Internet of Robotic Things: Context-Aware and Personalized Interventions of Assistive Social Robots

Pieter Simoens, Christof Mahieu, Femke Ongenae, Femke De Backere, Stijn De Pestel, Jelle Nelis, Filip De Turck
Dept. of Information Technology - IBCN
Ghent University - iMinds
Ghent, Belgium
Email: psimoens@intec.ugent.be

Shirley A. Elprama, Katriina Kilpi, Charlotte Jewell, An Jacobs
Studies on Media, Information, Telecommunication (SMIT)
Vrije Universiteit Brussel - iMinds
Brussels, Belgium
Email: selprama@vub.ac.be

***Abstract*—Assistive service and companion robots are versatile and dexterous actuators that operate in our daily living environment. These robots are able to manipulate physical objects, to displace themselves and to engage in conversations. Human behavior is dynamic and oftentimes unpredictable, therefore it is crucial for such robotic systems to be assisted by a cloud-backend which: i) analyzes data from sensor and wearables ii) determines which robotic tasks need to be executed and iii) provides the necessary support for the execution of these tasks in our daily living environment. In this paper, we present our Internet-of-Robotic-Things system architecture design for a case study on personal interactions by a companion robot to alleviate behavioral disturbances of people with dementia.**

***Keywords*-IoT; robot; intervention**

I. Introduction

The swarm of sensors and wearables in our living environment produces a vast amount of data. From this data valuable knowledge can be extracted about the context in which people find themselves and about their activities [1]. As of today, this knowledge is mainly applied in intelligent mobile and cloud-based software applications. The reverse path from the cyber to the physical world remains far less exploited. Contemporary scenarios are limited to automation algorithms driving thermostats, light armatures as well as service robots such as vacuum cleaners and lawn mowers.

Compared to these single-purpose actuators, assistive social robots are much more dexterous and versatile. The main function of such robots is either to support independent living or to act as a companion [2], a domain growing in importance in view of the ageing population. When such robots are integrated as additional actuator in smart environments (home, office, factory), we create an Internet-of-Robotic-Things (IoRT). The smart IoRT environment analyzes data from sensors and wearables and then infers an actuation strategy to reach the desired environment state. This strategy is dependent on the context, as well as on the functional capabilities and availability of all robotic and non-robotic actuators. For example, when an older person must be notified, the smart home can deliver the message indirectly via the smartphone of visiting family or caregivers when the companion robot (which has a tablet) is unavailable because it is currently charging.

The integration in the Internet-of-Things is not only important to determine *which* tasks must be executed by the robot, it is also crucial for the assistive social robot to *execute* the assigned tasks. The information provided by on-board sensors is not sufficient for a robot to fully grasp the complex and dynamic environment it operates in. Instead, the robot needs to fuse on-board sensor data with information provided by the manifold external sensors, smartphones and wearables.

In view of this tight relation between robots and their environment, as well as the significant computational challenges to interpret the context information, support from a cloud back-end in the IoRT is crucial. In this paper, we present our system architecture for an IoRT cloud back-end platform, applied to a case study we are currently working on regarding technological care support of older adults in nursing homes (NH).

II. Case Study: Personalized Robot Interventions for Persons With Dementia

Almost all persons with an advanced form of dementia exhibit behavioral disturbances (BD) such as mood and disorders, wandering, physical and verbal aggression. These BD impose an enormous emotional toll on the patient, family and increase the burden and stress of caregivers. Empirical evidence suggests that manifestations of BD can be prevented by care strategies that preserve the dignity of persons with dementia (PWD) and promote their comfort and quality of life. For example, activities organized by the NH care staff have the largest effect on reducing the number of BD if they are adapted to the individual's needs, emotions, interests and functional ability and carefully spaced throughout the day [3]. The labor intensity of such person-centric care, combined with downward pressure on health care budgets worldwide, forms a clear need for technological solutions assisting the NH caregiver staff.

A. Technology concept

We are currently building the IoRT service platform visualized in Figure 1. This platform drives personalized interventions of the humanoid care robot Zora[1] in the dementia ward of nursing homes.

