Towards an implementation of a social electronic reminder for pills

Ignasi Gómez-Sebastià, Dario Garcia-Gasulla, Sergio Alvarez-Napagao, Javier Vázquez-Salceda and Ulisés Cortés

Departament de Llenguatges i Sistemes Informàtics. Universitat Politècnica de Catalunya (BarcelonaTech-UPC)*

igomez,dariog,salvarez,jvazquez,ia@lsi.upc.edu

ABSTRACT

Non-compliance with prescribed medication is a major problem for elder people living alone in developed countries. Forgetfulness and confusion can lead to it, specially when multiple pathologies require a cocktail of different medications each delivered at different time intervals during different periods of time. Assistive technologies, a recent application area for a wide range of Artificial Intelligence techniques and tools, have been effectively used for supporting people in their daily activities. This paper introduces the design and implementation of a system for assisting elder people on following the treatment prescribed by a professional, with the novelty of being based in social and organisational aware assistive technology.

Keywords

Assistive Technologies, normative agents, agent-oriented software design, Ambient Intelligence

Categories and Subject Descriptors

D.2.8 [**Software Engineering**]: Human Factors—*Assistive Technologies, normative agents, agent-oriented software design, Ambient Intelligence*

1. INTRODUCTION

In 2002 it was estimated [19] that the European population above 65 years old represented between a 12% and a 17% of the total population. Over the next few years, this proportion is likely to increase due to a decreasing birthrate. At the same time, the cost of supporting an elder person is greater than the cost of supporting a child in a ratio of five to three [20], most of this cost being caused by higher health expenses. In the coming years this situation (together with other economic factors) will put great pressure on the national healthcare budgets, mainly because therapies for managing chronic diseases (*e.g.*, diabetes, parkinson, *etc.*) are performed away from the institutional care setting (typically at home). This distributed approach to daily care requires that elders are capable of autonomously taking several different medications at different time intervals over extended periods of time. This can easily lead to forgetfulness or confusion when following the prescribed treatment, specially when the patient is suffering multiple pathologies that require a treatment with a cocktail of drugs. This gets worsened when elders suffer a cognitive impairment.

Assistive Technologies (AT) are an application area where several Artificial Intelligence techniques and tools have been successfully applied to support elder or impeded people on their daily activities. However, approaches to AT tend to center in the user-tool interaction, neglecting the user's connection with its social environment (such as caretakers, relatives and health professionals) and the possibility to monitor undesired behaviour providing both adaptation to a dynamic environment and early response to potentially dangerous situations.

AT can be effectively used for guiding elders with their prescribed treatments, avoiding major problems such as non-compliance with the treatment and adverse drug reaction. Several devices are available for helping patients to manage their daily doses of medication. They range from simple pill containers with multiple compartments that can hold a month's supply to intelligent pill dispensers [13] with an alarm function which can detect when the patient takes the pill, and that can be telematically programmed in case the treatment changes. However, these kinds of devices tend to have a static encoding of their functions, and are unable to react to changes in the environment (*e.g.*, they will keep on dispensing the pills even if the patient is on holidays away from home) and autonomously react to potentially dangerous situations (*e.g.*, the dispenser is about to run out of supply for a given pill). Furthermore, to the best of our knowledge none of these devices take into consideration the important role that third parties may have in the activity. For instance, the prescribing doctor scheduling a visit with the patient when the treatment finishes, a delivery company refilling the dispenser when it is about to run out of medication, or patient's personal computer displaying reminders when it is time to take a given medication. Nor they reflect the social constraints that apply in the relation between the user and the other actors. For instance, forbidding the delivery company employee from entering user's home if the doctor considers the user can fill the dispenser autonomously.

The COAALAS [10] project (COmpanion for Ambient Assisted Living on Alive-Share-*it* platforms) is based on organizational and normative theories and Ambient Assisted Living (*i.e.*, ambient intelligence applied to assistive technolo-

*C/Jordi Girona 1-3, E-08034, Barcelona, Spain

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gies). The project aims to create a society of organisational aware devices (typically sensors and actuators) that are able to adapt to a wide range of Ambient Assisted Living situations. COAALAS models the device network around the user as a society, including the set of behavioural patterns the devices are expected to follow. COAALAS effectively supports smart assistive tools that integrate human actors with the surrounding devices, contributing to the state-of-the-art in semi-autonomous and intelligent devices for elder people by allowing the devices to be both social and norm aware.

In this paper we present the design and implementation of a social-norm aware pill dispenser. The dispenser, based on the concepts developed by the COAALAS project, will help the elderly or disabled people to manage their daily doses of medication while presenting the following three properties:

- *Socially awareness*: The device is connected with other assistive devices and with relevant actors (such as doctors, caretakers and other health professionals, familiars, etc) for helping the elder take his daily doses of medication.
- *Autonomy*: The device can react to changes in the physical or social environment without requiring human intervention. Furthermore, it should be able to react to simple changes in the scenario autonomously (*e.g.*, a change in the scenario implies the pill dispenser is not filled by the patient any more, but by a care giver).
- *Normative awareness*: The device performs its task while following a set of specified behavioural patterns. However, due to its autonomy, the device has the option of breaking the patterns, provided it considers it will be in the benefit of the society (*e.g.*, if an incoming stock break is detected).

The rest of this paper is structured as follows. First a short survey on existing works for assisted living, focused on these works that facilitate taking a prescribed medication, is presented. Then, one of such existing works, the COAALAS project is explained in depth. Later, a use case is introduced and modelled using the ALIVE methodology which one of the theoretical foundations of the COAALAS project. Finally, conclusions are drawn.

2. STATE OF THE ART

This section presents a short survey on the existing work in the area of Ambient Intelligence for supporting independent living, with special emphasis on the works focused on facilitating daily tasks (specially taking a prescribed medication). Special attention is put on the COAALAS project, that has been selected as basis for the work presented in this paper.

