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INTELLIGENT PILLBOX: AUTOMATIC AND PROGRAMMABLE ASSISTIVE TECHNOLOGY DEVICE

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ABSTRACT

Assistive Technology (AT) maintains and improves the individual's functioning and independence, thereby promoting their well-being. But today only 1 from each 10 people in need have access to AT due to high costs and a lack of awareness, availability, personal training, policy and financing. By 2050, more than 2 billion people will need at least 1 assistive product with many elderly needing 2 or more. Elderly make important contributions to the society. Though some people aged well, other become frail, with a high risk of disease. In this paper, we propose a first approach related the design of AT device. This uses open source technologies and gives a new choice in taking medication dosages. "The Intelligent PillBox" allows the organization of several medication schedules that health disorders presented in elderly need basically. Arduino Mega 2560 was took as the principal controller. This prototype contains; a programmable alarm system with an automatic opening and closing system, an interactive user interface and a notification system through GSM network. The development of this device is focused in the support of elderly people and other vulnerable groups that may need for an assisted care.

KEY WORDS

Assistive Technology, Elderly, Intelligent PillBox, Design, Arduino, Internet of Things, Ambient Assisted Living, Medication Schedule.

1. Introduction

Assistive care area has become an important field in medical sciences. World Health Organization (WHO) defines Assistive Technology (AT) "As systems and services related to delivery of assistive products…that enables people to live healthy, productive, independent, and dignified lives, and also able to participate in education, the market labour and civic life"[1]. AT includes adaptive, assistive, and rehabilitative devices, which are classified into a software, hardware based and prosthetic implants [2].

Priority groups on medical area (could vary according the location) are; pregnant, individuals with intellectual and development disabilities, also special needs, individuals with catastrophic diseases, kids, and elderly [3]. All of them could be benefit from assistive technology in order to reduce the need for formal health services. Then, by 2050, more than 2 billion people will need at least 1 assistive product with many elderly needing 2 or more [4].

Elderly, those aged 60 or above, make important contributions as family members, active economy participants, volunteers, etc. Though some people aged well, many other become frail and some of them at risk of disease and a costly dependence [5]. Particularly, demential and cognitive disorders have become a common health problem of elder people. This is due the natural aging which increases chronic diseases [6]. Those health problems require dosages of drugs, which could be supplied many times on a day. Brain troubles are common because of brain tissues deterioration and ends among other things in problems to remind the time to take the medication [7].

The classical practice of dispensing medication to a patient has allowed the patient to take the medication by himself, or delegate those responsibilities to a keeper or a doctor. The administration by nurses and doctors is often costly and impractical for the administration of medicine within home. Forgetting to take medication or taking wrong dosages is common in elderly patients who frequently are lonely and lose track of time [8]. Nowadays there are systems like scheduled alarm clocks or apps dedicated to schedule and notify medication´s time in cellphones. Also there´s a pill organizers commonly used by patients to save and remind by themselves dosages. The disadvantages of those systems are; in first place there are not medication (pills) stored and in second place it doesn't have an alarm system. Electronic developments covering this requirements have resulted in pill boxes or dispensers [8]–[11],many of them only with alert systems to notify the patient as alarms (sound alerts) or lights, and others expensive ones with mechanical dispense systems but without reports about dosages.

The lack of availability patient-related information causes many errors in healthcare. The use of new information and communication technologies (ICTs) could increase the accessibility of medical information and it´s essential for patient safety [12]. Internet of things (IoT) is a global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communications capabilities [13]. The connectivity of sensors and other healthcare devices (IoT) plays an important role on care of patients, because it allows to get access in real-time of medical information. Thus, the study and development of an effective Healthcare/IoT gateway could be crucial in patient care.

The creation of alternatives of AT devices looks promising and necessary due to that today only 1 in 10 people in need have the access to AT due to high costs and a lack of awareness, availability, personal training, policy and financing [1]. The introduction of AT devices in IoT could lead us to a future where important information of patients would be available anytime and anywhere, in order to make a correct treatment and to prevent calamities.

In this paper, we propose a first approach related to the design of AT device, to give a new choice of taking dosages which uses new technologies linked to free hardware and software, with a low cost that does not have limitations on licenses and functions. This programmable device has been built with consideration to quality attributes (e.g., usability, reliability), which allows the organization of several medication schedules that health disorders used to present in elderly need. This device is focused in the support of elderly people due to this special and sensible group for assisted care.

