV System. The Digital TV Application was built using NCL and Lua languages and allows the patient to inform the medicine in-take with a click of the TV remote control green button; if the patient did not take the medicine he uses the red button.

2.4 Taxonomy Recap

The table 2.1 was created to have a short recap about all the technologies present on the market and in scientific world and categorize all of them according to some specifications like the place where it is used, the technology on which it is based on, the duration of the treatment and the dose of the medicine to intake.

TABLE 2.1: Recap classification of existing devices using taxonomy

Name	Where used	Technology	Last	Posology
mechanical physical devices	home	mechanical	daily, weekly	fixed
mechanical physical devices	home	electronical, with reminder	weekly, monthly	fixed
Dispensers	home	electronical, with reminder	usually 28 different doses, monthly	fixed, can be "as needed" (variable)
RMAIS	home	electronical, RFID-based	SW: monthly, pills: as many are in box	fixed
RFID Medication Dispenser	home	electronical	28 different doses	fixed, no control on repeating assumptions
Omnicell M5000	big american pharmacy	electronical, fully automatized	depends on pills request	fixed
Intelligent cart	RSA, hospitals	electronical, wireless	One day for multiple people	fixed. Every day can be setted by doctors
APP	home	reminder	can be setted forever	generally fixed, can be managed "as needed"
Mixed solution	home	reminder, electronical with sensors	SW usually manages one month but can be more	fixed, can be changed by SW "as needed"

Chapter 3

RFID Technology

RFID stands for **Radio-Frequency IDentification**. The acronym refers to small electronic devices that consist of a small chip and an antenna.
The RFID device provides a unique identifier for an object. And, just as a bar code or magnetic strip must be scanned to get the information, the RFID device must be scanned to retrieve the identifying information.
A significant advantage of RFID devices over others is that the RFID device does not need to be positioned precisely relative to the scanner. They will work within a few meters (we will better specify this later).

3.1 Structure of RFID System

A RFID system has three parts:

- A scanning antenna
- A transceiver with a decoder to interpret the data (The reader)
- A transponder - the RFID tag - that has been programmed with information

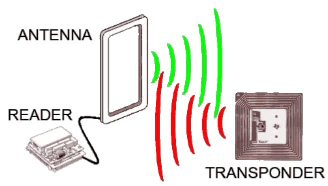


FIGURE 3.1: Example of a RFID system

The scanning antenna puts out radio-frequency signals in a relatively short range. The RF radiation does two things:

- It provides a means of communicating with the transponder (the RFID tag)
- It provides the RFID tag with the energy to communicate (in the case of passive RFID tags)

This is an absolutely key part of the technology; RFID tags do not need to contain batteries, and can therefore remain usable for very long periods of time (maybe decades).
The scanning antennas can be permanently affixed to a surface; handheld antennas are also available. They can take whatever shape you need.
When a RFID tag passes through the field of the scanning antenna, it detects the activation signal from the antenna. That "wakes up" the RFID chip, and it transmits the information on its microchip to be picked up by the scanning antenna. So when wirelessly interrogated by RFID readers, tags respond with some identifying information that may be associated with arbitrary data records.

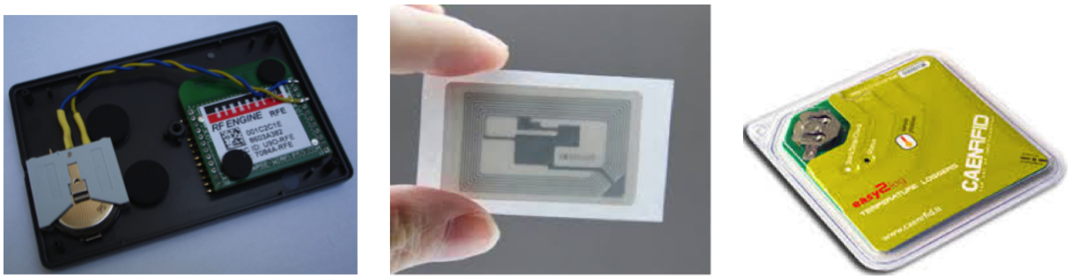
3.2 Types of RFID Tags

There are different types of RFID tags: they are mainly of two types.

Active RFID tags have their own power source; the advantage of these tags is that the reader can be much farther away and still get the signal. Even though some of these devices are built to have up to a 10 year life span, they have limited life spans.

Passive RFID tags , however, do not require batteries, and can be much smaller and have a virtually unlimited life span. The tag reader is responsible for powering and communicating with a tag. The tag antenna captures energy and transfers the tag's ID (the tag's chip coordinates this process). The encapsulation maintains the tag's integrity and protects the antenna and chip from environmental conditions or reagents.

Two different RFID design approaches exist for transferring power from the reader to the tag: **magnetic induction** and **electromagnetic (EM) wave capture**. These two designs take advantage of the EM properties associated with an RF antenna — the *near field* and the *far field*. Both can transfer enough power to a remote tag to sustain its operation. Through various modulation techniques, near- and far-field-based signals can also transmit and receive data.



(a) Active RFID TAG (b) Passive RFID TAG (c) Semiactive RFID TAG

FIGURE 3.2: Type of RFID TAG

3.3 Problems With RFID

3.3.1 Collision Problems with RFID

Some common and known problems [32] with RFID are **reader collision** and **tag collision**. *Reader collision* occurs when the signals from two or more readers overlap. The tag is unable to respond to simultaneous queries. Systems must be carefully set up to avoid this problem. *Tag collision* occurs when many tags are present in a small area; since the read time is very fast, it is easy to develop systems that ensure that tags respond one at a time. An example of this is shown in fig. 3.3.

3.3.2 Problems with RFID Standards

RFID has been implemented in different ways by different manufacturers; global standards are still being worked on. It should be noted that some RFID devices are never meant to leave their network (as in the case of RFID tags used for inventory control within

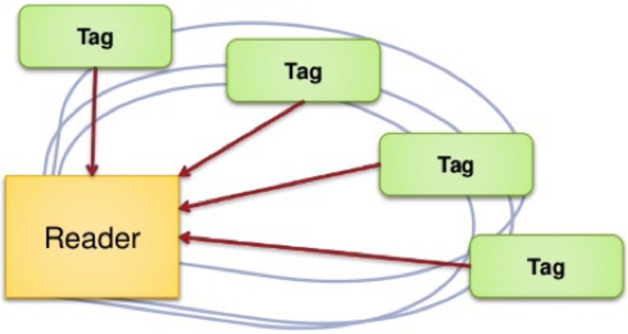


FIGURE 3.3: Example of tag collision

a company). This can cause problems for companies.
Consumers may also have problems with RFID standards [33].