Robocare [6] is a project deployed on a domestic test-bed environment that combines a tracking component for people and robots and a task execution-supervision-monitoring component. Robocare has the goal of contributing to improving the quality of life of elder people living autonomously in their homes. The system is composed of several software and hardware agents, each providing a set of services, and an event manager that processes requests to the different services and directs them to the appropriate agents. The system also includes a monitoring agent, with knowledge of the assisted person's usual schedule. The monitoring agent is able to detect discrepancies between the tasks performed by the user and the expected schedule and react to them. In order to coordinate all the agents and monitor user's behaviour heavy computational processes take place, limiting the tested scenarios to non-crowded environments, where only 2-3 persons and only a small portion of the domestic environment are monitored. What is more, the expected schedule is non dynamic and small justified deviations (*e.g.*, relatives visiting the user) are currently detected and corrected.

The AHRI (Aware Home Research Initiative) [16] is a residential laboratory for interdisciplinary research where several projects have been evaluated. The most relevant one is the ISLA (Independent LifeStyle Assistant) [12] project, that passively monitors the behaviours of the inhabitants of the residential laboratory, alerting relatives in case of potentially dangerous situations (*e.g.*, the user falls). The ISLA project presents two main innovations with regards to the Robocare project:

- Agents autonomosly interact within them in order to achieve their goals, without the need of an event manager agent that coordinates them. However, in order to transform context-free perceptions provided by the agents into context-aware perceptions, a centralized coordinating agent is used.
- Agents are able to learn schedules based on the daily tasks performed by the inhabitants. Models are built, reflecting which devices are triggered when given activities are performed, and alerts are raised whenever an unlikely activity takes place. Therefore, instead of using generic static schedules for the users, the schedules are built dynamically based on user's detected behaviour. However, once a schedule has been learned, user is not able to deviate from it without raising an alarm.

Evaluation of the ISLA project presents two main conclusions:

- The need for coordination of the agents and centralized control outweights the benefits of the distribution and independence of components agents architectures provide.
- Partial observability of actions performed by the inhabitants is a problem, specially when plans are abandoned due to forgetfulness and reminders need to be issued. Inhabitants do not tend to be in favour of having every of their moves observed.

In the scope of the MINAmI project [15] a qualitative study of three ambient intelligence scenarios is reported, being the most relevant one a scenario that deals with monitoring the taking of medication. In the scenario users are given a smart pillbox, with a cap that counts the number of opening and closing events and a clock. The pillbox can communicate with a mobile phone, that displays the timed record of cap openings and closings. If the users forgets to take his medication for a prolonged period of time, the pillbox sends a notification to a care center. During the evaluation of the scenario, users felt it was too intrusive on their privacy, arguing the data should not be reported to their doctors. They considered relying on such devices for the reminders could weaken people's cognitive abilities, and that such a system would not be suitable for users taking a cocktail of medication rather than just a single medicament, as several pillboxes should be provided. The scenario presented seems to be mainly theoretical, lacking an implementation, and does not provide a fully integration of the pillbox with the rest of the devices in the Smart Home (*e.g.*, the system can notify that the user forgot to take his medication even when the rest of the devices are showing that the user has not been at home on the last 3 weeks, for instance, because he is on holidays).

In [5] ECA (Event-conditioning-action) rules are used for Smart Homes that support assisted living for the elderly. A basic interpretation of the ECA rules is that, on detecting certain events, if certain pre-conditions are satisfied, then a given set of actions are to be enacted. By using rule-based systems and other AI techniques, devices and hardware-oriented technologies for Smart Homes can be augmented and enriched. With that goal in mind, authors propose connecting the devices to a central monitoring facility that performs all the reasoning. This approach differs from the resnt in the sense that devices show a complete lack of intelligence, leaving all the reasoning to a central component, effectively preventing coordination and cooperation among the agents representing the different devices. A similar work [18] proposes using abductive logic programs for the reasoning process. Abductive logic programs provide active behaviour, just like the ECA rules, but they also provide added declarative semantics and a extensive background knowledge available via the logic programming. For instance, this approach allows for easily applying preferences to the reminders issued to the user. Both works present a higher system adaptability, allowing even for a customization that adapts the system to the preferences of the user. However they lack the coordination among different agents that would allow the system to autonomously recover from a failure if one of the agents stops working.

In COAALAS (COmpanion for Ambient Assisted Living on Alive-Share-*it* platforms), organizational and normative structures are used to model the device network around disabled users as societies, along with the expected behavioural patterns, effectively supporting smart assistive tools that integrate with the human actors around them. The project aims to make the devices intelligent enough so they can autononosmly organize, reorganize and interact with other actors. This intelligence allows the integration of the devices in a Smart Home with the rest of actors involved with the user (*e.g.*, doctors and other health professionals, caretakers, *etc.*), and to embed the devices with autonomous, proactive, social and adaptable behaviour. The COAALAS project puts the theoretical basis for modelling and deploying assistive scenarios as societies of cooperating adaptable norm-aware actors. This approach makes COAALAS suitable for two main scenarios:

- Dynamic scenarios. Having adaptable actors implies the system design does not require major adaptations when changes in the scenario occur. For instance, if a new actor is to be added or the actions an actor performs are to be enacted by a different actor, changes on the system design are few and simple. Even more, changes on the system implementation can usually be completely avoided. Therefore, in dynamic scenarios where changes to the design are to be applied often, COAALAS allows for a fast and swift adaptation to the new scenario.

- Scenarios where the actors (specially artificial ones) have to be norm aware. Actors in COAALAS follow a set of expected behavioural patterns by default, but with the possibility to temporally stop following them if they consider it is beneficial for the society or the individual. Therefore, COAALAS facilitates the specification and implementation of normative constraints, provided they are important for the scenario being developed.

However, the COAALAS project only presents a theoretical basis and, to the best of our knowledge, no implementation exists. Therefore, we consider COAALAS to be the best project to base our work on from the ones analysed, as we intend to provide a proof-of-concept implementation of a dynamic scenario with flexible behavioural patterns that can be easily modelled as a society of cooperating actors.