The structure of this paper is: section two focused on related works, section three includes the device contribution, section four are materials, section five is device structure, section six a testing methodology is presented, section seven is focused on future works and finally the conclusion section.

2. Related Works

In this section, a combination between electronic and mechanical pill boxes or dispensers is presented. Its been included certain traditional pills organizers, which represents a first step in these developments and allowed us to obtain ideas about design useful patterns in development of this solution.

In [9] is presented a pill dispenser which has different prescribed administration schedules. It includes a plurality of pill storage compartments, each of them capable of holding more than one pill. This device has a pill detector and generates a signal to alert patients to take the prescribed medicine. There are twelve storage compartments, arranged in a ring about a vertically rotating wheel. However, this solution has a limitation due to this pill dispenser can only hold doses for 24-hours.

A current design presented in Cheyene [14], shows a device that allows the storing and dispensing of pills and various supplements (i.e., food, drug, supplements, liquids, powders or pills). This device works such as an alarm clock and may work with blister-packed pills or alternatively uses an encapsulated compartment to hold and dispense loose pills. Also, it can be connected by wireless to external environments (cellphones, computers). However, this device does not allow the management of several dosages and different kind of pills.

Another solution is the e-pill. [10]. It has in its stock various alternatives to organize and dispense pills, can be mentioned especially two: i) A device dedicated to dispense pills composed by 2 medication trays, and 3 day-dosage discs [15]. It has a circumference shape and it has turning compartments for each dosage time. The dosages are dispensed when an alarm is activated, this device does not use referential diseases, just use dosages per days, and is also not programmable for any schedule; ii) it is a reminder medication product focused on patients, caregivers or medical health professionals. This device locks automatically and includes 2 keys. For patients trying to get medications before it is time there is tamper resistant. This device consider supply pills in one week, four times per day. Also it has alarm and text message reminders [16] disadvantages perceived are to close device by interaction of keeper and is not independent.

As far as we know, more than it has been described before, there are many solutions which offers advantages as dispensing or alerting system however they do not provide an automatic reminder system, different alert forms or a study in IoT field, besides devices are economically difficult to access. In this work, it is proposed a solution that solves these problems.

3. Device Contribution

Improving lifestyle not only in elderly sick people also in general sick people is a main goal of this development, our device involves reliability and usability with a friendly technology.

In the case of elderly people as in Marcellini et al [17]. It is well known with the years, the gradual degradation of faculties can affect the ability to cope with machine technology that is nowadays common in public spaces, like telephone cards and ticket machines (which requires physical and mental agility) or automatic tellers (where codes are needed to be memorised and alternatives must be selected rapidly). It is important to understand that these devices could become more an obstacle than an aid. This conclusion obtained through a study using two generations of men and women (aged 55–74 and 75+ years, respectively), giving us a way to focus our priorities in development of a pillbox, considering parameters to interact correctly with elderly users mainly.

Achieving an appropriate reminder system combined with a new type of programming dosages inside a device may be a possible solution to currently interface that nowadays are everywhere to interact in a better way with a keeper or doctor who are tied most of the time to keep track from their patients, who can use easily technology interfaces. Give them partially release from that responsibility and focus only in load dosage in device. While the interaction between patient and object won´t be deep, is necessary to give a solution which doesn´t complicate prospective interaction patient – pillbox, even though interact between them through technology is an important contribution which this work looks for.

As Fig 1 shows, a block diagram which summarizes the contribution of this paper. Here, it is an interaction between keeper and doctor (1) with the pillbox (4) through an interface (3) and a microcontroller. The device (4) sends notifications (5) to patient (6) and keeper (1). When a patient (6) takes the pill, there is an interaction between the pillbox (4) and a sensor (7). Finally, about that interactions are send.

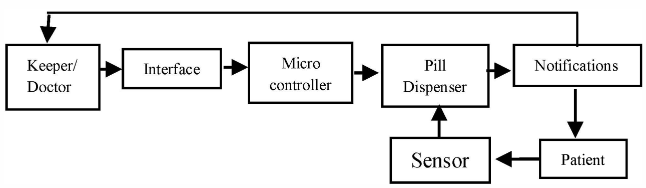

Fig 1. Pillbox Block Diagram.

4. Materials

The elements has been selected due free hardware and software, and another, look for functionalities that we pretend to give to the device.
With this preambles, selected materials are listed below:

4.1. Arduino Mega 2560

We consider Arduino Mega as the most important element in our development, it will command all the features that are proposed.
The Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila [18]. Associated compatible products and capabilities in Arduino let user manage different modules including SIM, stepper motor controllers or touch screens which are part in materials chosen and which will have a specific task in the pillbox.