3.3.3 RFID systems can be easily disrupted

Since RFID systems make use of the electromagnetic spectrum (like WiFi networks or mobile phones), they are relatively easy to jam using energy at the right frequency. Although this would only be an inconvenience for some kind of users, it could be disastrous in other environments where RFID is increasingly used, like hospitals or in the military in the field.
Also, active RFID tags (those that use a battery to increase the range of the system) can be repeatedly interrogated to wear the battery down, disrupting the system.

3.3.4 RFID tags are difficult to remove

RFID tags are difficult for consumers to remove; some are very small (less than a half-millimeter square, and as thin as a sheet of paper) - others may be hidden or embedded inside a product where consumers cannot see them. New technologies allow RFID tags to be "printed" right on a product and may not be removable at all.

3.3.5 RFID tags can be read without your knowledge

Since the tags can be read without being swiped or obviously scanned (as is the case with magnetic strips or barcodes), anyone

Band	Data speed	Remarks	ISO/IEC 18000 Section	Range
120–150 kHz (LF)	Low	Animal identification, factory data collection	Part 2	10 cm
13.56 MHz (HF)	Low to moderate	Smart cards, memory cards, payments	Part 3	10 cm–1 m
433 MHz (UHF)	Moderate	Defense applications, with active tags	Part 7	1–100 m
865-868 MHz	Moderate to high	EAN, various standards	Part 6	1–12 m
2450-5800 MHz	High	802.11 WLAN, Bluetooth standards	Part 4	1–2 m
3.1–10 GHz	High	requires semi-active or active tags	Not Defined	to 200 m

TABLE 3.1: RFID Frequencies range in Europe

with an RFID tag reader can read the tags embedded in consumer products without your knowledge. Usually RFID reader/tag systems are designed so that distance between the tag and the reader is kept to a minimum (see the material on tag collision above) but with a high-gain antenna it is possible read the tags from much further away, leading to privacy problems.

3.4 RFID frequency bands

The range of frequencies used in RFID technology is very wide [34]. The operating band normate from ISO / IEC standard can be summarized in the table 3.1.

For the project, and its required specifications, the choice was to use passive tags at 13.56 MHz. The low frequency reader is not able to interact with the individual tag when more than one is in the antenna's field [35].

The UHF technology was not considered since the reading distance is very high and it is difficult to identify when a transponder is moved away with a small distance from the antenna.

3.5 RFID TAGS with high frequency

Passive tags are powered by the radio frequency received from the reader. Even communication is substantially different from the active transponders. In fact, they do not generate the carrier, but they radiate back, applying a modulation on it, some of the energy received from the reader who is doing request to them. This is done by varying the antenna impedance transforming it from absorbing to reflective - like to the use a mirror and the solar light for light signals at a distance. Exploiting this principle there is no more need of local oscillators, which would be indispensable to generate a carrier, and therefore reduces the power needed to power the tag.
Talone and Russo [36] explain that exists two methods used to take energy from the reader and communicate with it: **inductive coupling** and **electromagnetic coupling** *with back-scatter effect*. The first one is widely used for bands with longer wavelength (LF and HF) while the second effect is more influencing if distances are longer and is used for bands with shorter wavelength (UHF and SHF).
Inductive coupling between the tag and the reader happens thanks to antennas with coupled coils: the two antennas are like a LC circuit and it behaves like an electrical transformer.
So the tag is inside the magnetic field; the flow, variable in time, is concatenated with the coils of its antenna generating an induced current. The energy obtained is used to power the electronic circuit. The communication between reader and tag is performed modulating in amplitude the magnetic field created by the reader with the digital baseband signal to be transmitted. The tag of the receiving circuit detects the modulated field and decodes the information that was transmitted. Communication back, from the transponder to the reader, is achieved by varying the loading of the tag antenna (load modulation); so the modulated signal is seen in the primary winding.

For the band of frequencies around 13.56 MHz, ISO and IEC define three standards, with some variants:

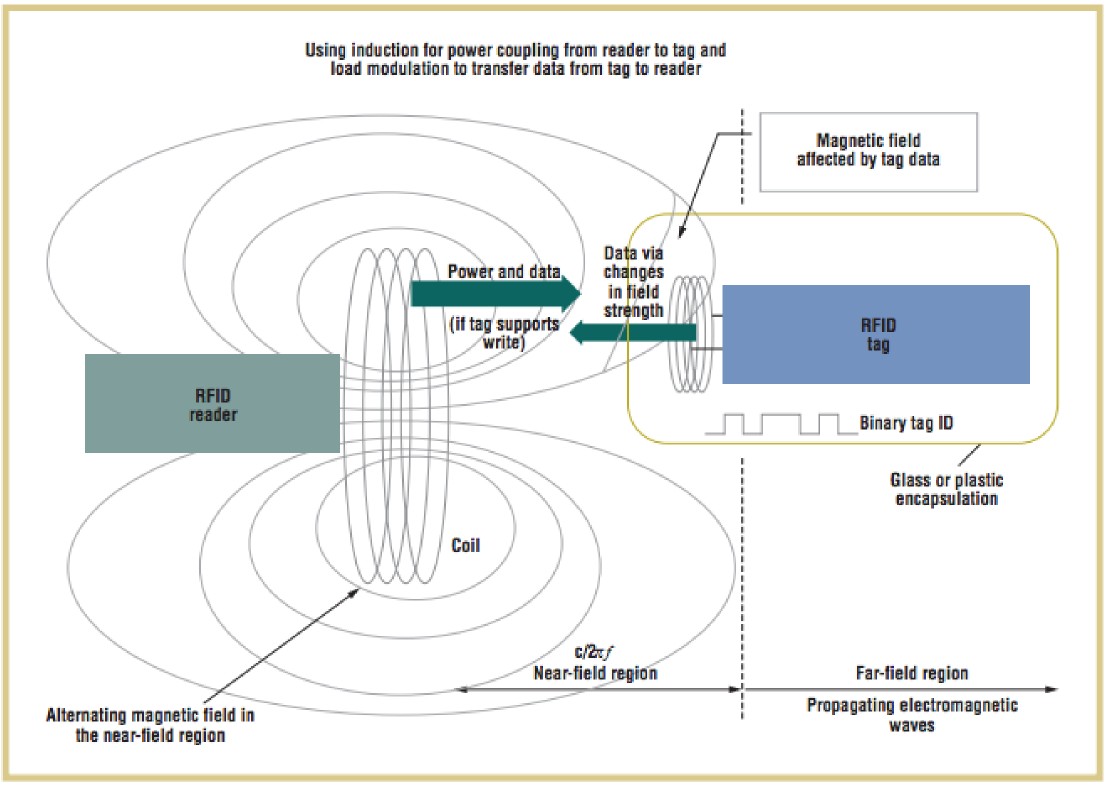


FIGURE 3.4: RFID near-field coupling

1. ISO / IEC 14443 (Type A and Type B) is used for very short communication distances (up to 10 cm). It operates with a magnetic field intensity of a minimum of 1.5 A/m, and can reach a half-duplex communication speed of 848 kb/s. Type A and Type B differ in the type of modulation, for the encoding of the bit and for the transmission of synchronization mechanisms. The two variants are different for anti-collision procedure, which is the set of techniques that allows the identification of a single transponder among all those who are in the antenna field. The high-level transmission protocol, on the contrary, is the same: it defines the frame for the reading and writing of the data present in the tag. Since the communication distance is restricted, the standard is suitable for applications that require a certain degree of security (for example, the access control, payment cards, identity documents, etc.), and this is the reason why very often manufacturers have implemented encryption algorithms on chip transponders.

