SPiDer: Integrating smart medical dispensing with multiple purpose elder assistance systems

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Abstract. *SPiDer* focuses in the specific problem elderly face when trying to follow a complex schedule of medications (*i.e.*, the low compliance with complex prescribed medication schedules) and aims to partially solve the aforementioned problems through the use of Assistive Technologies and AI tools.

1 Introduction

Life expectancy for Europeans has increased around 30 years since 1900 [5,6], as have the available pharmacotherapeutic options. Unfortunately, pharmacotherapy mishaps occur commonly in the older adult population and in patients with diseases that requires poly-pharmacological treatment. This problem greatly affects the morbidity and mortality of patients and greatly increases healthcare costs requiring the necessity to develop safe and effective drug therapy plans for older adults and patients with chronic diseases. Medication non-adherence can be considered an important health care problem. This is especially true for patients with a chronic illness because medication adherence is a crucial factor in the effectiveness of therapy [3].

Initiatives attempting to address medicine non-adherence promote patient involvement in treatment decisions, but remain ineffective in older patients or in patients with cognitive disorders. Interventions using applied high-technology show potential for supporting medication adherence in patients with diseases that requires poly-pharmacological treatment. Concordance and adherence management are of high priority, having a significant effect on the cost effectiveness of therapy. This is especially important for disorders with high healthcare costs, such as oncological diseases, psychiatric disorders, HIV, geriatrician disorders or dementia. High technology interventions could help to reach optimal cooperation between patients and healthcare professional, as one of the main objectives is to improve the rate of patient adherence in long-term drug therapy.

In this paper we present the *SPiDer* system which has the goal of increasing the compliance of elders with their pharmacological treatments. *SPiDer* includes a Smart Pill Dispenser (SPD), a device which interacts with the patient as a reminder and provider of medications in its own house. The system includes further functionalities to increase its capabilities and empower its responsabilities. Most significantly, *SPiDer* implements components for monitoring the presence and access rights to the house through a domotic door, and communicative capabilities to keep a flow of information with responsible actors on real time (*e.g.*, with doctors, relatives, caretakers, *etc.*). *SPiDer* is designed and implemented as a MultiAgent System (MAS), making the system a flexible, reliable and addaptable solution for increasing medication adherence.

1.1 Related work

Nowadays, a variety of projects address the problem of increasing medical treatment compliance. Most of them focus on specific pathologies, using questionaries or self-reports to monitor medication adherence [4][1]. Others try to promote better compliance with prescribed medications by developing new practices or medical trials, mainly considering interviews as input [11] [10]. A different approach is that of designing dispensers to be set at the patient's house. We can classify those in three main types: passive; reminder; and smart. Passive dispensers are only pillboxes which keep medical doses organized. Reminder dispensers incorpore alarms that can be programmed (mostly manually) to notify the patient when it is time to medicate [7] [9]. Finally, smart dispensers, are usually reminders which include additional features, such as remote configuration, personalized alarms, history recording, *etc* [12].

Our proposed system would fall within the smart dispensers category, but its features surpase any of the currently present in the state of the art. Addaptability (capability to addapt dispenser behavior to the each patient particular conditions and to real-time events), extensibility (capability to integrate additional components which extend the features provided by the system) and robustness (degree of reliability of the system to potential failures and reaction policy) are three of the properties achieved through our proposal which are not found in any of the other approaches.

The rest of the paper is organized as follows. §2 presents the proposed system, together with the most relevant features we expect to achieve. In §3 we introduce the architecture of the actual system, and give some implementation details of the *SPiDer* components and its agents. Finally, in §4 we give our conclusions and present some future work.

2 Approach

SPiDer focuses in the specific problem elderly face when trying to follow a complex schedule of medications (*i.e.*, the low compliance with complex prescribed medication schedules) and aims to partially solve the aforementioned problems through the use of AT and AI tools [8]. *SPiDer* presents an approach to solve the problem of patient's compliance with the prescribed medication, while enhancing the system's capabilities through the integration with various health-related services. The system has its origin in the *SHARE-it* project [2]. *SHARE-it* developed applications to give support to individuals suffering some diseases in their ADLs through the use of AT. Relatedly, one of the use cases presented in *SHARE-it* tries to help users to properly take their medication.

The system developed by *SPiDer* has three main components: the Smart Pill Dispenser (SPD) which allows to perform the dispense tasks and the sensing of the environment, the Identification Access Management (IAM) which allows to monitor and manage the entrance and exit of the house, and the MAS which integrates both the SPD and the IAM components and adds new features as communicative tools between the system and the outside world.