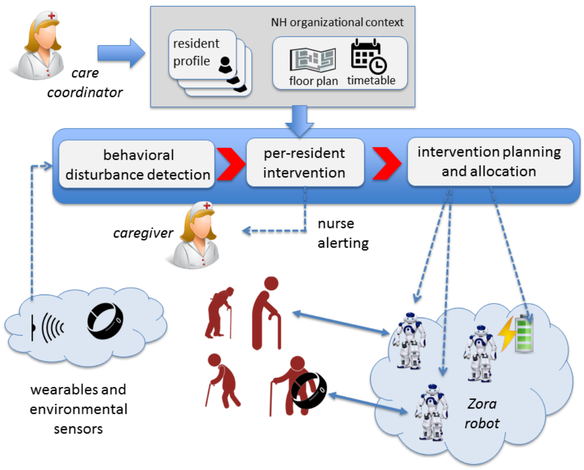

Figure 1. Behavioral disturbances are detected by combining sensor and wearable data with context information. The platform alerts a caregiver or creates a companion robot intervention task. Tasks are scheduled over a pool of robots, taking into account their current position and battery level.

The aim is to have Zora walking from one resident to another, each time engaging in a personalized interaction, e.g. playing a favorite song or asking questions about memorable events in the lifetime of the PWD. As PWD revisit the past more and more, the research hypothesis is whether the robot will be able to elicit positive memories associated with positive feelings, which in turn could prevent or alleviate BD manifestations.

Currently, Zora is used for recreational and therapeutic activities. These are essentially predefined sequences of instructions that are manually activated by the care staff. Our service platform instead embeds Zora in a more structural way in the care process, so as to have one or more robots operating 24/7 without involvement of the care staff. BD manifestations are detected by analyzing sensor and wearable information. These detections are combined with personal information about the residents provided by the care coordinator, as well as organizational context information (menu, floor map, activity and meal timetables) to generate a per-resident intervention strategy. In acute situations, the actuation strategy is to alert the staf or to send a robot to temporarily distract the PWD. In addition, proactive interventions are scheduled collaboratively over multiple robots throughout the day/night (24/7), based on historical knowledge extracted from the sensor and wearable data, and taking into account the limitations of individual robots, e.g. on battery lifetime or walking speed.

[1] www.zorarobotics.be

B. Use case scenarios

Wandering *It's 23:50 and the NH residents are in their rooms. Marie, a PWD, woke up, left her room, and is currently wandering in the hallways. She is known to wander around at times and bother other residents by entering their rooms. As soon as the presence sensors in the NH register that Marie left her room, the Zora robot is instructed to approach her. In the mean time, the nurse on night shift receives a message that Marie left her room but that Zora is on her way to Marie. The robot finds Marie using a combination of tracking sensors and signals emitted by a chip in her bracelet. Zora says to Marie that it is too early to be up and suggests to go back to her room. Marie goes back to her room and the system sends a message to the nurse that Marie is back in her room.*

Screaming *Paul, a PWD, is waiting in the common area of the NH after dinner, while all residents are brought to their rooms one by one by a team of caregivers. Some residents are able to go to their room by themselves, but the majority - like Paul - needs help. Paul raises his voice and calls for the caregivers, but they are busy taking care of other residents and go to him immediately. The calling has been detected by microphones and Zora is walking towards Paul. At the same time, the caregivers on duty receive a message on their smartphone that Paul is calling but that Zora is on her way. Since it is known that Paul likes American music, Zora plays a song of Sinatra. Paul enjoys the song and is distracted, so he stops calling for the caregivers and starts singing along with the robot. Then, the caregivers receive a message on their smartphone that Paul has calmed down and stopped screaming by Zora playing music for him.*

III. System Architecture

Figure 2 visualizes the different modules of our cloud platform. Each module is further discussed below.

A. Sensor and wearable data input layer

This layer provides the necessary input data to accurately detect and predict BD manifestations, and to assist the humanoid robots in their personal interventions. We have installed GrovePi+ gateways at various places in two NH participating in this project. The installed sensors capture data relevant for the two use cases described, as well as additional context information so as to identify possible patterns and triggers of BD manifestations. To hide the different protocols and interfaces of the installed sensors, we leverage on our DYAMAND middleware [4].

Wandering behavior is an umbrella term for various in-room and out-of-room movement patterns, and can be captured using indoor localization techniques [5]. Because PWD are removing body-worn sensors and wearables, we

