Personalized Robotic Intervention Strategy by Using Semantics for People with Dementia in Nursing Homes

Femke Ongenae[1]**, Femke De Backere, Christof Mahieu, Stijn De Pestel, Jelle Nelis, Pieter Simoens, and Filip De Turck

Ghent University - imec, IDLab, Department of Information Technology, Technologiepark 15, B-9052 Ghent
Femke.Ongenae@UGent.be, Femke.DeBackere@UGent.be,
IDLab.UGent.be

Abstract. The increasing number of People with Dementia (PwD) increases the strain and burden on caregivers in nursing homes. When PwD exhibit behavioral disturbances, they need personalized interventions of the nursing staff, however, the staff only has limited time to spend on these interventions. Within this paper, an Internet of Robotic Things platform and an accompanying robotic intervention strategy are presented that enable the nursing staff to rely on robots to assist them during these personalized interventions.

Keywords: semantics, robotics, intervention strategy, dementia, nursing homes

1 Introduction

Along with the ageing population, the number of people with dementia (PWD) is steadily increasing [1]. The Alzheimer Liga Vlaanderen estimates a prevalence of 100,000 PwD in Flanders. Nursing homes around the globe are pulling out all the stops to provide the best possible care for residents with dementia. Almost all PwD exhibit behavioral disturbances (BDs) [2] like agitation (e.g., wandering or aggression), mood disorders (e.g., depression or apathy), sleep disorders and psychotic symptoms (e.g., delusions or hallucinations). These BDs can be prevented by non-pharmaceutical interventions [3], like personal interaction, revisiting positive personal memories and promoting comfort and quality of life of the PwD. However, because of increased strain on the available resources within healthcare, a dwindling number of caregivers needs to care for an increasing number of elderly [4]. This inhibits the staff from allocating a lot of their time to these interactions.

A robot solution could help to provide such person-centric care by interacting with the PwD in order to prevent and alleviate BDs [5]. By audio-visual stimuli

** The authors wish it to be known that the first two authors should be regarded as joint First Authors or by engaging communication, humanoid robots can elicit memories with associated positive feelings that have a calming effect on PwD. This improves the well-being of the PwD, but it can also be used to temporarily distract the PwD until the staff arrives in acute situations. As manifestations of dementia and the stimuli they react to, vary widely amongst PwD, a personalized approach is required. The key idea is that personalized interaction by robots improves 1) the well-being of residents, thus reducing the prevalence of behavioral disturbances, and 2) can temporarily distract PwD until the alerted staff arrives in acute situations. Personalization is especially important for companion robots, as it has been shown that this leads to more enjoyable experiences for the person and prevents losing interest in in the long-term [6], [7].

In the WONDER project[1], we are developing an Internet of Robotic Things (IoRT) platform to enable personalized robot interactions with PwD to reduce and intercept BDs. In an IoRT platform the robot is integrated in a smart environment outfitted with a variability of sensors and wearables that capture the current context. A semantic cloud back-end then analyzes this captured information and combines it with other context information sources (e.g. profile of the PwD or day schedule of the institution) to extract valuable knowledge about the context and activities of the persons active in it. This derived knowledge is then used to steer the actions of the robot. The IoRT platform autonomously detects whether a BD occurred and determines which actions should be performed by the robot to respond to it in a personalized manner. Although several researchers have looked towards semantics to support the care for people with dementia, none of them focused on the combination of IoT and semantics in order to detect behavioral disturbances and derive the accompanying personalized intervention strategy [8], [9], [10].

This paper brings two contributions. First, the technical architecture of the IoRT platform is presented, together with the knowledge-base that was built up to capture the gathered sensor data, model the environment & context and capture the PwD profiles. Second, the co-design methodology, where researchers and nursing staff join forces to determine the robotic intervention strategy in case of a detected BD, is discussed, together with the resulting personalized algorithms.

2 Internet of Robotic Things Platform

The overall architecture to realize the robotic task assignment platform will be based on the Internet of Robotic Things Architecture (IoRT) [11]. The following subsection will discuss the different components of this architecture.