Thus, *SPiDer* develops a distributed MAS which provides extensibility and integrability. Integrability is achieved by using well defined communication standards, design protocols and ontologies for sharing information. Extensibility is facilitated by the use of services by agents, as means to consume and serve information and throughout the MAS. In that regard, we acknowledge the possibility of extending the features currently implemented in *SPiDer* with additional components to enhance its capabilities.

In the context of interaction and monitorization with the user, *SPiDer* integrates both sensors and actuators which provide the whole system with world-interaction features (*e.g* communication channels among stakeholders and the system itself, monitorization of the patient's routines). Furthermore, through its actuators, *SPiDer* implements various complex behaviours in order to assume more responsibilities, if needed due to a severe impairment of the patient. In that regard, the addaptation of *SPiDer*'s services to a specific patient's requirements makes of the system a flexible solution for multiple patologies and patient-specific situations.

Distribution and robustness are two key features for any system assuming responsabilities in health-related cases. Through distribution one can guarantee that critical aspects of the system are not found within the same physical entity, making potential technical failures less dangerous (*e.g.*, punctual hardware malfunctions). At the same time, through roboustness, systems such as *SPiDer* are expected to adapt to unexpected scenarios and respond to them coherently. In our proposal, we have decided to achieve distribution by separating the various components of *SPiDer* in different autonomous computational devices. For example, medication dispensing and notification services will be found in different computers, such that if communication goes down for whatever reason (*e.g.*, Internet connection failure), pills can still be dispensed according to the last validated schedule. In §3 we will present in detail the various autonomous components we have designed and their responsabilities.

Robustness is hard to test, since it must deal with the unexpected. In that regard, considering the importance of the domain we work with, we decided to establish certain emergency procedures for when the unexpected happens. Those procedures will be empowered by the distribution of the system we just introduced. As a brief example consider the following case; if the service in charge of communication detects some anomalous and potentially dangerous behavior in some of the other components (*e.g.*, incoherent data, no response to requests, *etc*), it will proactively notify a responsible person (*e.g*, a caregiver) about that fact so that repairing actions can be issued.

3 *SPiDer* implementation and evaluation

The three main components of *SPiDer* are the Smart Pill Dispenser (SPD), the Identification Access Management (IAM) system and the MAS. The MAS, which integrates both the SPD and the IAM is composed for three agent platforms where each platform has different responsibilities regarding to the meaning of its functionalities. The *SPiDer* architecture with these three platforms can be seen in Figure 1.

3.1 Smart Pill Dispenser

The most relevant component of *SPiDer* is the SPD. The SPD is an AT tool designed to assist the user in the task of taking its medication, and its principal aim is to notably increase the compliance with the prescribed medication schedule. It is capable of interacting with the user, to sense its surrounding environment and react to it. Its two main functionalities are reminding the user when it is time to medicate and assisting the patient while doing so by dispensing the correct doses of medication at those times.

One of the main problems that affects the compliance with prescribed medication, *forgetfulness*, can be solved if the patient is notified of when to take the medical doses. Another common problem is *indecision* and *confusion*, which can be solved by the SPD by always dispensing the correct doses. In that regard, dangerous mistakes are avoided (*i.e.*, no quantity mistakes and correct time intervals between doses). *SPiDer* also provides an *ad hoc*, accurate and adaptable schedule for each user. For an elder patient the complexity of her medication schedule can be a problem. That is solved by making the SPD assisting the patient in keeping that schedule updated and precisely following it. The fact that the schedule is dynamic allows the doctor to make changes to it in real time (*e.g.*, due to medical reasons) or by the family (*e.g.*, in the case the patient has to leave house for several days). Such modifications can be directly made to the SPD by authorized persons through a simple online interface.

Monitorization of treatment compliance is also implemented in the SPD. The dispenser detects when the patient does not take the pills, therefore holding the information required to evaluate critical situations (*e.g.*, the patient did not take an important dose). Through the compliance schedule produced by the SPD, doctors can learn the exact compliance of patients, and react to it in real time or in a delayed manner.

