eHealthCare - A Medication Monitoring Approach for the Elderly People

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Abstract. For the regularly medicated population, the management of the posology is of utmost importance. With increasing average life expectancy, people tend to become older and more likely to have chronic medical disorders, consequently taking more medicines. This is predominant in the older population, but it's not exclusive to this generation. It's a common problem for all those suffering from chronic diseases, regardless of age group. Performing a correct management of the medicines stock, as well as, taking them at the ideal time, is not always easy and, in some cases, the diversity of medicines needed to treat a particular medical disorder is a proof of that. Knowing what to take, how much to take, and ensuring compliance with the medication intervals, for each medication in use, becomes a serious problem for those who experience this reality. The situation is aggravated when the posology admits variable amounts, intervals, and combinations depending on the patient's health condition. This paper presents a solution that optimizes the management of medication of users who use the services of institutions that provide health care to the elderly (e.g., day care centers or nursing homes). Making use of the NB-IoT network, artificial intelligence algorithms, a set of sensors and an Arduino MKR NB 1500, this solution, in addition to the functionalities already described, eHealthCare also has mechanisms that allow identifying the non-adherence to medication by the elderly.

Keywords: Medication · Elderly · Non-adherence · Sensors network

1 Introduction

Forgetting to take a dose or two of a certain medication may not seem critical. Sometimes ignored doses do not cause obvious problems, but many medications will not work properly if they are not ingested at the right time and in the right way. Non-adherence to medication is unfortunately quite common, especially among patients with chronic diseases and the elderly [1–3]. This non-adherence [4,5] is usually associated with factors such as [6]: fear of possible related effects; mistrust, making many patients believe that prescriptions passed by doctors are

X. Gao et al. (Eds.): MobiHealth 2021, LNICST 440, pp. 221–234, 2022.
https://doi.org/10.1007/978-3-031-06368-8_15

for pharmaceutical benefits; the absence of symptoms leading many patients to believe that they do not require medication.

Regardless of the causes that lead to medication non-adherence, depending on the chronic disease in question, the incorrect medicines ingestion quickly becomes a problem for the patients health. However, identifying whether the medication was taken correctly, in many cases and especially in the elderly, is an extremely complicated task since many of them do not have permanent caregivers to assist in the management of medicines. A good example of this difficulty, is the case of schizophrenia [7], where there are patients who can survive treatment failures for considerable periods without adverse consequences. However, in the case of schizophrenia, recidivism rates are very high after treatment interruption, and in many cases they occur within weeks of interruption. In these cases, to aggravate the situation, there are no reliable signs of early warning for caregivers or doctors in identifying individuals with an imminent risk of relapse whose symptoms, instead of gradually appearing, usually return quickly. Thus, a careful observation approach to patients suspected of non-adherence, with a view to introducing rescue medication at the first sign of recurrence, is unlikely to be effective in real-world contexts.

In this way, it's important to prepare institutions that provide support services for medication with solutions that make possible not only to identify non-adherence to medication, as well as allowing better medication management, for both final users and their staff. Additionally, the COVID-19 pandemic [8], which exposed inequalities in social assistance different social groups, especially in the older one [9–11], makes medication monitoring an even more difficult task to perform, since the measures adopted worldwide to contain the pandemic do not promote direct contact with the population.

Through a small set of sensors, chips and artificial intelligence processes, the solution illustrated in this paper presents as its main scientific contribution, a tool that allows to identify possible users who do not adhere to medication. In addition, the restrictions implemented to contain the COVID-19 pandemic, which, as already mentioned, encourage the reduction of physical and social contacts, further reinforce the importance of building tools such as the one presented.

The remainder of the paper is organized as follows: Sect. 2 offers a brief analysis of the others possible solutions to the problems presented; Sect. 3 describes the architecture constructed as a response to the problems identified; Sect. 4 illustrates the conclusions of the paper and the goals for future work.

2 State of the Art

The development of solutions to help identify non-adherence to medication is not something new in the market [12]. During this section it will be detailed a set of solutions similar to the tool presented in this paper. Despite eHealthCare has similar functionalities to the following solutions, it's important to clarify that its target audience is different.

Thus, while the solutions presented in the following section are targeting of any user who needs medication, the eHealthCare solution, as already illustrated, is aimed at institutions (e.g., day care centers, nursing homes) and was conceived as a monitoring and control solution for the detection of medication non-adherence. So, this solution has as main purpose, assist institutions that provide medication control services and will not be available to the end-users.