3. THE COAALAS PROJECT

The main goal of COAALAS is to contribute to the state-of-the-art in semi-autonomous and intelligent devices for elder people. COAALAS builds on the results of two European funded projects: EU-Share-*it* [4] and EU-ALIVE [1]. COAALAS aims to produce a new generation of Ambient Intelligence devices for elder people by embedding several state-of-the-art AI techniques:

- **Autonomy**: The device is integrated in the environment, able to perceive it and react to it in a timely fashion.

- **Proactivity**: The device is able to anticipate and take the initiative in order to fulfil its design objectives.

- **Social behaviour**: The device is integrated in a community of actors and is aware of social regulations and protocols.

- **Adaptability**: The device will modify its behaviour based on the rest of the actors around it.

By a combination of these techniques, COAALAS focuses in making devices intelligent enough to organize, reorganize and interact with other actors. Devices have an awareness of their social role in the system – their commitments and responsibilities – and are capable of taking over other roles if there are unexpected events or failures. The objective of the COAALAS project is to create a society of physically organisational-aware devices able to adapt to a wide range of Ambient Assisted Living situations that could have an impact on the user's well-being.

3.1 The ALIVE architecture

The ALIVE framework presents a multi-level structure that combines model-driven design techniques and agent-based system engineering providing support for *live*, open, and flexible service-oriented systems. ALIVE's organisational and normative structures make it suitable for highly regulated scenarios like the one presented in this paper. The ALIVE framework applies substantive norms that define

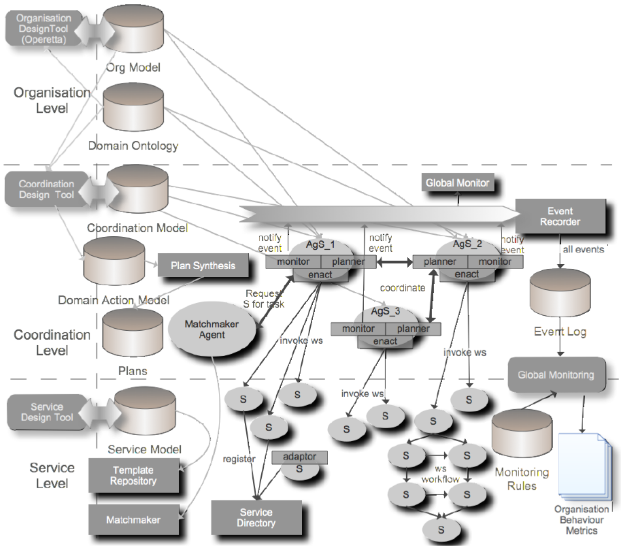

Figure 1: ALIVE architecture [2] (S stands for Service)

Property	Value
Activation Condition	isActive(Provide_medication)
Deadline	
Expiration Condition	isFullfilled(check_best_before_date)
Maintenance Condition	¬ ~isFullfilled(Provide_medication)
Norm ID	o_check_best_before_date_before_Provide_medication

Property	Value
Activation Condition	isViolated(O_check_best_before_date_before_fill_dispenser)
Deadline	
Expiration Condition	isFullfilled(Apply_generic_sanction)
Maintenance Condition	
Norm ID	o_Apply_Generic_Sanction_fill_dispenser

Figure 2: Example of norms of the use case

commitments agreed upon actors and are expected to be enforced by authoritative agents, imposing repair actions and sanctions if invalid states are reached. Substantive norms allow the system to be flexible, by giving actors (human or computer-controlled) the choice to cause a violation if this decision is beneficial from an individual or collective perspective.

The ALIVE organizational level represents the organizational structure of the system via the organizational model. The organizational model is formalized following the Opera methodology [8], including the following concepts:

1. **Objectives**: States of the world pursued by actors. Derived from organisation's goals.

2. **Roles**: Groups of activity types played by actors (either agents or human users). The set of roles and the relations between them constitutes the *Social Structure*.

3. **Landmarks**: Represent important states of the world regarding the achievement of goals. They are identified by the set of propositions that are true on the state of the world represented by the landmark.

The organisation level supports the definition of norms, adding a normative structure to the social and interaction structures. The normative structure is useful for imposing patterns of behaviour. The elements on the normative structure contain the following main components, expressed using Partial State Descriptions of the world: a) *Activation Condition*: when the world reaches the state specified in this condition, the norm starts to be checked. b) *Expiration Condition*: when the world reaches the state specified in this condition, the norm stops to be checked, and has not been violated. c) *Maintenance Condition*: when the world reaches the negation of the state specified in this condition, the norm stops to be checked, and has been violated. *Figure* 2 shows an example of an ALIVE norm.

The ALIVE coordination level provides actors' patterns of interaction. The organisational model is transformed into a repository of coordination plans. Plans bring the system from the state represented by a landmark to the next one (as defined on the interaction structure) and are formed by chains of tasks. The model of tasks contains both pre and post-conditions, that define the state of the world before and after a particular task is performed, and the permissions (roles in the organisational model) required for executing the task. Being organizational aware, agents can select one or several roles according to their capabilities (*e.g.*, the tasks the agent can perform) and start enacting the plans associated to that role as required.

The ALIVE service level maps actions in the environment to abstract tasks. Non-organizational aware agents in the system register their capabilities (*e.g.*, tasks they can perform) via a white pages system and are coordinated by the organizational aware agents to execute the tasks required for enacting the different plans.

The monitor tool is the back-bone of the ALIVE framework, connecting all the three levels allowing the exchange of events among them, from a action on the environment that fails to an update on the Organisational design (*e.g.*, a new role or objective is introduced) that affects the agents in the coordination level. Agents enact their roles by interacting among them via direct communication (coordinating among themselves) or by interacting with the environment. The monitor tool observes these interactions and matches them with the normative and organisational states (*e.g.*, Obligations, Permissions, Roles) effectively allowing agents to reason about the effects (in a normative sense) of their actions.

4. EXTENDED AND GROUNDED USE CASE

The COAALAS project has a main milestone: solving the difficulties presented in the use case described in [11]. Such use case was originally presented in [3]. For coherency with the COAALAS project, our design will also be based on that use case. This will allow us to state how far can we take the implementation of the COAALAS project.