2. ISO / IEC 15693 (ISO / IEC 18000-3 Mode 1) [37] uses a

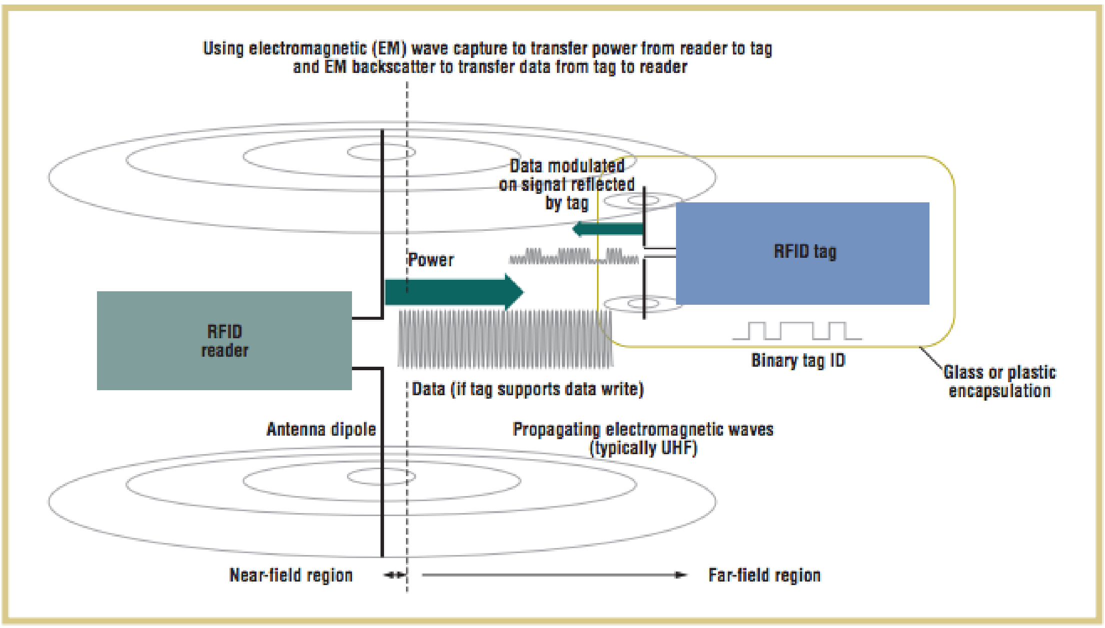


FIGURE 3.5: RFID far-field coupling

magnetic field with a minimum intensity equal to 0.15 A/m (much lower than that of the ISO / IEC 14443 standard), but, since the velocity and communication are extremely limited (up to a maximum of 26 kb/s), the communication between reader and tag is performed even at distances of the order of some tens of centimeters. The labels that adhere to this standard are used for applications like traceability of products, non-bank electronic cash, etc.

3. ISO / IEC 18092 (NFC, Near Field Communication) is a standard that is rapidly spreading in consumer business because available in many mobile phones recently produced and used, in combination with encryption algorithms in the SIM, for contactless payments replacing the traditional credit cards. Velocity and communication distances are similar to the ISO / IEC 14443 standard, and it is also fully compatible with it[38]. In addition to the classic reader/tag paradigm, NFC introduces the operating modality card emulation and peer to peer. Using the first, an active NFC device allows you to emulate an NFC tag, acting like an RFID passive transponder. With peer to peer instead, two NFC devices can enable two-way communication to exchange data: alternately each

of the two will behave first as a player and then as a tag.

Among the three listed standards it was chosen the ISO / IEC 15693. In fact, it allows a working distance compatible with the project's objectives; the reduced velocity communication does not represent a limit [39], since we do not need the exchange of large quantities of data, but only the tag identification.

Chapter 4

Hardware Architecture

The core of the prototype is an electronic board named "Seriz II" that is composed by one microprocessor "LPC4350", a RFID antenna (which has been disconnected and modified to connect a different antenna - bigger in dimensions and more suitable for our purpose) and a LCD display. To this board has been also connected a small module to create a wi-fi connection to configure medicines. Let's see those components with some more details.

4.1 Silica Seriz II Board

Seriz II Board is a secure RFID and NFC development board [40]. The development of RFID and NFC applications is being challenged due to the many different kinds of RFID tags on the market. Furthermore, some cards are becoming very complex as there is a growing need for security.
Software can be written, modified and compiled with the LPCXpresso IDE from NXP [41].

It is composed by several components, and among them the more relevants are:

- **Microcontroller LPC4350**. This microcontroller is ARM Cortex-M4 based microcontroller for embedded applications which include an ARM Cortex-M0 coprocessor, up to 264 kB of SRAM, advanced configurable peripherals such as the State Configurable Timer/PWM (SCTimer/PWM) and

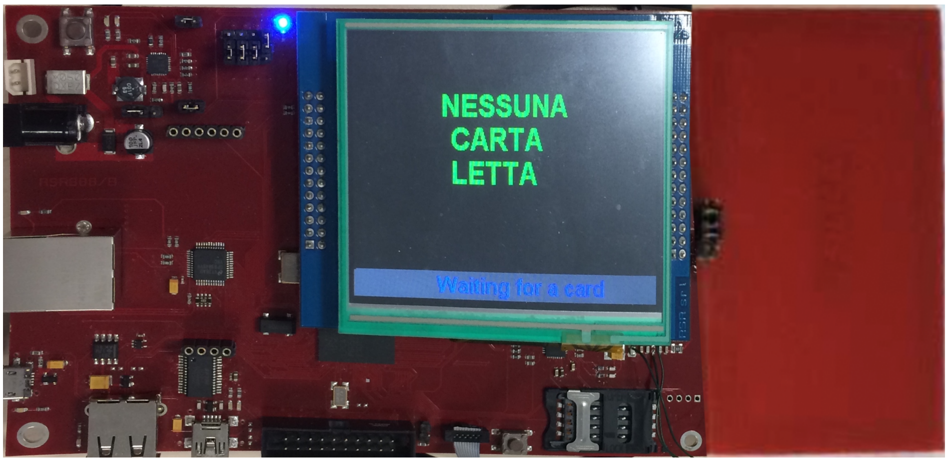


FIGURE 4.1: Silica Seriz II board

the Serial General-Purpose I/O (SGPIO) interface, two high-speed USB controllers, Ethernet, LCD, an external memory controller, and multiple digital and analog peripherals [42]. It operates at CPU frequencies of up to 204 MHz. The ARM Cortex-M4 is a 32-bit core that offers system enhancements such as low power consumption, enhanced debug features, and a high level of support block integration. The ARM Cortex-M4 CPU incorporates a 3-stage pipeline, uses a Harvard architecture with separate local instruction and data buses as well as a third bus for peripherals, and includes an internal prefetch unit that supports speculative branching. The ARM Cortex-M4 supports single-cycle digital signal processing and SIMD instructions. A hardware floating-point processor is integrated in the core.