As shown in Table 1 there is already a set of solutions that are intended to assist the taking of medication, which may reinforce the importance of the theme addressed in this article.

Table 1. Comparisons between solutions

	Config	Alarm	Management	Stock	Tool
eHealthCare	Simple	Yes	Non adherence alerts; Mobile and Web control	Auto pharmacy contact; Automatic meds refill	Web; Mob; Organizer
TabTime Timer [13]	Nonex	Yes	No	No	Organizer
e-pill TimeCap [14]	Nonex	Yes	"Last Opened" display; Same meds in a row prevention	No	Online pharmacy
PillPack [15]	Nonex	Yes	Doctor is contacted	Auto purchase and recharge	Mob
MedMinder [16]	Hard	Yes	Missed dose alerts; Weekly reports; Wrong meds prevention	No	Pill Dispenser
MediSafe [17]	Nonex	Yes	App synchronization with someone	Specific company contact	Mob
CareZone [18]	Nonex	Yes	Doctor is contacted	Automatic meds refill	Mob

Despite the great diversity of solutions, the great advantage of eHealthCare, in addition to the technical functionalities that its architecture presents, is in the simplicity of use and target of the population for which it is intended - the elderly who live in more remote regions.

Thus, although most of the solutions illustrated in Table 1 present a set of quite interesting functionalities, some even surpass the functionalities presented in eHealthCare.

A general overview, shows that all presented solutions have some sort of alarm/reminder to help the user remember to take the medicines, and almost all of them provide one or more features to medication management.

However, unlike eHealthCare where only the medication organizer is delivered to the patient, in the solutions presented in this section it is always necessary to integrate them with other technologies/mechanisms (internet/smartphones), where often older people and especially the ones living in more remote regions do not have.

Due to this reason, the authors considered that a comparison between eHealthCare and the other solutions isn't that feasible, since, as mentioned above, the remaining solutions are not optimized for older people to use them.

3 Implementation

In Fig. 1, it's possible to analyze the overview of the built architecture, consisting of 4 elements:

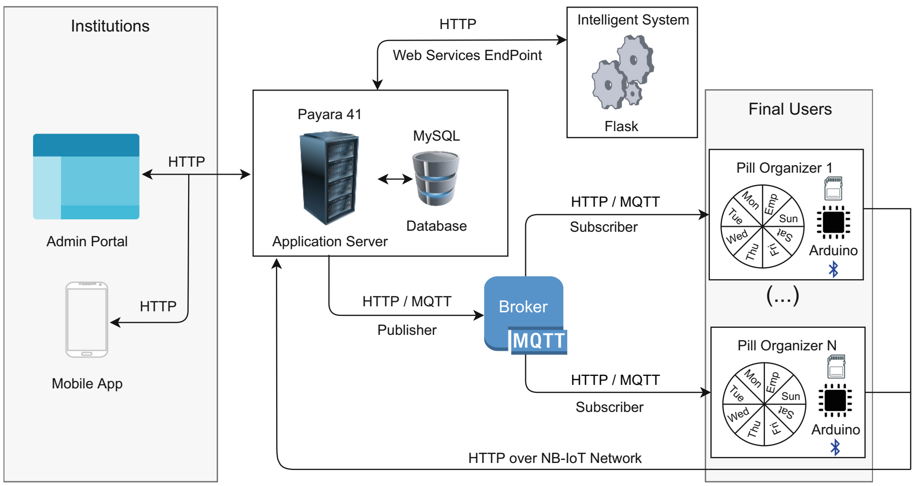

Fig. 1. Overview of eHealthCare architecture.

- a web server that provides a set of endpoints (see Sect. 3.4), used by the mobile application and the administration portal. It can control distributed organizers, registered users and interact with the intelligent part of the architecture.
- the medication organizers described in the Sect. 3.1, adapted to the users which have a strong rejection of the use of technologies [19,20];
- a broker who will be responsible for managing the exchange of messages between the web server and the Arduino MKR 1500 board (the first and only Arduino to be compatible with LTE Cat M1 and NB-IoT [21,22]) inserted in the organizers of medication;
- a set of intelligent processes, available through the Flask framework, described in the Sect. 3.2 that will be responsible for identifying users who are not non-adherent to medication. Additionally, these processes will be responsible for trying to predict the likelihood of new users not adhering to medication based on their characteristics and data already entered in the system.