The original scenario focuses on an elder or disabled person with difficulties to leave his house. It is assumed that such person is following one or more medical treatments which require periodical doses of medication. The main problem to solve is that of supplying the required stock of medicines to the subject while supervising that he follows the medical treatment prescribed by his doctor, not missing any dose due to forgetfulness or taking it at the wrong time due to confusion. It must be remarked the design presented in this paper includes some minor modifications with respect to the original COAALAS scenario in order to make the implementation feasible. *Figure* 3 shows the interfaces of the different actors. These are the main actors in our scenario:

- *User*, as the main character of the scenario. Responds to medication notifications sent by the *Medical dispenser* actor. Provides access to user's calendar in case other actors (typically *Doctor* and *Caretaker*) need to query it.

- *Doctor*. Responsible for prescribing the medical treatment. When the treatment is about to expire, the *Doctor* is notified and must decide to: 1) continue with the same treatment. 2) continue with a modified treatment (*e.g.*, different doses or medications). 3) schedule a visit with the *User* to control his evolution. The *Doctor* has the commitment of deciding in a reasonable period of time.

- *Caretaker*, as the responsible for looking after the patient. If a potentially dangerous situation is detected, the *Caretaker* is notified. Then, the *Caretaker* has the commitment to go to the user's place to check the anomaly. This process implies acknowledge of the notification and a textual report of the solution provided for the anomaly. The *Caretaker* can also perform tasks in substitution of another actors that are temporally unable to perform them. For instance, the *Caretaker* can take medication to the user's home in case the Logistics company is unable to deliver it on time for the treatment.

- *Health Insurance Company*, as the entity organizing and controlling the interactions. The *Health Insurance Company* applies sanctions in case commitments are not fulfilled. It also coordinates other actors in order to enact repair actions (*i.e.*, actions that take the state of the world from a potentially dangerous situation to a safe one). For instance, the *Health Insurance Company* can ask a *Caretaker* to bring medication to the user's place if the *Logistics company* is delayed and will not be able to deliver the medication on time for the treatment. Finally, it coordinates other actors in the most efficient way possible, planning and optimizing medication delivery routes.

- *Pharmaceutic*, as medication retailer. Pharmaceutics provide medication to logistic company employees so they can take it to the user's place. They have the commitment to avoid providing medication until the logistic company employee has successfully authenticated. *Pharmaceutics* receive notifications on user's medication stock and consumption, so they can plan ahead of medication consumption and coordinate among them in order to satisfy medication supply needs. Pharmaceutics provide reports to the *Health Insurance Company* with relevant information on their current stock of medications. The *Health Insurance Company* actor uses this information for choosing the pharmacies that will provide the medication based on several efficiency terms.

- *Logistics company*, as the responsible for home delivery. Logistics company employees authenticate at pharmacies in order to take medication from pharmacies to user's place. If they are granted access to user's place (because the *Doctor* considers the *User* is not able to refill the *Medical dispenser* on his own) they have the commitment to refill user's *Medical dispenser*. Otherwise they have the commitment to avoid entering user's place. They can issue delay notifications in case they realize they will not be reaching user's place at the expected time.

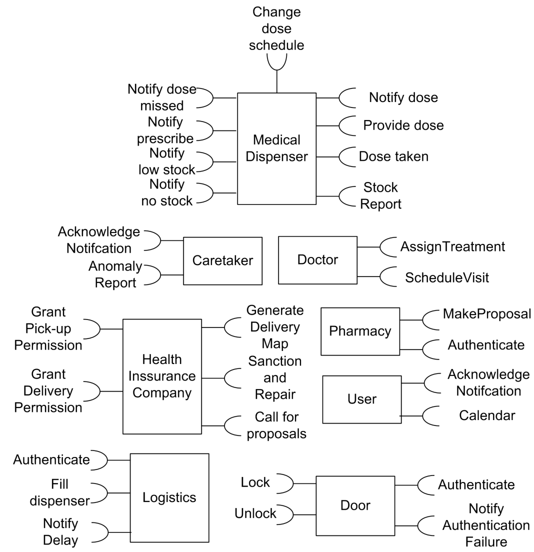

Figure 3: Interfaces of the different actors

- *Domotic house*. In the current scenario only domotic doors are taken into account. We plan adding more domotic actors in the future. The *domotic door* is the actor responsible for allowing other actors access to the user's place (typically *Caretaker* and *Logistics company*). Actors authenticate at the *domotic door* and the door will allow access provided actor can get into user's home, denying it otherwise, and contacting a *Caretaker* in case too many unsuccessful authentication attempts are performed.

- *Medical dispenser*, a device which provides medication doses. The *Medical dispenser* is able to provide pills at scheduled times and asses, with an *acceptable* degree of certainty, weather the user has taken the pill from the dispenser or not. An intelligent controller attached to the dispenser can coordinate with another actors (typically *Doctor* and *Caretaker*) to change the schedule of medication doses, or do it autonomously (*e.g.*, providing more pills if an interpretation of user's calendar indicates he will be away from home when the medication should be provided, so the user can take the pills with him at take them at the scheduled time). The controller can send reminders to user's smart-phone when it is time to take the medication, control the stock of medicines (autonomously coordinating with the *Health Insurance Company* to schedule more medication deliveries) and react to unexpected events (*e.g.*, user not responding to reminders).