- **JTAG Connector**. It is necessary for the communication between the board and an extra circuit (known as emulator) that performs the debug of the program the board is running. This communication is very useful only when developing the program for the board to let developer know the values of variables and how the program is working. For the final user the debugging feature is completely useless, that's why there is only the JTAG connector where to place an external circuit for debugging. The final user won't need it.

- **Ethernet connector**. It is important for the TCP communication between the board and a PC or anything else supports

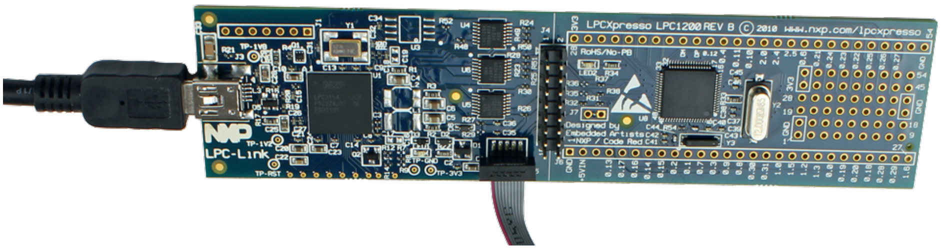


FIGURE 4.2: Emulator LPC-Link with the connector JTAG to communicate wit board Seriz II

this type of communication. In our project has not been used since it was preferred to use a wireless connection using AT commands and a simple serial communication that will be described later.

- **Bank of flash memory**. It is necessary to store the program and all the instructions that the microcontroller has to perform. Depending on the boot configuration, the board uses different positions in memory to search the code it has to perform to start the program. The flash memory can be one option if the code was uploaded on the board (usually is used the ROM on board). During debugging the program comes from the JTAG Connector.

- **CLRC663 Antenna**. The default antenna has been disconnected and is no longer used. Instead of using this antenna, it has been connected a larger and longer antenna to fit our need of coverage. Its structure, how it is done and the way it is connected is described later.

4.2 Display LCD

The display LCD 3,5" is directly connected to the board through several pins which can control the colors displayed, light intensity, written words and even images. To control the behaviour of the display it's useful the support of an external and free library "emWin" and use its default functions. Thanks to this external library the display is useful and can be easily used. It is also comfortable for the final user to see if he is taking the correct medicine

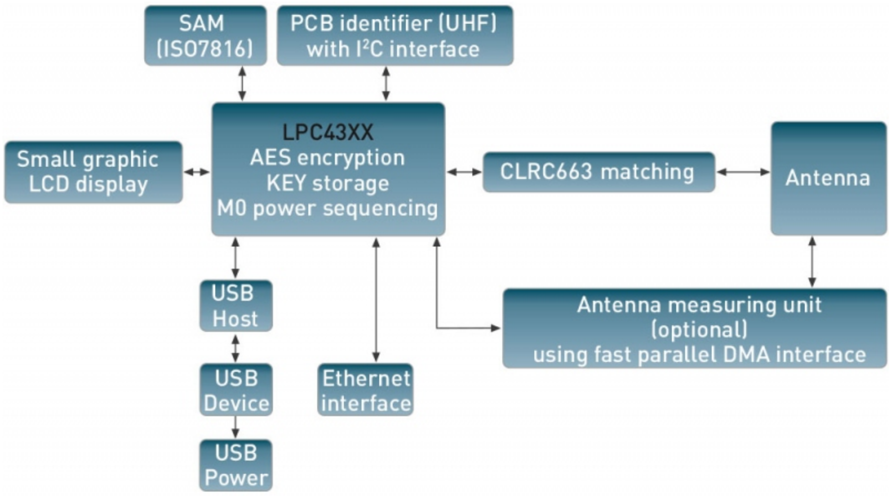


FIGURE 4.3: Schema of all the components connected on the board Seriz II

or other notifications.
For future improvements to the screen, it can be developed and activated the touch screen control and in this way it could also be used for programming the system or any other future feature.

4.3 RFID Antenna

The RFID antenna used for the project is not the original one integrated in the board, but it is a special antenna connected to the place of the previous one. The connection to the board is the same as the original one.
The particularity of this antenna is its dimension (three times greater than common RFID antennas) that can cover a wider space as needed for the project. It is composed from several different RFID antennas that should work alternately and detect all the RFID tags present in the area of the antenna.
Testing the behaviour of the antenna with tags placed on it, it has been discovered that a big antenna is not so very functional and it doesn't work as good as expected because of some problems explained in another chapter. It has been thought an alternative solution to solve those problems and it will require several "standard RFID antennas" placed on each separator inside the box so that each medicine can be correctly detected and there will also be