The operation of eHealthCare can be defined in 3 phases. The first phase corresponds to the preparation of the pill organizer (described in Sect. 3.1) which will be delivered to each user. This preparation corresponds to the filling of the medication for the corresponding user, as well as the transfer of the timetables of each dose to the memory of the Arduino Board. The second phase corresponds to the normal detection by the system of the intakes medication, that is, as the user withdraws/ignores medication from the organizer. For each occurrence, the Arduino Board sends a message, to a server, that will be processed later by the intelligent part of the architecture. The last phase, is the presentation of the results, that is, where the institutions can monitor almost in real time the state of the medication of each one of its users, being clearly identified the users who are suspected of not adhering to the medication.

Finally, all components of the solution intended for majority use by the elderly, were designed to make them as simple as possible and according to the capabilities of this target audience as will be illustrated in the next sections.

3.1 Pill Organizer

In the Fig. 2 it is illustrated the organizer created and introduced in the architecture of the eHealthCare solution. This organizer contains 29 slots[1] that correspond, for the 7 days of the week, to the morning, lunch, snack and dinner periods, very similar to what already happens in common pill organizers. The last slot (Empty slot) corresponds to the medication collection slot.

All the remaining 28 slots are blocked, that is, their upper limit is covered with a plastic layer preventing the users to take the medication out of their intake time. However, the collection slot (represented in Fig. 2 by an Empty slot) is the only one that does not contain such protection. This allows, when it is reaching the given time to intake the medication, the Arduino to activate the stepper motor so that it positions the division corresponding to this intake in the collection slot, making possible for the user to withdraw the medication.

When the institution prepares an organizer, it already contains all the timetables by which the medication should be available for the user to ingest. Added to this information, a timeout value that corresponds to the time that the Arduino must wait until it blocks the slot of the corresponding portion is also defined. Thus, when the Arduino detects a timeout related to the actual time of ingestion of the medication, it activates the stepper motor in order to position in the collection slot, the division that corresponds to the time of the taking. In parallel, a LED is activated, and a horn is issued to alert the user that medication is available and should be taken.

Each slot contains a [23] force sensor that makes it possible to identify when the user changes the content of the medication. Thus, in the tests performed, it was identified that four situations may occur when the medication becomes available: total removal of the contents of the slot; partial removal of the contents of the slot; removal of the content with addition in the near instance; not removal

[1] In the Fig. 2 only 8 are represented to facilitate the understanding of the architecture.

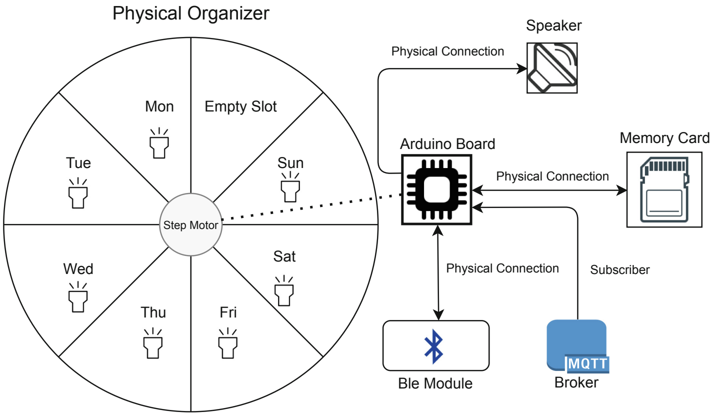

Fig. 2. Detailed architecture of the pill organizer.

of the content inside the slot. Thus, only in the first situation is that the system considers that non-adherence to medication did not occur and the remaining are considered situations of non-adherence to medication.

Listing 1.1. Example of JSON string sent by Arduino board to webserver

```
{
    "id_pill_organizer":150,
    "state":0,
}
```

When Arduino identifies one of the four situations described above, it sends a message to the web server, using NB-IoT, with information similar to that represented in Listing 1.1. The information sent contains only two fields: id_pill_organizer that identifies the organizer in question and the state field that identifies which of the four previously identified situations occurred, where the medication in question is identified by the time the message is sent to the server through the current timestamp. For cases where NB-IoT support does not exist, Arduino stores all records generated on a memory card added for this purpose. In this context, the data will then be collected by the collaborators of the institutions using the mobile application (see in the Sect. 3.4).