Considering the importance of the role played by the SPD, it is key to establish a reliable and well-structured interaction for providing medication with the patient. Such routine interaction can help in maintaining mental skills by

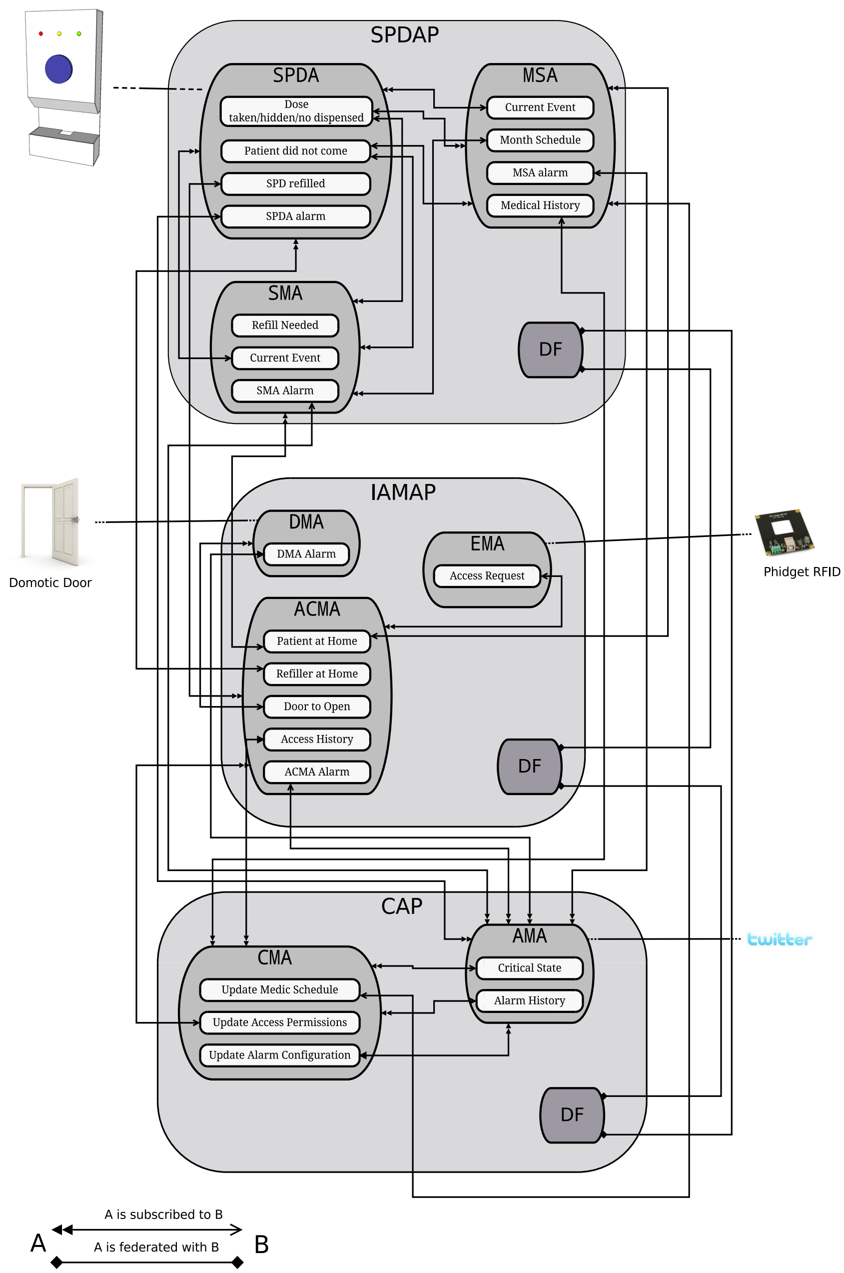

Fig. 1. The Agent Platforms of the *SPiDer* architecture, their agents and its services offered and consumed. Also displayed the external components of each platform.

promoting behavioral patterns in elder patients. The specific steps of the interaction can be addapted for each patient's conditions. Inhere we will descrive all the possible steps for the sake of illustration. Those are as follows:

– ***SPiDer*** detects it must provide a dose (*e.g.*, it is the right time to do so, the patient is at home, *etc.*). The SPD notifies the patient through audible and/or visual signals.
– **Patient** after noticing the signals, the patient approaches the SPD.
– ***SPiDer*** detects the patient has approached the SPD (*i.e.*, through a presence sensor), and asks the patient to request for pills through audible and/or visual signals.
– **Patient** pushes the button of the SPD for it to provide the pills.
– ***SPiDer*** detects the request for pills and dispenses the appropriate doses.
– **Patient** picks up the medications.
– ***SPiDer*** detects the patient has taken the pills (*i.e.*, through a weight sensor), and annotates the dose as correctly taken.