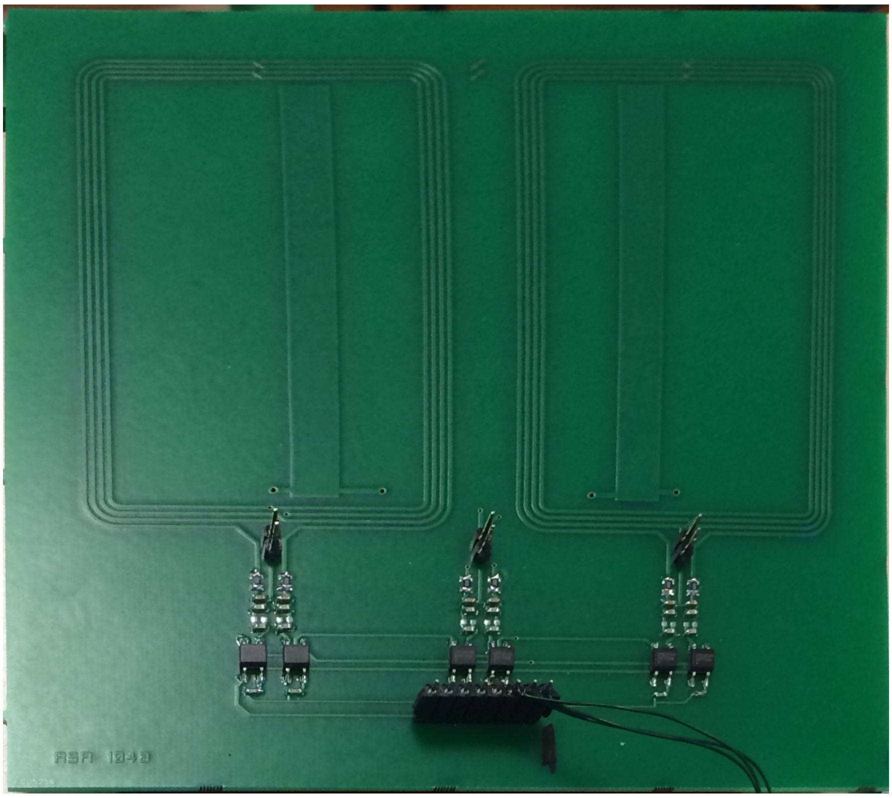


FIGURE 4.4: New RFID antenna with bigger area covered by EM field

the possibility to know with rough precision the positioning in the box of the medicine.

4.4 Wifi Module

The wi-fi module is the RN-131 module built by Microchip [43]. It is a full-featured 802.11 b/g Wi-Fi module, and a complete, ultra-low power embedded TCP/IP solution. The combination of ultra-low power and the ability to wake up, connect to a wireless network, send data, and return to sleep mode in less than 100 milliseconds, allows the RN-131 to be considered a very important product from the point of view of power efficiency.
It can be connected directly to a PC via a standard USB interface or to embedded processors through the TTL/UART interface. For our project was used the UART interface.
The communication between the board (the microcontroller) and

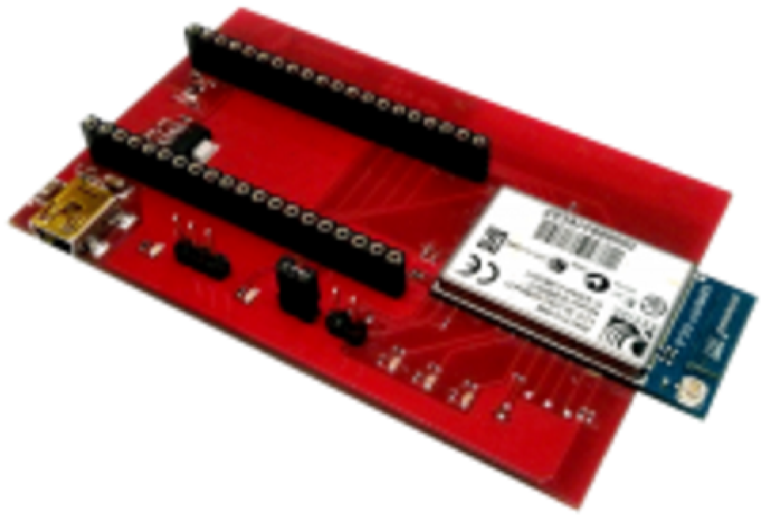
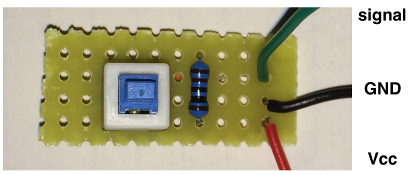
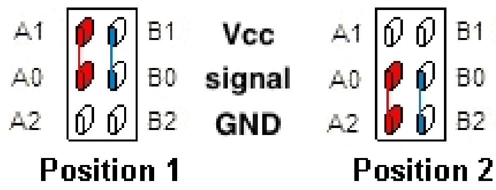


FIGURE 4.5: Board with module RN-131 used to create wi-fi connection

the module is based on the UART interface using simple AT commands. From the board to the module are needed 2 signals (RX - Receive and TX - Transmit) with GND and VCC (given by USB cable for the project). TX signal let the microcontroller to send commands to the module and the RX signal is used from the module to send back to the microcontroller the replay. In addition to the usage of those 2 signals, 3 more signals must be controlled from the microcontroller to let the wi-fi module work properly: RTS, CTS and SHDWN. Those 3 signals are important for the communication between the microcontroller and the module because they manage the exchange of commands and, thanks to them, there should be no loss of informations and no missed command. RTS (Request To Send) is the signal that indicate a desire to transmit to the receiver. If it is ready to receive the commands, it will send the signal CTS (Clear To Send) and grant permission for the transmitter to send data and be sure that the receiver won't miss them. The SHDWN signal is used to restart and reboot the wi-fi module: this signal can control the VCC of the USB cable and force the module to shut down; it also can wake it up.



(a) Switch for the state of the system



(b) Schema of the switch

4.5 Switch

The switch is used like a simple button: it is connected to VCC, to GND and every time is pressed it changes the signal on the third pin connected to it. This button has to be pressed if the user wants to set up and configure the system. If it is pressed again the system is no longer in configuration mode and works as it is supposed to do: like a medicine reminder.
In possible future evolution of the project this switch could be removed so that elderly won't have the chance of accidentally switching from configuration function to the reminder function bringing the system in a blocking situation.

4.6 Composition of the prototype

The system is composed by several parts described in the whole chapter: now we will show how they work together.
The principal component is the microcontroller LPC4350 and gives all the other elements all the commands.
The microcontroller can tell to the antenna to search RFID tags in its field and waits for the reply: it will know all the ID of the tags present. Thanks to this information it can check, according to the table of medicines stored in memory, if a tag connected to a medicine is missing or not. From this, it controls the LCD to give to the user a feedback about the state of the system.
When all the tags are present in the field of the antenna, the microcontroller checks, thanks to the RTC (Real Time Clock) if the current time is related to one intake of some medicine and, if it is the case, it advice the user.