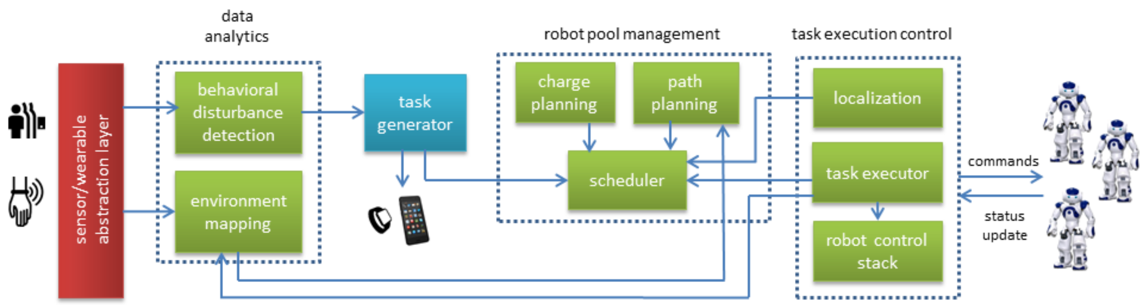

Figure 2. Technical architecture of our IoRT service platform, comprising five modules.

are experimenting with positioning sensors placed on walls[2], complemented with Bluetooth Low Energy tags attached to wheelchairs and rollators. Screaming can be detected by measuring the sound level in various parts of the NH. Additional sensors provide context information on room presence, temperature and humidity.

B. Data analytics (DA)

This layer is responsible for translating raw sensor data into meaningful context information. It is comprised of two modules, one for the detection of BD manifestations and one to track the robots, NH residents and caregivers.

In the first module, state-of-the-art probabilistic pattern recognition algorithms for BD detection [6] are combined with reasoning algorithms on an ontology-based context model. The ontology is an extension of the Ambient-aware Continuous Care Ontology [7], with specific knowledge needed in the BD domain, such as the observations made by the sensors and their interrelationships, the spatial layout of the NH, the time of day, the activity schedule, and the profiles of the elderly, e.g., which BDs they exhibit, preferences and needs, severity of dementia. To implement this context- & profile-aware algorithm, the MASSIF platform [8] is used for semantic annotation of and reasoning on IoT data.

The second DA module is the environmental mapping. This component enriches the floor plan of the building with information that is particularly relevant for the robotic path planning. Zones such as a bathroom are inaccessible for the robot for privacy reasons. Other regions should only be accessed under very specific conditions. For example, robots underneath a table might surprise older adults, yet this region can be used in case the robot must rapidly free the way for an approaching older adult. All this information is encoded as annotations to the floor plan. The floor plan is also updated based on dynamic information, e.g. doors being closed, residents moving around, etc.

C. Intervention Task Generation (ITG)

This component determines the appropriate IoRT actuation strategy, based on the context, type and priority of the BD detected. The algorithms are also implemented with the MASSIF platform using the same ontology as the DA component. Possible actuations are alerting caregivers or robotic tasks. For example, when the algorithm detects with a low probability that somebody is wandering in the hallway, but the identity of the PWD is difficult to assess, the intervention could consist of sending the robot to the scene in order to gather additional information through its camera and through conversation. On the other hand, when aggressive behavior of a PWD is detected, a better intervention is to immediately alert the staff. The type of intervention also depends on the PWD and on the context. Some PWD might respond better to particular types of interactions (conversation, playing music), and the sound level of the robot should be adapted to the degree of PWD hearing impairment as well as to the time of the day. Variation over time should also be taken into account, to ensure long-term interest of the PWD in robot interaction. Lastly, the platform's intervention strategy also comprises pro-active robot tasks, e.g. the robot should visit each PWD two times a day, or it should announce the news item of interest to the PWD each morning.

D. Robot Pool Management (RPM)

The RPM module is responsible for scheduling the personal intervention tasks over the set of robots deployed in the NH, taking into account priorities and robot availability.

The scheduler receives interventions tasks from the ITG, as well as other types of tasks, such as to return to a charging station, or to take an evasive maneuver when encountering a resident. The actual execution of the tasks is delegated to the Task Execution Control Module. Decoupling the task planning from the task execution is necessary because robots are frequently taken out of the system, e.g. because they are used for therapy, have lost Wi-Fi coverage or are locked up by a closed door. In these cases, the tasks assigned to that robot will be redistributed. The scheduler is supported by two planning services.

Charging needs to be planned carefully to ensure 24/7 operation without manual interventions from the NH staff. Two robots cannot be connected to the same charging station at the same time, and a robot should have sufficient

[2]provided by another project partner, see www.xetal.net

remaining battery capacity to move from its current position to the selected charging station. It is also important to have a sufficient number of robots available with an acceptable battery level at all points in time in order to respond adequately to acute BD manifestations.

Path planning identifies the most appropriate trajectory for a robot to move from point A to point B. It takes input from the environmental map, avoiding areas as needed. Approaching a person needs to take additional considerations into account, such as the estimated position of a wandering older adult by the time the robot arrives, and the angle of approach to avoid scaring someone. This might require a continuous refinement of the path based on input from the sensor and wearable abstraction layer.