Physically, the SPD is a device which goes attached to a wall at the patient's home or at a nursing home. It includes three lights and a buzzer for audiovisual signals, and several sensors (*e.g.*, presence sensor, weight sensor, vibration sensor) for capturing the necessary data about the patient's actions. In order to manage all these sensors an *Arduino Uno*[1] is used. An image of the SPD prototype design can be seen in Figure 2.

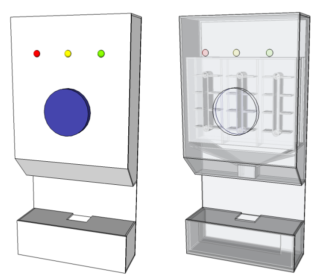

Fig. 2. The SPD design

3.2 Identification Access Management

The IAM monitors the entrances and exits in the patient's house. This system is placed at door and is composed of a *PhidgetRFID*[2]. Through the use of RFID technologies the system allows to identify and differ between different TAGs. It

[1] Official website: www.arduino.cc
[2] Official website: http://www.phidgets.com

also includes a domotic door capable of automatically open/close the door as needed. Through the use of the IAM, *SPiDer* can detect when the patient is going in and out of the house. With that information available, the system can be aware of when to provide doses. Additionally, knowing when the patient is usually at home allows doctors to adapt the medication schedule to the patient's routines for increasing the adherence.

Thanks to the IAM, *SPiDer* can also involve pharmacies and doctors in an innovative way. If the doctor wants to prescribe a medicine remotely (*i.e.*, through a digital prescription), a pharmacy recipient of such prescription can be responsible of sending a qualified person to refill the SPD once they have recieved it. In that regard, the IAM would be notified of the identity of the *refiller* and his expected arrival time, and could grant access to that responsible person authomatically through RFID. Through the integration of the IAM, *SPiDer* could partially solve the problem elders with mobility limitations face when trying to keep a medical supply. Since medications will be delivered based on the medication schedule and medical requirements, problems such as lack of medications will not happen again. In that regard, when the system detects that the SPD is short of supply, it proactively requests the doctor for the needed medications. Consequently a simple protocol can be triggered in which, on one hand, the doctor prescribes remotely a new electronic prescription and, on the other hand, the pharmacy, once it receives the electronic prescription sends to the house a qualified person to refill the SPD. Such interaction may be performed without the user's intervention and be empowered by the IAM, granting access and notifying the patient of the incoming authorized visit.

3.3 *SPiDer* Multiagent System

The MAS organizes *SPiDer* responsibilities in three groups: tasks intimately related with the physical SPD; tasks related with the IAM; and finally, the rest of tasks needed to satisfy the objectives that SPD and IAM cannot perform on their own (which are almost all of them communicative tasks). Hence, the MAS taxonomy is based in three platforms containing the logic that implements the required functionalities:

1. SPD Agent Platform
2. IAM Agent Platform
3. Communication Agent Platform.

These platforms are composed by sets of agents, each one having one or more implemented behaviours to reach its goals. Each platform runs on a *Raspberry Pi*[3], a low consume, credit card sized computer. Let us now we introduce the concepts of *service* and *subscription* in the context of a MAS to understand the agents' functionalities.

For each agent within *SPiDer* to perform its responsibilites and achieve its goals, they need of the cooperation from other agents. Concretly, every agent

[3] Official website: http://www.raspberrypi.org

needs information which is produced and shared by agents in the same or in a different platform. Agents comunicate through *services* and *subscriptions* to those services, to automatically build the relations needed for communication. Each agent publishes its list of services which are accessible to the rest of the MAS through the Directory Facilitator (DF). When an agent finds a service it is interested in, it subscribes to it and adds it to its *list of subscriptions*. At the same time, the owner of such service adds that agent to its *list of subcribers*. Those lists are used for automatic communication of updates (as soon as new data is learnt regarding a service, an agent will communicate so to its list of subscriber). Through the list of subscriptions an agent also can proactively request for information.

Next we will outline the agents composing the system, as well as their capabilities and responsabilities. For a complete list of services offered and subscriptions implemented among agents, see Figure 1. To start with, the SPD Agent Platform is in charge of the functionalities directly related with the SPD (*e.g.*, dispense a pill, monitor compliance). It is composed by 3 agents, as shown in Figure 1:

Smart Pill Dispenser Agent (SPDA) knows *how* to dispense doses and it is able to capture information from the direct environment of the SPD. It offers important information to the other agents such as treatment compliance.