4.2. Five inches TFT LCD display

Resolution 800 x 400, SSD1963 Controller, resist film to protect the LCD screen, write images/icons to flash memory via SD card with zero programming, also 64Mbit can store 1800 42 x 42 pixel icons/images, LCD Type: TFT Transmissive Normal White super wide viewing angle 50IDW1, about its Interface: 8/16bit parallel bus interface
On board DC-DC Boost regulator TPS61040 to provide power supply to LCD back-light, with SD Cage and Flash IC footprint reserved, LCD-specified initialization code is provided, so that you can save time to optimize power control register and gamma curves for the best display performance.
Module dimension: 0.039in x 3.35in x 0.91in (including pin header extrusion) and Active Area: 4.25in x 2.56in Pixel pitch: 0.005in x 0.005in Standard 2 x 20 0.1in pin header for connection to MCU/development board. [19]

4.3. GSM SIM900 Module.

The SIM900 delivers GSM/GPRS 850/900/1800/1900MHz performance for voice, SMS, data, and fax in a small form factor and a low power consumption. With a tiny configuration of 0.94in x 0.94in x 0.12in, SIM900 can fit almost all the space requirements in your M2M application, especially for slim and compact demand of design. [20].

4.4. RTC DS 3231

The DS3231 is an extremely accurate I2C real-time clock (RTC) with an integrated temperature compensated crystal oscillator (TCXO) and crystal. The device incorporates a battery input, and maintains accurate timekeeping when main power to the device is interrupted. The integration of the crystal resonator enhances the long-term accuracy of the device as well as reduces the piece-part count in a manufacturing line. The DS3231 is available in commercial and industrial temperature ranges, and is offered in a 16-pin, 300-mil SO package. The RTC maintains seconds, minutes, hours, day, date, month, and year information. The date at the end of the month is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator [21].

4.5. Stepper Motor 28BYJ-48

Is a small stepper motor suitable for a large range of applications, its rated voltage is 5V, speed variation ratio: 1/64, friction torque: 58.84-117.68 mnm, stride angle 5.625°/64. [22]

4.6. Infrared LED

Diode LED emitting infrared waves, this component has high reliability and high radiant intensity, its peak wavelength is p=3.7e-5in and 1.00e-7in lead spacing. Its applications are in free air transmission system or infrared applied system. [23]

4.7. Infrared LED receiver (Photodiode)

This element works as photo detector, it has fast response time and high photo sensitivity to visible and infrared radiation. Its physical features seems to a traditional LED [24].

5. Device Structure

In this section, an analysis of the proposal device is performed.

The objective of this analysis consists about using free hardware and software in order to develop a valid and effective device to assist people in taking correct doses of prescribed medicine. Arduino Mega 2560 was taken as the principal controller. "The Intelligent PillBox" is used as a pills storage device, which contains a programmable alarm system, an automatic opening and closing system, an interactive and friendly user interface and a notification system through GSM network.

5.1. Programmable Alarm System

Regarding to different medication schedules, this device allows to program the exact hour to take medicines. A priori this programming would be stored by the patient or keeper on the Arduino. However it is the final user who will provide users the information to set schedules. The proposed system gets the hour from the Real Time Clock (RTC) DS3231 and compares with a previous saved hour in order to create a specific alarm for the each doses of medicine.

5.2. Opening and Closing System

When the alarm system gets active, the specific compartment door is automatically opened by using a step motor, which is controlled by the Arduino. For the closing system there are two scenarios; if the patient takes the medicine from the device, a system composed by an infrared transmitter and an IR receptor notifies the arduino to close the door after a short wait. The other one is an automatic system that wait 10 minutes for the patient to take the medicine from the device, and if it does not happen the door closes.

5.3 User Interface

The device includes a box with different compartments with a LED light system each one of them in order to help the patient to take the correct dose of medicine from the pillbox. It is activated when the door opens. In addition, the LCD touch screen shows information about patient, hour and dose that should be taken.

5.4. Notification System

The alarm activates the notification system that sends a Short Message Service (SMS) through the SIM900 to the patient's phone or Smartwatch in order to remind her/him taking the medicine. It is important that the doctor or keeper receive also notifications about the medication of the patient. If the IR sensor doesn't receive any signal the message; "The patient X DID NOT take the medicine corresponding to: Day X Dose X" is send.