Finally, it should also be noted that Arduino performs Subscriber in the Broker illustrated in Fig. 3. This action allows the Arduino to perform any unlocking of the slots triggered in the administration portal (see Sect. 3.4). It also makes it possible to receive the information necessary to monitor and make available the medication of the user concerned.

3.2 Intelligent System

Nowadays, artificial intelligent systems/processes are becoming helpful tools in countless tasks, since forecasting academic dropout [24] to plant classification

[25]. In this paper, the authors explored artificial intelligent processes to classify the level of non-adherence to medication of a new patient with the collected data. In addiction, an intelligent algorithm was implemented to monitor the medication non-adherence rate of the eHealthCare system patients.

For better understanding, in Fig. 3 can be observed the architecture of the intelligent system proposed by the authors.

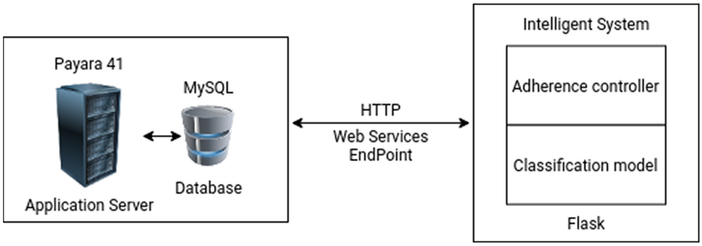

Fig. 3. Overview of the intelligent system of the eHealthCare system.

The eHealthCare intelligent system is composed by two components, the adherence controller and the classification model. The adherence controller is responsible for controlling the rate of non-adherence to medication of the patients of the eHealthCare system by receiving the messages send by the Arduino when a patient does not consume the pills that he has to consume. The classification model is responsible to classify the level of non-adherence to medication of a new patient.

For the usage of the intelligent system, two metrics were associated/added to the patients, the level of non-adherence to medication and the rate of non-adherence to medication. Both this metrics were stored in the database of the system. The levels of non-adherence to medication and their description can be seen in the Table 2.

Table 2. Levels of non-adherence to medication.

Level	Range of rates	Description
Green	[0%, 5%[	The patient is rarely non-adherent to medication
Yellow	]5%, 40%[	The patient is sometimes non-adherent to medication
Orange	]40%, 80%[	The patient is non-adherent to medication with some frequency
Red	]80%, 100%]	The patient is totally non-adherent to medication

The level of non-adherence to medication is used in the classification and to monitor the rate of non-adherence to medication. Another value added for the usage of the intelligent system, was the effect in the rate of non-adherence to medication of every medication. This value was added because the effect of not consuming some medications is greater than other medications. Thus, if a medication A has more importance than a medication B, the medication A will have a higher effect value than medication B. All values mention before are key elements to the operation of the adherence controller.

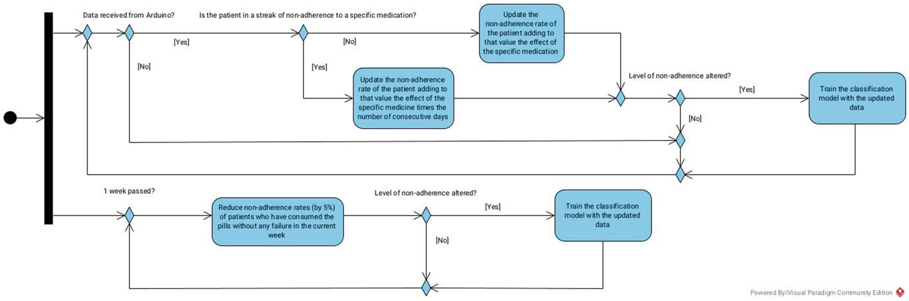

Fig. 4. Overview of the operation of the adherence controller.