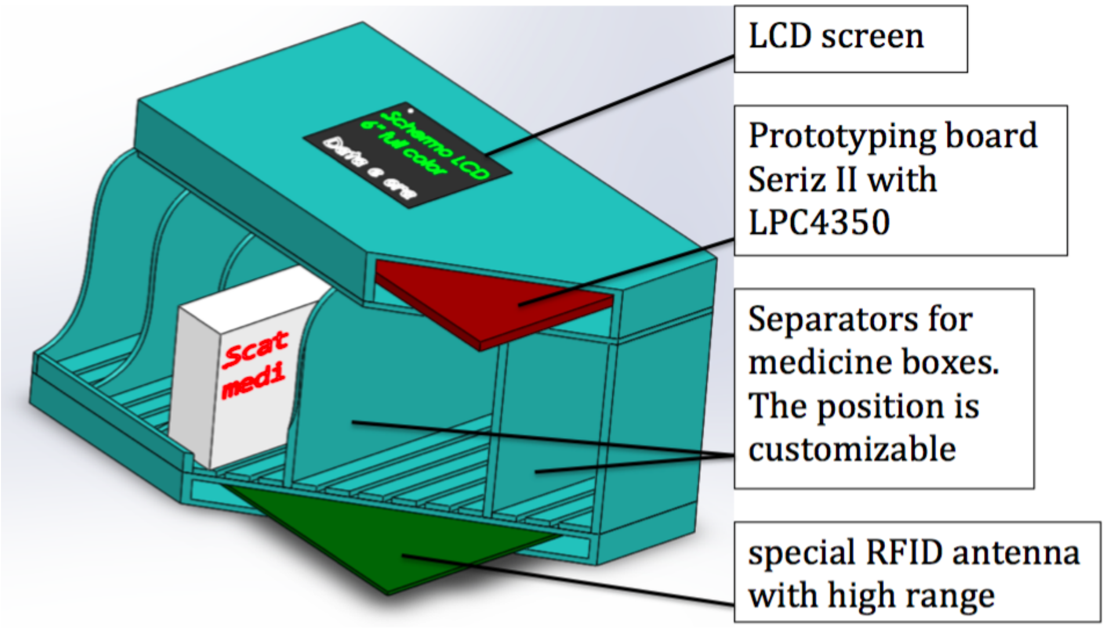


FIGURE 4.6: 3D model of the prototype

If the user or his relatives configures the system, the microcontroller stops these actions and runs a webserver, a state machine that allows the online visualization of a page for the configuration of medicines.
Since we discovered a problem related to aluminium (it stops the communication between the antenna and the RFID) and medicine blisters are usually done with an aluminium film, we decided to oblige the user to put the medicine boxes vertically to the RFID antenna so the aluminium does not interfere so much.

Chapter 5

System Description

In this chapter we shall consider the management of the pills and how it has been developed the part about pills reminder.
Since our purpose is to create an embedded application, we couldn't use some kind of database to be installed and the best solution was to create a simple, but useful, table containing all the informations about medicines and also about the recurrency of the intake [44].
A possible different approach to this could have been the creation of a C structure for every medicine to be taken and related to an RFID tag in which could have been saved all the informations in different attributes with a name. For reason of space efficiency this work uses the table that will be described later and has not been implemented the structure. Future works can easily change from to this approach with small effort in case there will be the need.
The biggest issue we had to deal with was about the different frequency of the intake: some pills has to be taken more times during a single day, other has to be taken with a very low frequency like once every two day, weekly, monthly, etc.
To solve this issue in the table were created different fields (columns) and they are filled with the different informations about the intake of the medicines.
The structure of the table used for the prototype project is shown in 5.1.

Now we will describe how they are used, which is their meaning and how informations are stored inside of the fields.

BIT LENGTH	4	35	4	4	4	3	1
LABEL	TAG	Name	Expiring date	Starting date	Ending date	Hour	Repetition day

BIT LENGTH	1	1	1	1	1	1
LABEL	dose	Hour Counter	Hour repetition	Day Counter	Day repetition	Importance

BIT LENGTH	2	1	1	35
LABEL	Number of remaining units	Limit number for notification	Number of intake per day	Optional infos

TABLE 5.1: Table for manage medicine assumption

TAG It's a mandatory field for the insertion of the medicine in the system. It has length of 4 bits and it will contains the Identification number of the RFID tag connected to a medicine. In this way the medicine can be recognised in a unique way from the system and it can discover if the user is taking the correct medicine. In case of wrong intake, the system is going to provide early warning to the user.

NAME It's a mandatory field for the insertion of the medicine in the system and has length of 35 bits. It contains the name of the medicine, the same name which is displayed on the screen and is inserted during the "configuration step" when it's configured time and date when the medicine has to be taken.

EXPIRING DATE It's a mandatory field for the insertion of the medicine in the system. It has length of 4 bits and contains the information about day, month and year when the medicine expires. This is necessary to advise user some days before the medicine expires in order to have the time to get new receipt from doctor and buy newer medicines.

<u>STARTING DATE</u> It's a mandatory field for the insertion of the medicine in the system. It is long 4 bits. It is the date when the medicine intake starts (the day the medical treatment begins). It can be different from the current day because can be a treatment already active, but can also be a programmed treatment for future. Before of this date the system do not consider the medicine to be taken.

<u>ENDING DATE</u> It's the same of "Starting date" described above, with the difference that it is used for the end of the treatment. If the current date is after this date, the system prevent user from intaking medicine.

<u>HOUR</u> It's a mandatory field for the insertion of the medicine in the system. It is long 3 bits. This field contains the information about hour, minute and second when the system has to notificate to the user the correct time of intake. Obviously if the user takes the medicines little time before this time, the notification will not be performed. The range of intaking time is setted in the field "Importance" described later.

<u>REPETITION DAY</u> This is a one byte field and it is filled with a sequence of 8 bits. The first bit is always 0 and the remaining 7 bits can be 0 or 1: each bit represents a day of the week (from Monday to Sunday) and is set to 1 if in that day should happen the intake. This is used for cases like "every monday"/"Every thursday and saturday"/"Every day but Sunday". In case of regular repetitions based on the number of days or hours this is set to 0 and it is used a different field explained later.

<u>DOSE</u> In this field is stored the number of the dose that has to be taken every time. It is not mandatory to set it, but can be useful to know how many units of medicine remain in order to be notified when they become too few.

<u>HOUR COUNTER</u> This one byte value is a counter that changes every hour for medicines that are regularly repeated based on a number of hour. It starts from the value set in the field "Hour repetition" and when it becomes 0 it means it is time to intake the medicine and the value becomes equal to "Hour repetition" again.

HOUR REPETITION This is one byte value and it is usually 0. If it is different from 0 it means that the medicine has to be taken regularly and the intake is based on hours. It is used for cases like "every 8 hours"/"every 48 hours".

DAY COUNTER This one byte value is a counter that changes every day for medicines that are regularly repeated based on a number of days. It starts from the value set in the field "Day repetition" and when it becomes 0 it means it is time to intake the medicine and the value becomes equal to "Day repetition" again.

DAY REPETITION This is one byte value and it is usually 0. If it is different from 0 it means that the medicine has to be taken regularly and the intake is based on number of days. It is used for cases like "every 2 days"/"every 30 days".

IMPORTANCE This is one byte value and it refers to the importance of a medicine: if a medicine is very important it means that the period of time in which you have to take the medicine is very short and if the user do not take the medicine at the precise time it consider the case of notify it. On the opposite if a medicine is not so important, means that can be taken even far from the time inserted and notified. There is no need to notify people with hurry.

NUMBER OF REMAINING UNITS This field is long 2 bytes and in it there are stored the number of units of medicine remaining for the user. With the field "Dose" let user to know when he should go to the doctor to take new medicines.