6. Testing Methodology

In order to verify the functionality of the device, a methodology developed for Paunovic, 2012 has been selected [22]. It explained four phases for testing a device:

- Hardware testing;
- Functionality testing;
- Stress testing;
- Robustness testing.

Phases need to be executed sequentially, then the transition to the next stage is only possible with positive report from previous stage. The advantage of this testing approach is providing an structured plan for finding and fixing errors and obtaining precise results [25].

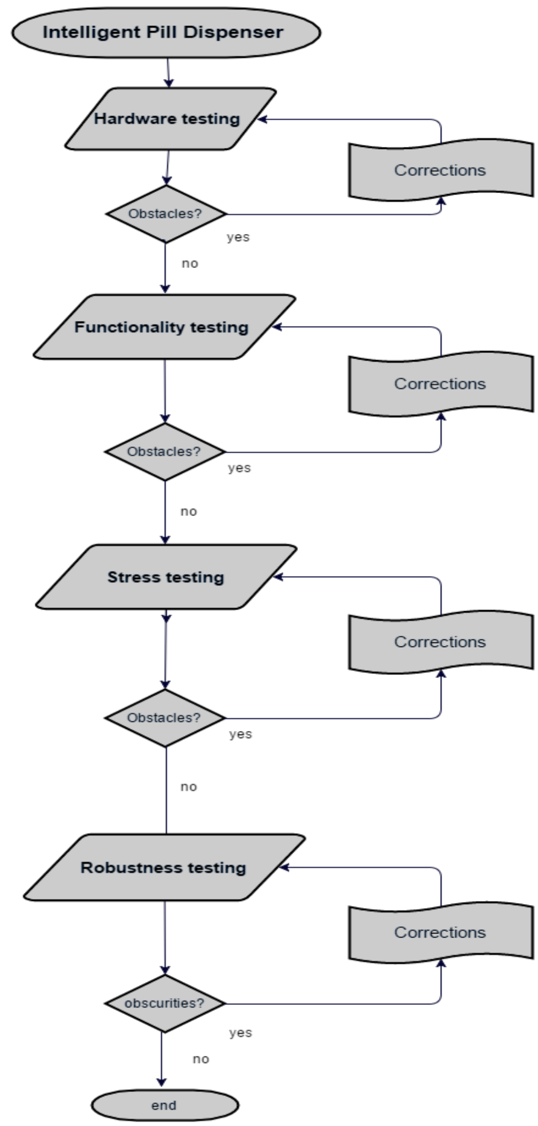

Fig 2. Testing Intelligent PillBox Flow Diagram

6.1. Hardware Testing.

The first step of testing a device it is to examine the correctness of the device's hardware. It means to verify the printed circuit board, links, components on the PCBs, etc. [25] On this case most of the components are PCBs, so it is important to check the correct state of each one. In order to make that revision a Fluke multimeter has been used to measure the resistance of the lines and also to measure continuity of the layers.

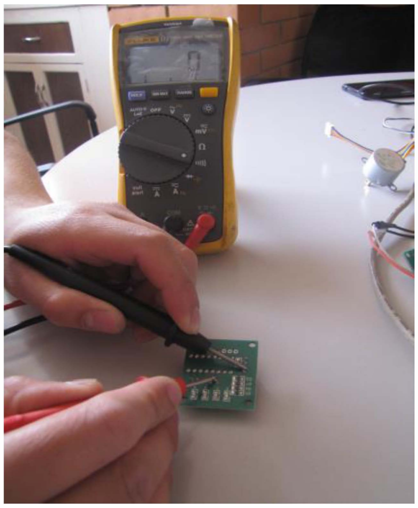

Fig 3. Checking Connections.

6.2. Functionality testing

In this phase we test the correct function of the components. Here we assembly those ones that have sub systems for example the TFT display and its shield or the stepper motor and its driver. We prove each component in conjunction with its software. The principal controller is an Arduino Mega 2560, so all the components work as extensions of Arduino. To prove the correct functionality of the components, an example program is charge on the Arduino, the corresponding pins are connected to the devices and a simple prove is made.