In Fig. 4 can be observed an activity diagram that represents a detailed overview of the operation of the adherence controller of the intelligent system. The adherence controller has two processes that are always running, where the first is waiting for the data sent by the Arduino but forwarded by the HTTP Server (Payara 41) when a patient does not consume the medication; the second runs periodically, once per week. When triggered, the first process is going to update the non-adherence rate of the patient in question, adding to that value the effect of the specific medication, if the patient is in a streak of adherence to a specific medication, or adding to that value the effect of the specific medication times the number of consecutive days if the patient is in a streak of non-adherence. If that update changes the level of non-adherence of the patient, the classification model that will be discussed further ahead, will be trained with the updated data. The training process occurs every time the conditions described above are met, to ensure that the classification model is based on up-to-date data. Relatively to the second process, it will update the non-adherence rates of patients who have consumed the medication without any failure in the current week, reducing that value by 5%. This update is done to "reward" the patients that are becoming more adherent to medication. So, the system will always have up-to-date data about the patients. As in the first process, if that update changes the level of non-adherence of the patient, the classification model will be trained with the updated data. The main objective of this component and its processes, is to always monitor and adjust the rates of non-adherence of the patients, increasing their rates when they don't consume their medication and reducing their rates when they consume their medication without any failure in a week. Like that, the institutions that use the eHealthCare system will always have updated data of their patients.

Since the adherence controller is training the model every time the level of non-adherence of the patients changes, there was a need for a machine learning algorithm that could be fast and computationally light. In addition, that machine learning algorithm needed to be a supervised machine learning algorithm, since the authors had labelled data to train, and solve a classification problem, since the objective of the model is to classify patients into four classes (green, yellow, orange, red) [26]. The supervised machine learning algorithm chosen was the K-Nearest Neighbors, since it fulfills the intended requirements and because the authors relied on simplicity and functionality to implement this solution, however for future work, testing of new machine learning algorithms will be done to perceive the effect of other machine learning algorithms in the intelligent system of the eHealthCare system [27–31].

Before the training of adherence controller classification model, the data needs to be prepared to be feed to the model. The first step in the preparation of data is the pre-processing of the data related to the patients. In this step, several data related to the patients are extracted from the database of the system, like age, education and gender. One of the most important data that is extracted is the target variable of the classification that is the level of non-adherence to medication. The queries responsible for the extracting of all variables were manually pre-coded by the authors and are just invoked by the adherence controller. After the pre-processing of the data, the next step is the identification of the type (nominal, ordinal, discrete, continuous and logical) of each variable. For example, the age will be a discrete variable since it's a number. However, the gender will be a nominal variable since it's a categorical value where there is no ordination between categories. With every variable identified, the next step is to normalize every value of every variable, e.g. between 0 and 1 [32,33]. This process is necessary to ensure that the different variables have the same range of values, so that no variable has more influence on the result than another, making the classification model more accurate.

After that, the classification model will be trained with the resulted variables. After the training, the classification model will be available through a REST endpoint that will be consumed by the applications. With that, every time a new patient is registered in the eHealthCare system, the classification model will classify the level of non-adherence to medication of the patient, and if the level is high, the staff of the institutions can observe that information and closely monitor that patient.

3.3 NB-IoT Comunication

Designing solutions that identify non-adherence to medication is not an easy task as explained in previous sections. Although the target institutions often have physical support and human resources for the use of this type of tools, on the end user side, this is often not the case. Thus, in contexts where users, who use the services of these institutions, and live in isolated locations, the use of tools such as eHealthCare is compromised due to the weak support for the Internet [34].

It was, therefore, necessary to add mechanisms to the presented solution in this paper that make it possible to overcome the difficulties identified. To overcome the lack of Internet support in some regions, communication between medication organizers and institutional servers is carried out using NB-IoT.

This technology is currently part of the LTE network and any place on the planet with network coverage, is fertile ground for NB-IoT that significantly improve IoT devices energy consumption. Currently expanding, NB-IoT already present in 69 countries by 2019 [35,36]. Since NB-IoT is a mobile IoT network, security is not a problem as mobile operators ensure the encryption of customer/user data, or in some cases, VPNs with encrypted connections and APNs. Other security features are included, like Data over NAS (DoNAS), Non-IP Data Delivery (NIDD), or white-lists [37]. Resuming, NB-IoT uses licensed spectrum and secure communication channels, being this an vantage that releases programmers and end-users of concerns related with security.

3.4 Admin Portal and Mobile Application

The portal of administration and the mobile application has as main function assist the institutions in the preparation and monitoring of the medication. In Fig. 5 it is possible to see the layout built for the administration portal.