Medic Scheduler Agent (MSA) is in charge of maintaining an updated schedule of the medication treatment for the patient, as well as historical information. Such information is used by agents such as the SPD for dispensing doses.

Stock Manager Agent (SMA) has the responsibility of controlling the supply and detecting potential stock breaks. It also contains an updated monthly schedule in order to provide additional robustness to the system in such delicate operation as is dispensing medication.

The IAM Agent Platform is in charge of the functionalities directly related with the access control (*e.g.*, monitor access history, allow/deny access). It is composed by 3 agents as shown in Figure 1:

Door Management Agent (DMA) is in charge of managing the domotic door (*i.e.*, opening and closing the door).

Entrance Management Agent (EMA) has the responsibility of detecting when somebody is trying to access the door, as well as capturing its identity through the RFID data.

Access Management Agent (ACMA) is in charge of keeping an updated list of access rights for all identities allowed in the system. For each one of them the ACMA keeps a relation of identity with the time at which such identity is allowed to enter the house, as well as supposed to leave it. Such information will be used for authorizing the door to open or not. The agent also maintains a history of the accesses (successful and failed) into the house and has a logic engine to raise possible critical situations, as the attempt to enter the house by somebody without permissions.

The Communication Agent Platform is purely software adding communicative features through the use of Twitter and also a engine capable of identify critical situations based on the information provided by the agents. Mainly, is in charge of the functionalities directly related with the flow of information among stakeholders (*e.g.*, communicate dose not taken, update medical schedule by doctor). It is composed by 3 agents which can be seen in detail in Figure 1.

Communication Manager Agent (CMA) is in charge of communicating with the different stakeholders of the system through Internet interfaces. Such agent manages the input/output devices which allow the flow of data from the system to the responsible stakeholders (*e.g.*, let a relative know that an unathorized attempt to enter the house happened) as well as from those stakehodlers to the system (*e.g.*, the doctor adds a dose to the schedule).

Alarm Manager Agent (AMA) is in charge of detecting when a situation is critical or not. It will recieve data from all other agents which may detect those situation (*e.g.*, SPDA detects a lack of compliance, SMA detects an incoming stock break, ACMA detects an unauthorized access attempt, *etc.*). The agent implements a logic engine which, from the data received from other agents, infers if a situation is critical or not. And if evaluated as critical, who of the external stakeholders should be notified. Once such decision has been made, the CMA will be requested to execute the communication..

All the aforementioned communications are implemented by means of *services* and *subscriptions*, with the only exception of the CMA, which communicates through Twitter.

4 Conclusions

The main goal of *SPiDer* is to improve the QoL and capabilities of the elderly to live autonomously. To reach this goal the project focuses on increasing the compliance with their medical schedule. Common problems such as *forgetfulness* and *confusion* can be avoided through the use of a dynamic, electronic schedule which both medical experts and relatives can see and edit. Similarly, the problem of keeping at all times the necessary stock of medications can be easily tackled by *SPiDer* through the integration with emerging protocolos such as electronic prescriptions.

Beyond the basic pill-dispensing capabilities, *SPiDer* also integrates components for managing and monitoring access to the house, which can be useful for security reasons and for patients with a middle to high degree of dementia. It also implements communication channels to send and recieve updates regarding the patient's behavior through the well known Twitter social network. The range of features provided by these components allows the adaptation of the system's behavior to the requirements of each particular patient's needs. Some patients may not be allowed to leave the house on their own. Some patients may have to pick up the medications from the pharmacy by themselves, to force their mobility. Whatever the case, *SPiDer* can be addapted to obtain the most of it.

The technological decisions taken for *SPiDer* guarantee its applicability in virtually any scenario. The low energy consume components it contains, together with their behavioral autonomy does no require any external component, beyond electric power and a continuos Internet connection. Each agent platform runs on an autonomous computer which handles the necessary sensors and actuators to perform all platform's tasks. Resulting in a critical system with robustness and error response capabilities.

We argue that *SPiDer* is a system potentially useful for any elder's house, capable of addapting its features to the patient's requirements. Additionally it is also possible to consider its integration into nursing homes as an interesting possibility to be explored.

Currently, *SPiDer* as described here it is fully implemented. A prototype of the SPD has been built, and it's behavior is being tested. Both agents and services of the other two platforms (IAM and Communication), are also being tested. As a future work we therefore expect to place *SPiDer* into a real environment so that we can obtain feedback from real patients, and therefore quantify the benefits of our proposal.

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