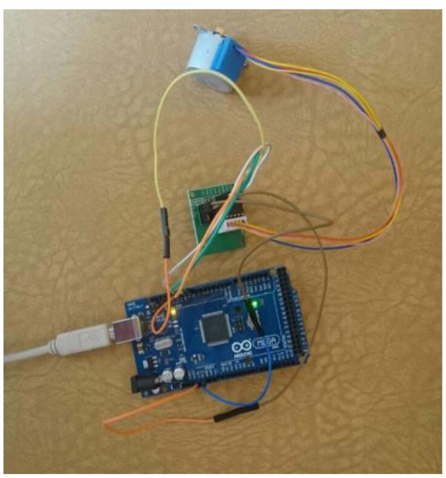

Fig 4. Arduino Mega 2560 + Stepper Motor and its drive.

This methodology recommends a table where the results of the test of the components is marked.

Table 1.
Test Report

Testing Results			
No	Component	Test case	Result
1	Arduino Mega 2560	Pass	07/09/2016
2	LED system	Pass	12/09/2016
3	Stepper motor & drive	Pass	20/09/2016
4	Real time clock RTC	Pass	01/10/2016
5	Tft LCD touchscreen CTE 50	Inconclusive	20/10/2016
6	Infrared transmitter & receptor	Inconclusive	29/10/2016
7	Sim900 GSM Module	Inconclusive	10/11/2016

Tested cases	7	
Passed:	4	57.14%
Failed:	0	0%
Inconclusive	3	42.85%

The components marked as "Inconclusive" would be case of study for future improvements on the device.

6.3. Stress testing

The third phase of the test aims to verify the stability of the system when the environmental and other conditions differ from nominal, defined by device specification. This phase involves testing beyond normal operation, often deliberate causing failure of the device, in the interest or consideration of the testing result [25].

6.4 Robustness testing

The final phase of device testing is to examine working in the conditions beyond nominal conditions, by improper use of the device, and the consequences of those situations. Robustness testing is defined as the degree to which a system or component can function properly in extreme conditions [25].

This two phases has been skipped, because the main goal of this study it's to prove the final functionality of the device.

6.5 Testing: "Intelligent PillBox"

The system is composed by different modules that are controlled by Arduino Mega. Fig 5 shows the PillBox's block diagram. There are different types of communication of each module. It could be one way or two ways. Therefore the Arduino sends commands to the modules but also receives data from them.

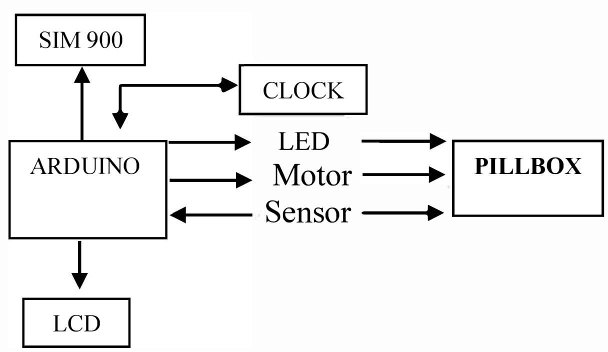

Fig 5. Intelligent pillbox composition.

Fig 6. Intelligent PillBox

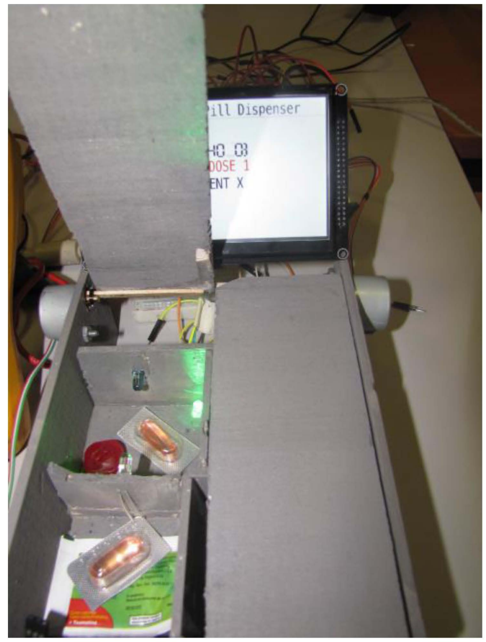

Fig 8. PillBox in operation

The controller obtain the hour from the RTC, the alarm is set when it's the correct time. The arduino send the command that activates the motor, the led system and also sends the SMS to the patient.