2.1 Input

Within the platform, data from various heterogeneous sources is gathered. First, sensors are placed within the continuous care setting to monitor the context, for

[1] https://www.iminds.be/en/projects/wonder

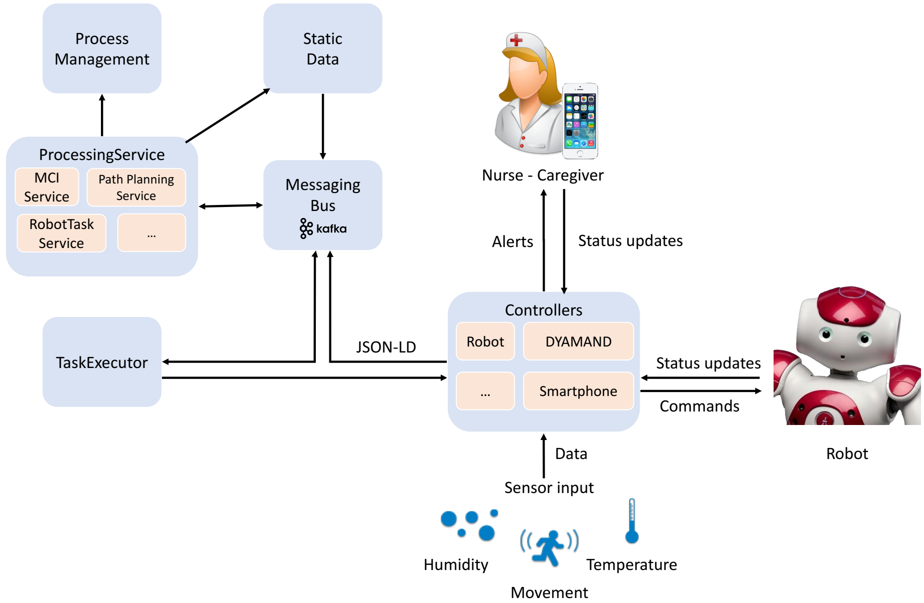

Fig. 1. The architecture to realize the robotic task assignment platform

example, humidity, movement and temperature sensors can be deployed in every room of a nursing home to get an overview of the personal setting of a patient. Moreover, also sensors can be deployed in the common spaces, for example, to track patients and/or caregivers in the hallways by using a wearable. Data produced by these sensors can then also be used to analyze walking patterns or other specific behaviors. Second, the caregivers can make use of smart devices, such as a smart phone or a smart watch, to give status update to the platform or to report irregularities. Third, input can also be expected from the robots that are deployed within the continuous care setting. These robots are equipped with a variety of sensors, which can have valuable input for the system. Moreover, the robot is also capable of sending status updates to the platform, for example,"the patient is currently looking at me and I am calming this patient down".

2.2 Components of the platform

Controllers Data enters the platform through the Controllers. These controllers are responsible for mapping the data from the sensors, robot and caregivers, which is often described using JSON, on a uniform model. These controllers are also responsible for communicating towards the outside world, for example, sending an alert to a nurse or assigning a task to a specific robot.

Currently, three different controllers are defined in this architecture:

- DYAMAND [12]: Sensor data will be transformed in the DYnamic, Adaptive MAnagement of Networks and Devices Controller (DYAMAND). DYA-

MAND maps its internal model onto the Semantic Sensor Network (SSN) ontology [13]. This way, the measured data and the accompanying background information, such as location and unit of the measurement, can be combined into interpretable data for the platform.
- Smartphone Controller: Data originating from smartphones and other smart devices, such as smart watches, will be converted in the Smartphone Controller. This Controller will also use an internal model to map the messages sent to the platform.
- Robot Controller: The Robot Controller is responsible for the translation of all data originating form the robot. All deployed robots will communicate using the same Controller. This data ranges from all sensor registrations to executed actions and tasks.

Similar to these three Controllers, other Controllers can easily be created within this component to support newly defined input sources. All Controllers will publish the received data onto the Messaging Bus, using JSON-LD.