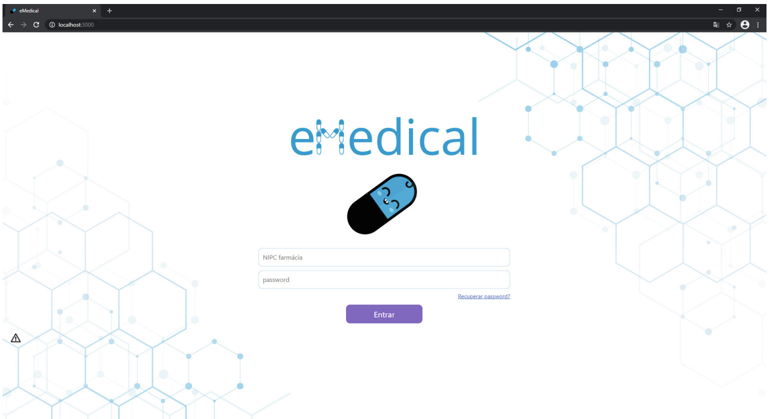

Fig. 5. Layout web portal eHealthCare

This portal has as main functions: the registration of new users; the real-time consultation of the medication taken that each user should take/made every instant; the unblocking of divisions in the drug organizers; the recording of medication-related information to be passed on to the organizers.

For the patient's registration, it's presented, based on the parameters already described in the previous section, the probability that a new user have to not adhere to the medication. For the divisions unblocking, it is guaranteed by the Broker, that is, when it is necessary to unlock a division, the web portal publishes in Broker a message that is later passed to Arduino. To record the medication information passed to the organizers, this is accomplished through a combination of touches on the button placed on the organizer, which obliges the organizer in question to establish an HTTP request over the NB-IoT network.

The layout of the mobile application can be analyzed in Fig. 6. This application allows the management of the parameters related to users and their medications. The great utility of this application is to enable the collection of data stored on the memory card added to each organizer. However, the collection of this data, performed using BLE, is only necessary in contexts where NB-IoT network is very weak or inaccessible. After collecting the data, the application sends it to the server to be processed as with the data sent by Arduino.

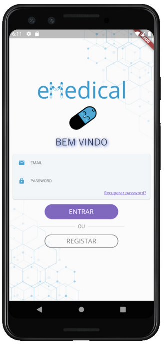

Fig. 6. Layout mobile application eHealthCare

4 Conclusion

This paper introduces a new tool that will allow institutions that provide assistance in medication to perform a better monitoring of their users as well as user's medication and to optimize some processes related to the preparation of medication. Through rigorous control, this tool allows caregivers/institutions a more agile mechanism to identify possible errors (non-adherence) in the consumption of medicines, contributing to increase the quality of life of its users. In the context of a pandemic, such as the current COVID-19 pandemic, the importance of such tools is even greater, because despite all measures of social estrangement, this solution may be something viable, since it allows support to users by greatly reducing social contacts.

However, the fact that the NB-IoT network is not yet supported in all regions, despite the existing mechanisms presented in the Sect. 3 to mitigate this issue, it may constitute a major disadvantage for the solution, since, although the data are collected and processed in it, this treatment presents a small delay (collection time) which in certain diseases can be a critical problem.

Although it is possible to clearly control the presence/absence of medication of the organizer, this solution, and unfortunately none of the reported in the Sect. 2, ensures that the medication is effectively ingested. The medicine may be removed from the correct division, but the user may not ingest it, a situation that it's very frequently in patients with medical disorders such as Alzheimer, dementia, schizophrenia, etc.

Finally, it should also be noted that, although the entire implementation cycle has already been tested and validated, that is to say, the sending of data from the organizers to the web platform, it has not yet been possible to carry out studies with the population, since the existing specimen is only for testing (it contains all wires and sensors completely disorganized). The production costs of this tool in the current state of the project, it is not yet possible to advance with an exact value, however, given the simplified architecture, it is estimated that the value is relatively low compared to similar approaches illustrated in Sect. 2.

Thus, at this moment, the current state of the work is dependent on the elaboration of 2/3 prototypes of the organizers presented to distribute among the small group of population, and then perform tests to understand the degree of success of the solution presented.

4.1 Future Work

Despite the great potential presented, this solution still has a long way to go. In this way, the following points were left for future work:

- Devise a solution to identify errors in the medication intake in the percentage of users who do not use the medication organizer.
- Conduct a study to quantify the impact of the detection of errors in medication intake with the use of eHealthCare.
- Append the medication stock replenishment detection process.
- Optimize methods to detect user's non-adherence.
- Consider/Use other machine learning algorithms and check their effect on the intelligent system of the eHealthCare solution.

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