LIMIT NUMBER FOR NOTIFICATION This field is only one byte and let the user to decide when he wants to be notified about remaining units of medicine. It is not mandatory to fill it and works only if the user has inserted the field "Number of remaining units" and "Dose" it help user to know when he is running out of medicine and need to go to the doctor to buy new medicine.

<u>NUMBER OF INTAKE PER DAY</u> This one byte field is used to select which field have to be considered for the management of the medicine. If it is 0 the intake of the medicine is regulated by the field "Repetition"; if it is 1 it means that the field to be considered is "Hour repetition"; if it is greater than 1 the user has decided some custom hours in the same day for the intake. The custom hours are stored in the field "Optional infos".

<u>OPTIONAL INFOS</u> It's a 35 byte field used to store custom hours if the user has decided to set customized intake of the medicines. It is free space connected to the medicine that can be used for future improvements.

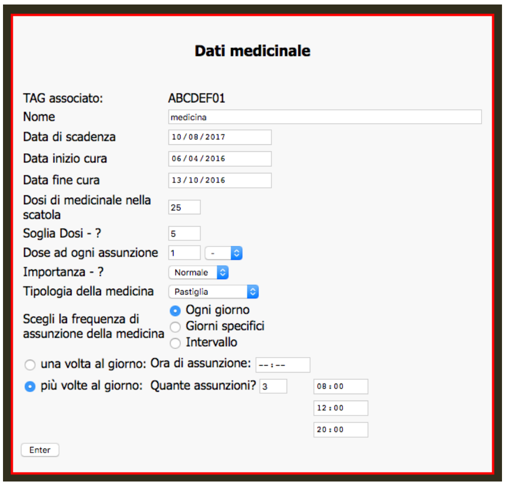
5.1 Functioning of the system

The system is created to be a simple but effective reminder for medicine intake. This system is supposed will be used mainly from elderly so the usage must be as simple as possible. For this reason the operation of the system has been implemented in a very simple way to give the user the feeling of simplicity during usage.

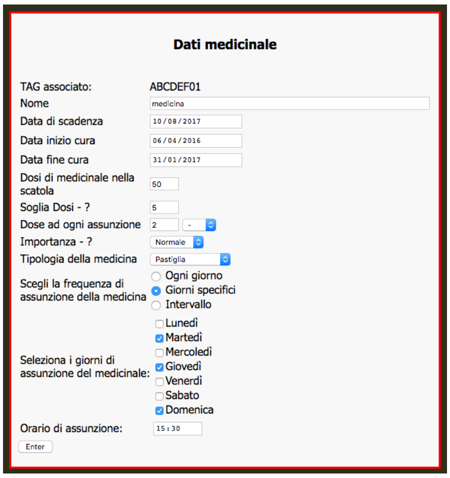
5.1.1 Configuring the system

To work properly, the system needs to be configured with all the medicine and all the reminders to be performed before it starts being a reminder. Perform this operation should be very easy even for normal people that do not have knowledge of medicine and are no doctor. It is needed the use of a computer, mobile phone, tablet or any other device with wi-fi connection. The system controls a wi-fi module (nr-131 produced by Microchip) that creates a wireless network. Connecting to it, and with the use of a browser, it is possible to connect to a webserver running on the board. From the web page it is possible to modify the day and the time displayed on the screen and it is also possible the insertion of new medicine to the list of medicine the system should remind to the user.
For the insertion of a new medicine, the person who configures

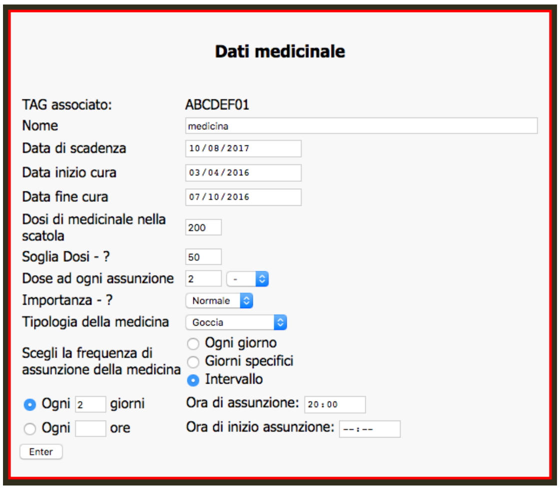
(a) Every day intake of the medicine



(b) Intake of the medicine more times per day with customizables times of intake



(c) Intake of the medicine in specific days



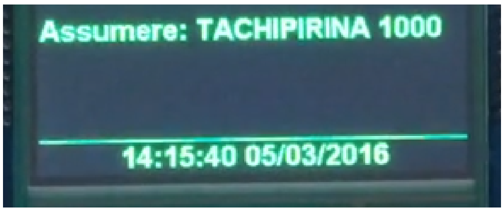
(d) Intake of the medicine with intervals (can be repetitive considering hours or days)

FIGURE 5.1: Four different possibilities of configuring the medicine intake

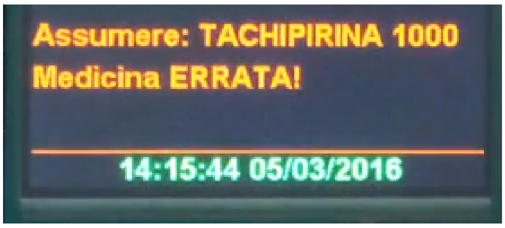
the system has need of an RFID tag to be applied to the box of medicine. He must place the tags on the antenna so that the system registers the ID of the tag. After this operation, the user can enter all the data required to tell the system when it has to remind him to take the medicine. Besides the name, the expiration date, time of intake, starting and ending dates of care, he has to enter the frequency with which the medicine has to be taken so that the system knows when to warn the user. There is also the possibility of inserting the number of medicines and the dose that each time is to be taken in such a way that the system can know the time at which the amount of medicinal product is low and must be replenished.
At the state of art the module only creates a wireless network and it is possible to connect to it to configure the system. It is also possible for the wi-fi module to connect to a wireless network already present so it can be also connected to the internet network.