The original COAALAS scenario contemplates a wide set of situations, but the main one can be outlined as follows:

The *User* visits the *Doctor* who assigns him a medical treatment. The *Health Insurance Company* receives a notification about the treatment starting, and contacts the different *Pharmaceutic* actors near user's place. The different *Pharmaceutic* actors reply with offers that state the amount of medication they can provide and when. Before replying, pharmacies can coordinate among them in order to provide group offers that are usually better than the offers they could provide individually. The health insurance company chooses the best offer based on several efficiency parameters (such as amount of medication provided, delivery time, expiration date, price, *etc.*) and sends a notification to the pharmacy or set of pharmacies selected. Then, generates a visual map with the location of the pharmacies and the user's place and provides it to the *Logistics company* actor. Finally, the *Health Insurance Company* grants the logistics company authorization to retrieve the medication from the pharmaceutic and to enter the user's house, provided it is required. The logistics company authenticates at the selected pharmacies picking the medication and goes to user's home in order deliver it, or put it on the medical dispenser unit. If the medical dispenser is to be refilled, the logistics company employee authenticates via the *domotic door* actor. An alert is sent to the *Caretaker* actor if too many failed authentication attempts are detected. Once filled with medication, the medical dispenser provides medication doses and notifies the *User* when a dose is to be taken. The *Medical dispenser* actor controls the stock of medications. For doing so, it takes into account the prescribed treatment (*i.e.*, both length and daily doses) and the number of available doses. If the stock of medications is low, the medical dispenser contacts the *Health Inssurance Company* actor, so a new delivery can be scheduled. If the treatment is about to prescribe, the medical dispenser contacts the *Doctor* actor. Then, the doctor can choose to continue with the treatment, modify it or schedule a visit to control user's evolution. Both the *Medical dispenser* and the *domotic door* actors can contact the *Caretaker* if a potentially dangerous situation is detected. Such situations include, someone entering the user's place without authorisation, running out of medication stock and user not responding to dose taking notifications. In order to check some potentially dangerous situations the *Caretaker* must enter the user's place. Therefore, both the *domotic door* and the *Medical dispenser* actors can grant the *Caretaker* actor access to the user's place.

From this simplified use case we extend the interactions and define a set of technologies to implement them. In our design, the authentication of the actors at the pharmacy and the domotic house is performed via RFID. Both caretaker and logistic company actors carry RFID tags with them. The tags can be used to authenticate the user at the readers on the pharmacy, domotic door and pill dispenser.

The communications required to coordinate the different actors in the use case are implemented via social networks, particularly Tweeter. The ready available APIs[1] for Tweeter will facilitate their integration and the development of the proof-of-concept prototype. *Figure* 4 depicts the different messages exchanged in the scenario. These are the main communications to be implemented via social network:

- When the *Doctor* receives the visit of the *User* and prescribes a treatment, he sends an encrypted message to the *Health Insurance Company* with information on the prescribed treatment and the medication required to follow it.

- Aware of the treatment user has to follow, the *Health Insurance Company* contacts different pharmacies, asking if they have the medications in stock. Pharmacies coordinate among them, returning different individual or collective proposals to the *Health Insurance Company.* Once the best proposals are selected, acceptance or refusal notifications are sent to the pharmacies.

- Pick-up permission notifications are provided to the selected pharmacy (or set of pharmacies) and the logistic company. if the *Doctor* consider the *User* needs help refilling his medical dispenser unit, delivery permission notifications are sent as well. Finaly, a message including the delivery route to be followed is provided.

- The *logistics company* actor authenticates at the pharmacy and at the domotic door by providing authentication messages that include his RFID tag. It allows the actor to pick-up the medication and access user's place respectively. If too many authentication attempts are

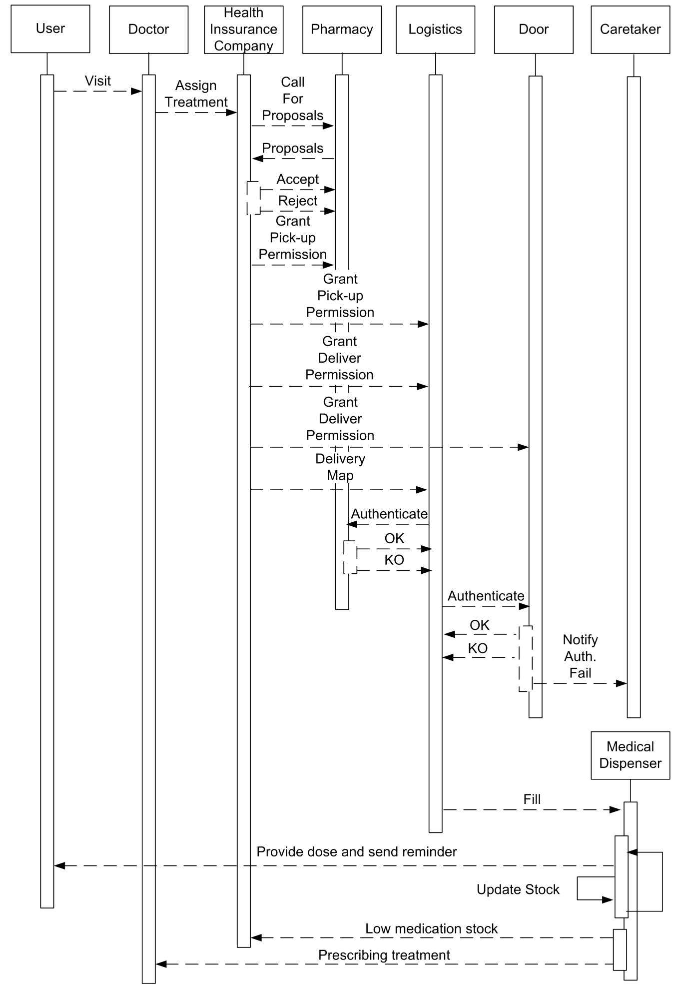

Figure 4: Sequential diagram of message exchange

[1] http://twitter4j.org/en/index.html

performed at the door, *Caretaker* receives a notification message.

- The *logistics company* actor fills the dispenser and notifies it with a message to the *Medical Dispenser* including relevant information on the medication provided (such as quantity, format, expiration date, *etc.*).

- The *Medical Dispenser* starts providing doses and sending reminders to the user according to a schedule. Stock is updated accordingly. Please notice stock update is not a message, but an action performed internally by the *Medical Dispenser* actor.

- When the *Medical Dispenser* is almost out of stock for an on-going treatment, it will send a message to the *Health Insurance Company* so that it can organize and schedule a delivery. If the situation is critical (for instance, being completely out of stock) the *Medical Dispenser* can send a message to the *Caretaker* instead, so he can get some medication doses quickly to user's place.