E. Task Execution Control (TEC)

This module governs the execution of tasks by the robot that was selected by the scheduler. Because of the unreliability of the wireless connection and the limited on-board robot resources, tasks are converted in event sequences. For example, if the robot is instructed to approach person X, we will not load the entire path onto the robot. Instead, we identify a number of waypoints on the path for the robot to report back to the platform and receive the next path segment. If the robot crosses an older adult, it will step aside, temporarily suspending the task execution. Once arrived in the room of the target of the intervention task, the platform will activate and configure the correct robotic software module. Internally, the module contains one controller per attached robot. This controller can be seen as the robotic counterpart of the sensor abstraction layer, as it hides the proprietary data structures and commands to steer a particular robot. The controller also acts as a connection daemon, throwing an unavailability exception to the scheduler if the connection to the robot is lost, or if the robot is temporarily taken out of service, e.g. because it has been picked up by a therapist to assist in rehabilitation exercises or has been locked in a room by someone inadvertently closing a door.

IV. Related work

Cloud robotics is an active research topic in the domain of ambient assisted living. To tackle the inherent heterogeneity of the end-user population, their housing arrangements, their individual situations and requirements, in [9], a cognitive robot approach is presented that is centered around the concept of robotic ecologies, consisting of sensors, actuators and robots. The main focus is on automatically detecting changes in the user's habits and evolving care needs. In the Robot-Era project, cloud services for user localisation, care reminding and environmental monitoring have been developed [10], [11]. Our work builds on these results, focusing on behavioral disturbances of persons with dementia. To this end, we will take an even more personalized and context-aware intervention approach: the strategy to achieve a specific goal are adapted to the specific situation and to the individual's preferences. We will also include a multi-robot planning aspect in the intervention strategy, with charging cycles being taken into account to ensure a 24/7 operation.

V. Conclusion

The Internet of Robotic Things is a new paradigm that combines the computational power of the cloud and the context information provided by sensors and wearables to intelligently define robotic tasks and support the execution thereof. We are currently working on the realization of a use case on personalized robot interventions to alleviate behavioral disturbances of PWD.

Acknowledgment

The work in this article is partially realized in the WONDER project, co-funded by iMinds and Agentschap Innoveren & Ondernemen. Project partners are iMinds, ZoraBots, Xetal, WZC De Vijvers, WZC Weverbos.

References

[1] E. A. Lee *et al.*, "The swarm at the edge of the cloud." *IEEE Design & Test*, vol. 31, no. 3, pp. 8–20, 2014.

[2] J. Broekens *et al.*, "Assistive social robots in elderly care: a review," *Gerontechnology*, vol. 8, no. 2, pp. 94–103, 2009.

[3] A. K. Desai *et al.*, "Behavioral disturbance in dementia," *Current psychiatry reports*, vol. 14, no. 4, pp. 298–309, 2012.

[4] J. Nelis *et al.*, "Dyamand: dynamic, adaptive management of networks and devices," in *Local Computer Networks (LCN), 2012 IEEE 37th Conference on*. IEEE, 2012, pp. 192–195.

[5] N. K. Vuong *et al.*, "mhealth sensors, techniques, and applications for managing wandering behavior of people with dementia: A review," in *Mobile Health*. Springer, 2015.

[6] F. Palumbo *et al.*, "Multisensor data fusion for activity recognition based on reservoir computing," *Evaluating AAL Systems Through Competitive Benchmarking, Communications in Computer and Information Science series*, vol. 386, 2013.

[7] F. Ongenae *et al.*, "An ontology co-design method for the co-creation of a continuous care ontology," *Applied Ontology*, vol. 9, no. 1, pp. 27–64, 2014.

[8] P. Bonte *et al.*, "The massif platform: a modular & semantic platform for the development of flexible iot services," *Knowledge and Information Systems*, 2016.

[9] M. Dragone *et al.*, "A cognitive robotic ecology approach to self-configuring and evolving aal systems," *Engineering Applications of Artificial Intelligence*, vol. 45, 2015.

[10] M. Bonaccorsi *et al.*, "Design of cloud robotic services for senior citizens to improve independent living and personal health management," in *Ambient Assisted Living*. Springer, 2015, pp. 465–475.

[11] ——, "A cloud robotics solution to improve social assistive robots for active and healthy aging," *International Journal of Social Robotics*, pp. 1–16, 2016.