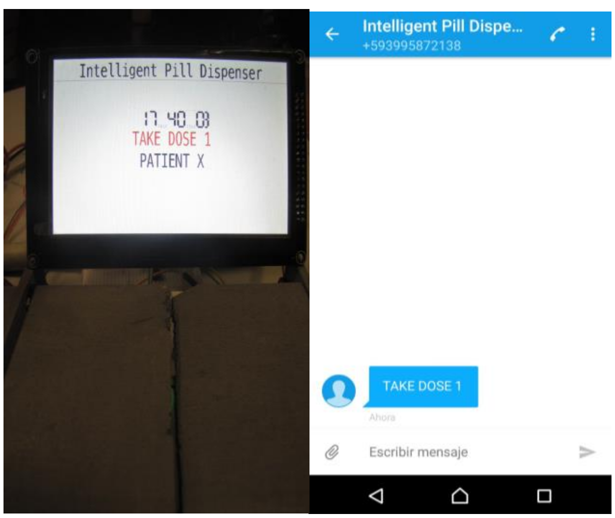

Fig 7. Alarm Notifications

If the patient take the pills from the correct compartment, the infrared system notify to the arduino and this closes the doors, but if the IR system does not send any notification after a set time the arduino automatically closes the door. Either a notification will be send to the doctor or the person in charge of the patient, is send. During all this process the exact hour is display on the LCD and when the alarm is set this shows the information about the correct dose.

7. Future Works

While this paper has demonstrated the potential of the assistive technology, from an specific and effective pillbox device, many opportunities for extending the study of this paper is remain.

- Infrared System
  As pointed on section 5, there will be an additional study of the actual modules; one of them is the IR system. The IR 333-A transmitter and PD 333-3B\H0\L2 receptor are used but they have a lot of problems on its operating distance and receiver angle. Therefore the study more precise IR system is needed.

- Touch Screen CTE 50
  Another module marked as inconclusive is the TFT LCD Touch Screen. In this process the touch function is not available, but the goal is to use this interface to configure the medication scheme.

- Methodology testing
  When the final elements are selected, the phases; stress testing and robustness testing, will be completed.

- Interviews
  In order to create an effective device, there will be a set of interviews at the "Universidad de el Adulto Mayor" in Cuenca, Ecuador, where points like: interaction between elderly people with technology and the principal obstacles of taking medication, etc, will be treated.

- Design
This prototype is "a proof of concept". Based on studies and the interviews the final design will be made. The goal is to create a device with 28 compartments, 4 doses every day during 7 days. A 3D printer will be used.

- Security
After the design is selected, a lock system will be added. The device will be used only by; doctors, keepers, and patients without significant disorders. They would only program the device with a personal password.

- Raspberry PI
All this proofs has been done using the Arduino Mega Controller. For future works maybe a more powerful controller will be needed. Raspberry PI model 3B has been selected because it has a better processor, RAM, additional ports and interfaces, SD card slot, and also; 802.11n Wireless LAN, Bluetooth 4.1, BLE (standards used on IOT) are included.

- Thermometer
A thermometer would be included in order to analyze the internal temperature of the device for the correct conservation of the pills. An alarm would be activate if the temperature exceed the previous set limit.

- Internet of Things (IOT)
A study of the Intelligent PillBox's performance into IOT will be made. Protocols, efficiency, availability and other topics will be studied in order to proof the feasibility or not to include this device into the network. The mean idea it is that a doctor or keeper could be able to configure the medications schemes and obtain information about the patient remotely.

8. Conclusion

Older people play an important role in the society. They are part of the priority group of healthcare. Therefore, creating new devices using the emerging technology in order to improve their lives quality, is necessary. The creation of alternatives of AT devices looks promising and necessary due to that today only 1 of each 10 people in need have access to AT due to high costs and a lack of awareness, availability, personal trainance, policy and financing [1]. The introduction of AT devices in IoT could lead us to a future where important information of patients would be available anytime and anywhere, in order to make a correct treatment and to prevent calamities.

Based on open source solutions, a new alternative to remind medicine dosages was raised. Arduino Mega, as main controller works totally right and give many other opportunities to develop. The objective of creating a device that allows the organization of several medication schedules, automatic opening system and an effective notification system, was reached.

As is mentioned in future works section, design and functionality will change not only with perceptions in developers of this prototype, is necessary to investigate a fellow implicated in this problem. IoT is an important aim pretended in this AT device, finding a way to keep pillbox connected to Internet and it will help surely to manage in better form the treatments in patients, mainly in elderly patients.

Scientific validation method used is dedicated to validate electronic equipment and applications, for the future works this method will change and it let us evaluate response between elder patient and keepers with pillbox and this one with the biggest network: Internet.

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