Messaging Bus As data is coming from a wide variety of different sources, the platform needs to cope with a huge amount of data. To make sure the platform is responsive enough and other components do not get overloaded, a Messaging Bus, using a publish/subscribe pattern, was chosen as a central component of the architecture. This Messaging Bus will be deployed in the cloud and implemented, using Apache Kafka [2]. Data published by the Controllers onto the Bus will be distributed to all specific components that have indicated a specific interest in that type of data fragment. This will be done by analyzing the JSON-LD message.

Static Data Not only real-time data will be used within the platform. But also static data, such as calendar information or profile information, has to be accessed. This data is made available through the Static Data component. Updates or new data will be pushed directly to the Messaging Bus, while static data will be directly queried by the specific Processing Services.

Processing Services The Processing Services are at the heart of the platform. These services contain the business logic components of the platform. Each service is responsible for specific functionality and will registered its filter rules to the Messaging Bus to indicated its interest in specific data. There are several examples of different Processing Services:

- MCI Services [14]: Meta Context Information (MCI) Services is a generic name for an atomic, semantic service that will use its own internal ontology and reasoner. As this internal ontology is kept small, this influences the performance and efficiency of the services in a positive manner. Data received

[2] https://kafka.apache.org/

from the Messaging Bus will be reasoned upon and possible findings of these services will be pushed to the Messaging Bus. This enables other Processing Services to use and incorporate the knowledge extracted in another service. Examples of MCI Services for this specific use case are the Behavioral Disturbance Detection MCI Service and the Task Assignment MCI Service.
- Robot Task Service: Within this service, tasks are selected that should be executed by a robot. The dynamic algorithm takes the current context and the personality of the person into account
- Path Planning Service: When the task is created, a robot should be directed towards the person. This is done within this service, using an Environment Model the floor plan of the care institution.

Task Executor Services within the Processing Service component will send out tasks, actions and gained knowledge to the Messaging Bus. The Task Executor will publish a filter rule to indicate its interest in all task information. Once the Task Executor receives a task, this component will decide which Controller is responsible for the execution of the task and delegates this to the Controllers component.

Process Management The Process Management component will be notified of all actions and tasks taken by the Processing Services component. Based on the data that this component receives, decisions can be made to overrule a specific decision, as not all services are aware of the decisions made by other services. For example, when the platform assigns a task to a robot to assist a patient, the Process Management component can decide to cancel this task because of a higher priority task.

2.3 Output

Communication to the outside world will always go through the Controllers. These Controllers are responsible for sending out commands and alerts. If a task needs to be sent to the robot, the Robot Controller will be used, while the DYAMAND Controller can be used for sending actions to actuators or smart devices.

3 Knowledge base

To ideally tune the personalized intervention strategy and interaction with the robot to the PwD, it is important to derive the relevant personal information about the PwD and link it to the current context. However, the context and profile information is provided by a plethora of sensors, devices, databases and software components. A semantic model can ideally be used to consolidate all this information and abstract it to high-level concepts that can be used by the intervention strategy to base its decisions on. Moreover, semantic reasoning can be applied by the various services to derive actionable robot insights out of the consolidation of context and profile data.

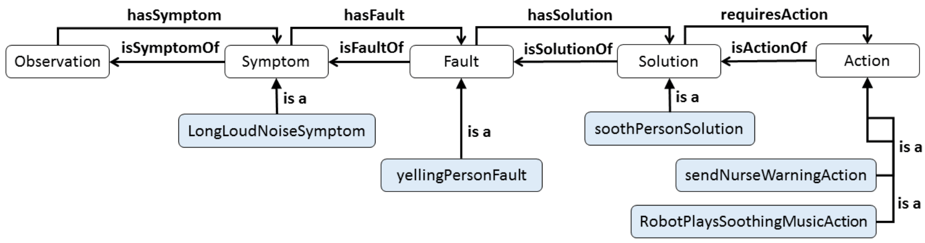

Fig. 2. Observation pattern example

3.1 Capturing behavioral data through sensors and linking to intervention strategy

Data provided by the various sensors & devices in the environment needs to be captured and consolidated to available background knowledge about these devices, their capabilities and set-up within the environment. To realize this, an extension of SSN [3]) [13] was used.