- When the treatment is about to prescribe, the *Medical Dispenser* sends a message to the *Doctor*, and the doctor decides to continue with the same treatment, modify the current treatment or schedule a visit with the user to control his evolution.

- If the *Medical Dispenser* detects that the daily dose has not been taken (typically, user does not respond to notifications), it will send a message to the *Caretaker* to let them now of the potentially dangerous situation.

In our design we also include several Web applications of integrated systems, which will provide additional features to the system. An example of that is Google Maps in the following case. When a new delivery is to be arranged, the Health Insurance Company will choose the pharmacy which is to provide the medications. That selection will be made by a Call For Proposals (CFP) to determine the best candidate considering a set of parameters (*e.g.*, location, medication stock, best before date of the medication required considering the treatment). Once the set of pharmacies are decided, the Health Insurance Company will provide the logistics company with a Google Maps of both the pharmacy and the house where the delivery is to take place. Another example of integrated web applications is connecting the medical dispenser to the user's on-line calendar (*i.e.*, via xcal). If the dispenser detects the user will be away from home (*e.g.*, the user is on holidays) it will stop dispensing pills and reminders will be forwarded to user's cell-phone (*e.g.*, via SMS).

Regarding the autonomous agents and its devices, we have decided to implement them using the newly marketed tiny computers. Concretly we will use *Raspberry Pi*[2], a credit-card sized computer with Ethernet, USB and HDMI ports, and Micro USB for power. The agents to be hosted by these computers are the domotic house (for the RFID reader) and the medical dispenser (for the embedded intelligence). That will allow them to communicate with each other and the rest of the agents through a network. Once the hardware is integrated into the organization, more agents and devices can be easily added (*e.g.*, motion sensor, temperature sensor) to further enhance the monitorization of the patient. Currently we are implementing a REST-based interface to connect lightweight agents with a set of sensors with Arduino and Phidgets interfaces. The preliminary diagram of the domotic house is depicted in Figure 5.

For the user interface with the system, we have decided to use a smart-phone with an Android based operative system, as well as a tablet PC. The former will allow the user to receive notifications and control his calendar, so it can be integrated with the caretaker and the medical dispenser actors. In case the user is away from home, the smart-phone can be used to track user's position, in case the doctor considers it is required. The latter will be used as a guidance interface, both by means of electronic tutorials [17], and as an audiovisual communication interface with doctors and nurses.

Finally, regarding the medical dispenser two out-of-the box solutions are analyzed, the Simple Med [14] pillbox from the *Vaica Medical* corporation in Tel Aviv and the *u*Box [13] from IIH (Innovators in Health). The Simple Med pillbox is a unit with a grid of boxes (7 days a week 4 doses a day) that can be plugged into the phone line and programmed by a provider to call the patient and notify which compartment to take the pills from. The Simple Med pillbox is able remind the patient (visually and audibly) to take his medication at the right moment of time. The system can be connected to an external monitoring center, sending signals in response to box opening and closing events as well as alert signals in response to recognized deviations (typically missed doses and doses taken at the wrong time). The *u*Box is a palm-sized pill dispenser that reminds a patient when it is time to take medication and records when the patient takes a pill from the dispenser. It is also able to track accesses to the box by program personnel (typically a health professional refilling the box) via RFID keys. Currently, the *u*Box is being tested in three districts in Bihar, India [9]. Comparing both solutions, the *u*Box seems a better approach for the implementation of our scenario as it provides a better connectivity (allowing for easier integration with the tiny computer) at the cost of lower integrated intelligence that we are not going to use anyway, as our custom controller module is going to be attached to the pill dispenser.

4.1 Modelling the use case using the COAALAS architecture

This section models the use case deployed in this paper using the COAALAS architecture that is based on the ALIVE framework. It introduces the model from the ALIVE Organisation, Coordination and Service level perspectives. Elements from the domain ontology are referenced when required.

4.1.1 Organisation level model

In the organisation level we identify the existing set of stakeholders, the goals of each of them, landmarks and scenes related to those goals and the normative structure of the system. The stakeholders map directly to the different actors in the use case. A role is created for each actor.

For each *role*, its *goals* within the use case have been identified. Also a hierarchical relation representing dependencies between roles is defined. For instance, to fullfil the goal *Prepare_deliver*, pick-up and deliver permissions must be as-