5.1.2 Using the system

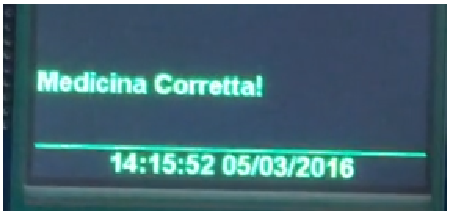
Once the user has inserted all the informations about medicine intake and has connected every RFID tag to every medicine in the treatment, the system can be switched in the usage mode. In this mode the system stops the webserver and it cannot be configured until it return to the configuration mode.
The usage mode performs continuously some actions needed to monitor the intake of medicine by the user: it verify the presence of the RFID tags on the antenna so it is sure that nobody is taking medicine. It also checks the current time and verifies if it is time for taking some medicine - due to informations inserted in the configuration step. If the current time is associated to some intake of medicine and the user hasn't yet taken it, the system alerts the user that he is missing the intake of a medicine.
To each medicine can be connected a value meaning the importance of the medicine and how long can be the time (before or after) the setted time. For example if a medicine is *very important* it means that the medicine can be taken in that precise moment, and every minute late can compromise the treatment. So in this case if the system recognise that the user doesn't intake the medicine



(a) Notification that a medicine must be taken



(b) The user is going to intake the wrong medicine: the system notify immediatly this to the user



(c) The user takes the correct medicine according to the medical treatment: the system comforts the user

FIGURE 5.2: Notifications on the LCD screen to help the user in the usage of the system

in few minutes, it will notify this bad behaviour and, if it is connected to the internet, it can also notify the caregiver or relatives of this behaviour.
Instead, if a medicine has a *low importance*, the time that can pass between the time setted and the notification of a bad behaviour can be longer (even some hours).

When the user takes some medicine from the system, this can recognise which medicine is going to be taken and can check if it is correct or not thanks to the RFID tag applied to the medicine box. If the user is going to take the wrong medicine (that is not configured in the treatment) the system warns the user thanks to the LCD screen so the user can understand he is doing something wrong. Instead, if the user takes the correct medicine according to the treatment, the system performs some operations to remain up to date: knowing the dose that the user should take and the number of doses of the medicine present in the box, it calculates the number of the remaining doses so it will be able to notify to the user when it is running out of some medicine in particular.

5.1.3 Considered scenarios

The use cases considered are about elderly who can live autonomously in home and can take care of themselves. Obviously the solution presented can be a strong help for them to remember to follow the medical prescriptions and without the anxiety of forgetting some medicine and get bad consequences about this.
The configuration of the system should be very simple and intuitive so even a smart elderly can manage this, but it could be preferable that some relative manages this step.
On the other side, the use of the system already configured is very very simple and it doesn't force elderly to change his habits to use it and to have benefits from it. The only particularity is that all the medicines required by user's therapy should be on the antenna inside the system box whit RFID tag pasted on the medicine envelope.
To have the benefits of the LCD screen the box system should be somewhere in the house where it is visible and in a room frequently used by the user. If the system will be connected to the wi-fi network of the user's home there would be other benefits like notifications.

Chapter 6

Conclusions

This work is a first step towards an embedded product that will help elderly people in their everyday life with respect to drug assumption and compliance to prescriptions.
The first goal of the thesis is to discover how the healthcare system considers autonomous people and what it does to help them with respect to the medical care of them.
Searching and discovering needs of elderly people and thinking about solutions to help them and make their life easier is an important step done by the thesis.
The solution proposed is focused on the embedded world: all the technology used is very basic and has been avoided the usage of any unnecessary part or any complex component to keep the cost of the system very low. It is based on a microcontroller to let the RFID antenna work and also to check the intake of medicine. One wi-fi module is connected to the microcontroller to create a wireless connection in order to set up the system and configure the prescriptions of the medicine the user will need to take.
Several problems were encountered during the development of this project, but this has always been a push to find some innovative solutions to make the prototype a better project than before.
The reading procedure of ID codes from tags has been proved reliable in time. The control procedure of the assumption of drugs has been verified in tests that allowed to evaluate the correctness of the operation of the control algorithms in the various scenarios considered.
The proposed prototype is not complete and is still to be tested by

real users.

6.1 Future Works

Some possible future improvements to this prototype can be performed.
The first improvement refers to the RFID antenna. As described in 4.6 the fact of having a big antenna only on the base of the box is a limit and some tags could be not properly detected because of the aluminium film on the blister packs.
A possible solution is the use of several small antennas placed vertically on the separators, so the tags will always be near to an antenna and there will be no problems in detecting the tags.
Another improvement deals with the usage of an external webserver. Indeed, an external webserver could be always accessed and will be more performing than the embedded one created for this prototype. The usage of an external webserver would also allow the system to communicate with other devices and the notification of the intake medicine will be better personalized (notification on mobile phones, on smart-watch, etc.).
Another upgrade refers to the check of the drug intake: the user can be the main actor of this activity thanks to a barcode-reader used to instruct the system which medicine is taken and the doses.
One more interesting task is the communication and the interaction between this device and the system BRIDGe, in order to have a useful feature integrated to a bigger and more solid system for helping people in independent living.

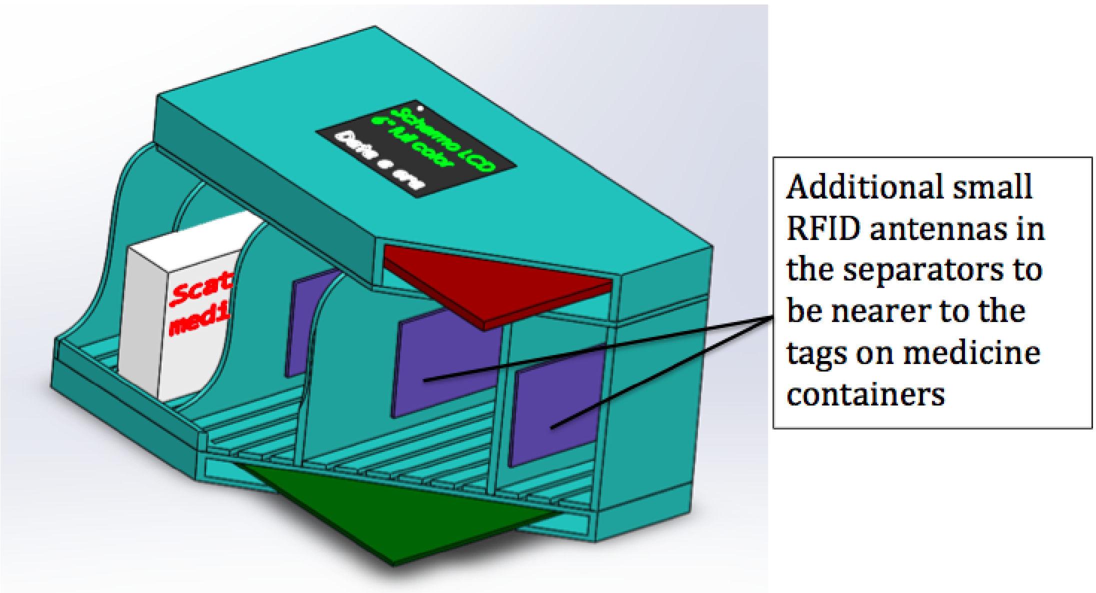


FIGURE 6.1: A possible improvement is to insert in every separator a small RFID antenna so the aluminium film do not affect the communication between the antenna and the microcontroller with the tags

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