First, all the sensors and devices were modeled which are deployed within the nursing homes in order to track the behavior of the PwDs, e.g., motion sensors, sound sensors, light sensors, wearables, etc.

Next, the SSN was extended with an observation pattern [15], as visualized in Figure 2. The `Observation` class of SSN models observations made by devices and sensors. We added four classes, namely `Symptom`, `Fault`, `Solution` and `Action`. A `Symptom` models specific phenomena that are detected in the `Observations`, e.g., when the sound in a room crosses a particular threshold for a

[3] https://www.w3.org/TR/vocab-ssn/

Fig. 3. Impressions of the co-design workshops

certain amount of time, a `LongLoudNoiseSymptom` is detected. Queries or axioms can then be defined that detect undesirable combinations of `Symptoms` and classify them as `Faults`, e.g., when the presence of a person, who is known to exhibit yelling as a behavioral disturbance, is detected within a room with a loud noise and no other rooms are exhibiting `LoudNoiseSymptoms`, a `yellingPersonFault` is detected. These detected `Faults` can then be coupled to `Solutions` that resolve them, e.g., `soothPersonSolution`. Finally, this `Solution` can be mapped on one or more `Actions` that need to be performed to reach this solution, e.g., `RobotPlaysSoothingMusicAction` or `sendNurseWarningAction`. As such, the various incidents and behavioral disturbances that are detected within the nursing home, can easily be linked to (robot) actions that need to be performed. To model the available robots, their capabilities and actions, is based on the ontologies provided by KnowRob[4] [16].

3.2 Capturing Profile and context data to personalize intervention strategy

To derive which action should be performed in which situation, co-design sessions with the caregivers of the participating nursing homes were organized. These workshops focused on eliciting from the staff which information they take into account intuitively to decide how one should intervene or interact with the PWD. Some impressions of the workshops are visualized in Figure 3.

At the start of the workshop, the participants described a complex situation involving an intervention strategy for a PwD exhibiting a behavioral disturbance, e.g., wandering or yelling. Next, participants were asked to suppose they were an intelligent system that had a complete overview of the current situation. This system takes detected BDs by PwDs as input and is tasked with assessing the priority of the situations and deciding which actions should be taken to resolve them, i.e., ensure that the PwD stops exhibiting the BD. The real life situations described by the participants were used to start the discussions by visualizing them, e.g. the location of the PWD, the BD, the available robots, on a blue print of the work environment of the participants. To gather more context and make an informed decision, the participants asked questions, e.g., who is the PwD? Which BD occurred? Which type of music does the PwD like? What is the time of day? Instead of answering the question, discussions were first held about the importance of the requested info and possible answers the participants envisioned. This way, the researchers could tap into the reasoning made by the participants. The reasoning process of the participants was visualized by the researchers as decision trees in which the formulated questions formed the various nodes and the possible answers indicated the possible branches. The order of the information in the tree reflects its importance, while the different nodes represent the parameters that should be taken into account to reach the robotic intervention strategy. More information about the derived algorithms is detailed in the next section.