[2]http://www.raspberrypi.org/

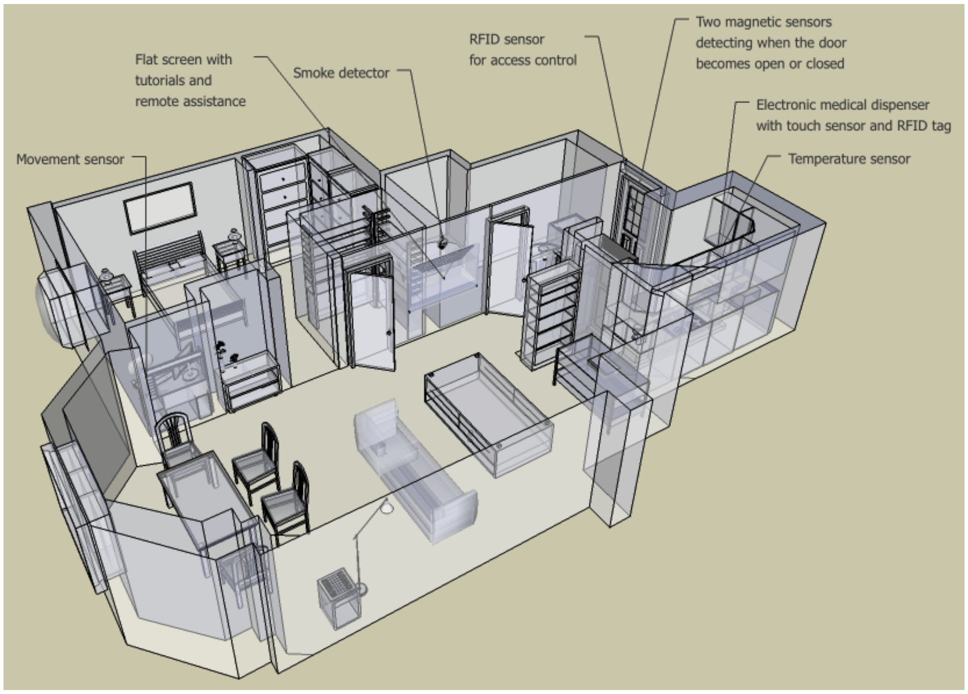

Figure 5: Plan of sensorisation for the COAALAS domotic house

signed to both *Logistic* and *Pharmacy* roles. Thus, the role fulfilling *Prepare_deliver* depends on the role assigning permissions. Each goal is assigned with a state description, representing the state of the world when the objective has been fulfilled. For example, the goal *Reach_pharmacy* has been fulfilled when the logistics person A (who has been given the order to go to a given pharmacy P) is in the same geographical coordinates as P.

Landmarks define important states on the achievement of the goals. A set of ordered landmarks define a scene. The execution of each scene entails the achievement of one or more goals. For instance, when the landmark *Check_treatment* is reached, the goal *Aprove_treatment* is fulfilled. Role *Doctor* participates on the landmark because it has the objective *Aprove_treatment* assigned.

The last element to be defined on the organisation level are the norms, which must be specified by an expert on the domain together with the supervising entity, if there is one (in this case it would be the Health Insurance Company).

4.1.2 Coordination level model

The elements on organisation level are derived into the coordination level. This level contains three main elements, actions, plans and organisational aware agents. Organisational aware agents enact roles based on their capabilities (*i.e.*, actions they can perform) and the goals associated to that role. Actions are derived from objectives on the organisation level. Actions contain both pre and post-conditions representing the state of the world before and after the task is enacted. Thus, the post-condition of a given task matches the state description of the objective the task is derived from.

Plans represent chains of actions. Typically, one plan is modelled for each transition between landmarks or scenes defined on the organisation model. In the case of the transition between the scenes $Prepare\_request\_medication \rightarrow Request\_medication$ and $Pick\_up\_medication \rightarrow Hand\_medication\_over$ one additional plan is provided for each transition. In this case, the agents have two options available in order to bring the world from the state represented by the first scene to the state represented by the second one. The norms defined on the organisation model provide means for pondering both plans (analyzing which plan will cause less norm violations) and choosing the most appropriate one on each situation.

4.1.3 Service level model

This model consists in a set of OWL-S annotations applied to the web services available in the system. These annotations, modeled in the form of Inputs-Outputs-Preconditions-Effects allow the matchmaker component to find suitable services for the tasks the agents try to enact. This intermediate component allow a dynamic mapping between the tasks and the services, choosing the most appropriate service on the fly. This means different services (with equivalent descriptions) can be chosen for the same task depending on service's availability and performance. For instance, the task *identify_delivery_person* can be performed by enacting the services *id_card_reader* or *domotic_door_iris_reader*.

5. CONCLUSIONS

In this paper we have presented our agent-based approach for assisting an elder in daily routine tasks related to his/her medication needs. The system presents a flexible multi-level architecture able to model the complex interactions among different actors involved in the assisted tasks (see *Section* 4). Actors have different responsibilities and offer or consume different services. Due to the connection among levels, a change in the organisational level can trigger changes both in the coordination level (*via* plan and agent generators) and in the service level (new plans will result in the execution of new tasks and, possibly, the invocation of new services).

Thanks to this approach, new roles, objectives and norms can be introduced in the organisational level, without designer having to perform any modification to the coordination and service levels, as these changes are automatically performed. The system introduced allows for monitoring the different actions performed by the set of actors in order to fulfill the assisted tasks. Deviations from the original plan can be detected, and sanctions or repair actions applied (*e.g.* sending a doctor, or an urgent shipment of medications to the patient).

Intelligent agents, at the coordination level, are an option for providing both exception handling and organisational-normative awareness capabilities to the system. Exception handling is common in other service-oriented architectures, however, most approaches tend to focus on low-level (*i.e.* service) exception handling. The ALIVE approach enables managing of exceptions at multiple levels either substituting services (service level) looking for alternative workflows to connect two landmarks (coordination level) or even looking to achieve alternative landmarks among the same scene (organisational level). Agents at coordination level enable this medium and high-level exception handling, which are not commonly seen in other service-oriented approaches. Regarding organisational normative awareness, making normative agents reason about the workflows (and the tasks included in them) before performing them, and discarding the ones that do not comply with organisational norms, adds organisational awareness to the execution of the workflows. Normative agents come in handy on the presented case, as they can perform reasoning about what actions to perform taking into account both the actions available and the norms defined.

Assistive technologies are applied to support people in their daily life. Most approaches focus solely on the direct interaction between users (in our case, disabled patients) and the assistive tool, but AI has the potential to provide innovative mechanisms and methods capable of taking into account more complex interactions. For instance, such an approach can take into account the important role that third parties may have in user activities, and explicitly reflect the social constraints that apply in the relationship between device and patient. In COAALAS (COmpanion for Ambient Assisted Living on Alive-Share-*it* platforms), organizational and normative structures are used to model the device network around disabled users as societies, along with the expected behavioural patterns, effectively supporting smart assistive tools that integrate in perfect harmony with the humans around them. The result is an assistive society of ambient-aware assistive tools.

The main goal of COAALAS is to contribute to the state-of-the-art in semi-autonomous and intelligent devices for elderly people. The target population for these supporting devices includes individuals who are independent enough to live autonomously in their community. The role of intelligent devices is to maximize their safety and comfort, thus increasing their quality of life and delaying their institutionalization.

Using a combination of these techniques, COAALAS focuses on making devices intelligent enough to organize, reorganize and interact with other actors. Devices have an awareness of their social role in the system – their commitments and responsibilities – and are capable of taking over other roles if there are unexpected events or failures. In short: our objective is to create a society of physically organizational-aware devices able to adapt to a wide range of Ambient Assisted Living situations that could have an impact on the well-being of the user.