[4] http://knowrob.org/ontologies

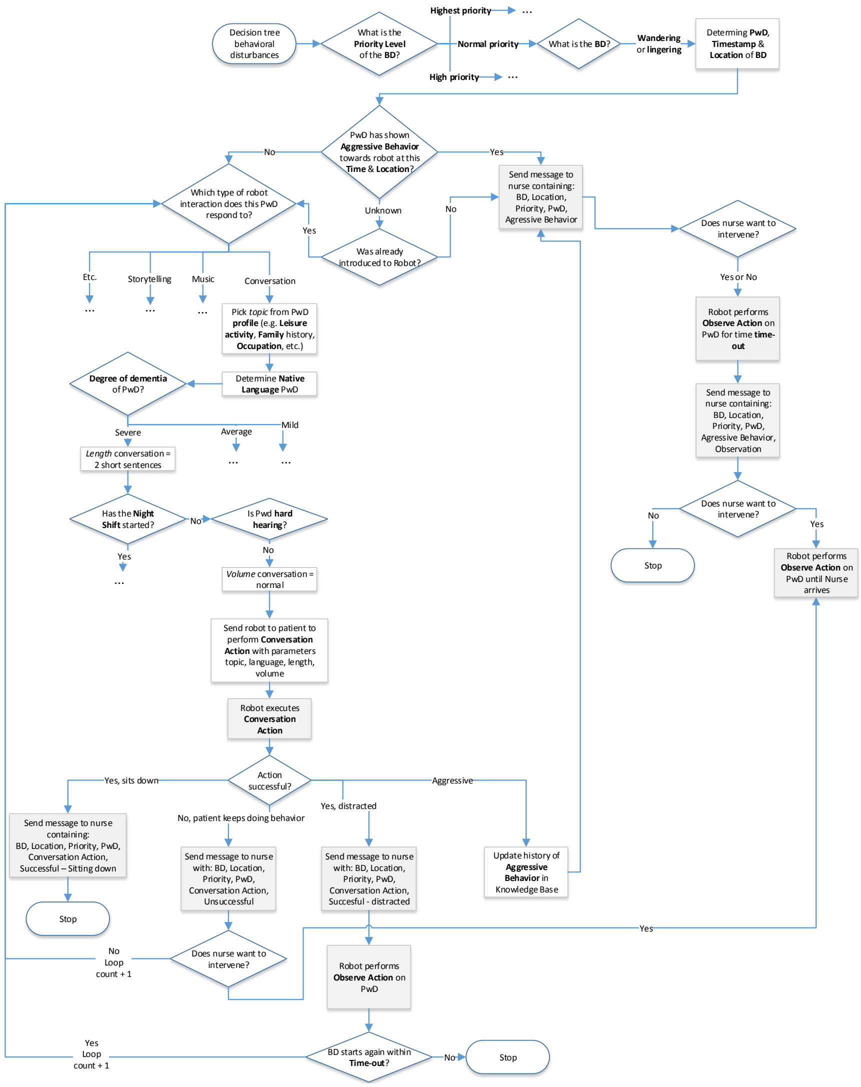

Fig. 4. Example decision tree: normal priority, wandering or lingering

The profile information that was deemed important during the workshop to take into consideration, was modeled as an extension of the Ambient-aware Continuous Care Ontology (ACCIO)[5]. ACCIO is a modular ontology, consisting of 7 core high-level ontologies modeling information prevalent to offering context-aware and personalized healthcare services, namely the Upper, Sensor, Context, Profile, Role & Competence, Medical and Task continuous care core ontologies. It

[5] https://github.com/IBCNServices/Accio-Ontology/

also consists of several low-level care ontologies, modeling knowledge exchanged within nursing homes. These low-level ontologies extend the core ontologies with concepts and relationships specific to these care settings, e.g., specific roles, competences, tasks and pathologies. More information about these ontologies can be found in Ongenae, et al. [17].

4 Personalized & context-aware robotic intervention strategy

To illustrate how this knowledge base, containing the gathered profile and context data, is then used to steer the interventions, an example of a co-designed algorithm is shown in Figure 4. The bold text indicates concepts from the knowledge base.

5 Conclusions

In this paper, we presented the first steps towards a semantic IoRT Platform and how it could be used to optimize the care for people with dementia through personalized robot interventions in case of behavioral disturbances. In future work, we will focus on the design of algorithms for the accurate detection of behavioral disturbances based on the profile and context information captured in the knowledge base of the IoRT platform.

Acknowledgement

The imec WONDER is a project cofunded by imec, a research institute founded by the Flemish Government. Companies and organizations involved in the project are ZoraBots, XETAL, WZC De Vijvers, and WZC Weverbos, with project support of VLAIO.

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