We plan to evaluate our approach via tests with disabled patients on a domotic house, as depicted in Figure 5. Still, we already had experiences using Agents to control and environment designed for elders at *Casa Agevole* [7]. This will allows us to asses the real potential of intelligent social aware devices, in comparison to other approaches for Assisted Living. Specially when reacting to unexpected potentially dangerous situations.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] S. Álvarez-Napagao, O. Cliffe, J. A. Padget, and J. Vázquez-Salceda. Norms, organisations and semantic web services: The alive approach. In M. Baldoni, C. Baroglio, J. Bentahar, G. Boella, M. Cossentino, M. Dastani, B. Dunin-Keplicz, G. Fortino, M. P. Gleizes, J. Leite, V. Mascardi, J. A. Padget, J. Pavón, A. Polleres, A. E. Fallah-Seghrouchni, P. Torroni, and R. Verbrugge, editors, *MALLOW*, volume 494 of *CEUR Workshop Proceedings*. CEUR-WS.org, 2009.

[2] S. Álvarez-Napagao, F. Koch, I. Gómez-Sebastià, and J. Vázquez-Salceda. Making games alive: An organisational approach. In F. Dignum, editor, *AGS*, volume 6525 of *Lecture Notes in Computer Science*, pages 179–191. Springer, 2010.

[3] R. Annicchiarico, F. Campana, A. Federici, C. Barrué, U. Cortés, A. Villar, and C. Caltagirone. Using scenarios to draft the support of intelligent tools for frail elders in the share-it approach. In J. Cabestany, F. S. Hernández, A. Prieto, and J. M. Corchado, editors, *IWANN (1)*, volume 5517 of *Lecture Notes in Computer Science*, pages 635–641. Springer, 2009.

[4] R. Annicchiarico and U. Cortés. To share or not to share share-it: Lessons learnt. In M. Szomszor and P. Kostkova, editors, *eHealth*, volume 69 of *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pages 295–302. Springer, 2010.

[5] J. C. Augusto and C. D. Nugent. The use of temporal reasoning and management of complex events in smart homes. In R. L. de Mántaras and L. Saitta, editors, *ECAI*, pages 778–782. IOS Press, 2004.

[6] A. Cesta, A. Oddi, and S. F. Smith. A constraint-based method for project scheduling with time windows. *Journal of Heuristics*, 8:109–136, 2002. 10.1023/A:1013617802515.

[7] U. Cortes, C. Barrue, A. B. Martinez, C. Urdiales, F. Campana, R. Annicchiarico, and C. Caltagirone. Assistive technologies for the new generation of senior citizens: the share-it approach. *Int. J. Comput. Healthc.*, 1(1):35–65, July 2010.

[8] V. Dignum, J. Vázquez-Salceda, and F. Dignum. A model of almost everything: Norms, structure and ontologies in agent organizations. In *AAMAS*, pages 1498–1499. IEEE Computer Society, 2004.

[9] T. P. Foundation. MIT's smart pillbox targets Tuberculosis. `http://www.prajnopaya.org/index.php/component/content/article/39-press-gallery/160-press-article-030308`, 2012. [Online; accessed 02-Feb-2012].

[10] I. Gómez-Sebastià, D. Garcia-Gasulla, and S. Alvarez-Napago. Society of situated agents for adaptable eldercare. *ERCIM news*, (87):23–24, October 2011.

[11] I. Gómez-Sebastià, D. Garcia-Gasulla, C. Barruè, J. Vázquez-Salceda, and U. Cortés. Alive meets share-it : An agent-oriented solution to model organisational and normative requirements in assistive technologies. In *VI Workshop on Agents Applied in Health Care (A2HC)*, Casablanca, Morocco, December 2010.

[12] K. Z. Haigh, L. M. Kiff, J. Myers, V. Guralnik, C. W. Geib, J. Phelps, and T. Wagner. The independent lifestyle assistant (i.l.s.a.): Ai lessons learned. In *In The Sixteenth Innovative Applications of Artificial Intelligence Conference (IAAI-04*, pages 25–29, 2004.

[13] I. I. Health. *u*Box, a Smart Pillbox for TB Treatment. `http://www.innovatorsinhealth.org/solutions/pillbox.shtml`, 2012. [Online; accessed 02-Feb-2012].

[14] V. Medical. The SimpleMed Smart Pillbox. `http://www.vaicamedical.com/en/`, 2012. [Online; accessed 02-Feb-2012].

[15] M. Niemelä, R. G. Fuentetaja, E. Kaasinen, and J. L. Gallardo. Supporting independent living of the elderly with mobile-centric ambient intelligence: User evaluation of three scenarios. In B. Schiele, A. K. Dey, H. Gellersen, B. E. R. de Ruyter, M. Tscheligi, R. Wichert, E. H. L. Aarts, and A. P. Buchmann, editors, *AmI*, volume 4794 of *Lecture Notes in Computer Science*, pages 91–107. Springer, 2007.

[16] G. I. of Technology. Aware Home Research initiative. `http://www.cc.gatech.edu/fce/ahri/projects/index.html.`, 2012. [Online; accessed 02-Feb-2012].

[17] C. Rubio, R. Annicchiarico, C. Barrué, U. Cortés, and C. Caltagirone. itutorials for the support of elderly population with cognitive impairment. In *Proceedings of the 2010 conference on Artificial Intelligence Research and Development: Proceedings of the 13th International Conference of the Catalan Association for Artificial Intelligence*, pages 131–140, Amsterdam, The Netherlands, The Netherlands, 2010. IOS Press.

[18] F. Sadri and K. Stathis. Ambient intelligence. In *Encyclopedia of Artificial Intelligence*, pages 85–91. 2009.

[19] P. D. UN Department of Economic Social Affairs. Population aging. `http://www.un.org/esa/population/publications/ageing/Graph.pdf`, 2002. [Online; accessed 02-Feb-2012].

[20] P. D. UN Department of Economic Social Affairs. World population to 2300. `http://www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf`, 2004. [Online; accessed 02-Feb-2012].