Towards a System for Aged Care Centres based on Multiuser–Multidevice Interactions in IoT Collectives

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ABSTRACT

This paper explores a possible use-case of creating an integrated multiuser-multidevice interaction (2MUDI) model in IoT collectives, in particular, in an aged care centre environment. A prototype has been designed and developed, which has given a name KATE. The system comprises Internet-connected robot(s), multiple mobile devices and multiple users. Family members of the seniors admitted to aged care centres can monitor the seniors via the robot. Staff members, including doctors and nurses, who look after these seniors can also interact with and use the robot(s). This data can also be accessible by family members via an application on their mobile devices. This work has modelled complex interactions and considered the implementation challenges, societal implications in a 2MUDI system and demonstrate its applicability with the KATE system.

KEYWORDS

IoT, human-device interaction, multihuman-multidevice interactions, aged care centre

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1 INTRODUCTION

With the advancements in Internet of Things (IoT) technology, this research increasingly seeing systems that comprise of multiple connected devices with computational ability, sensors, and actuators, with multiple users involved. For instance, a modern home can contain various IoT devices and appliances such as personal computers, smart TV, smartphones, digital photo frames, smart lighting, home-robots, Amazon Alexa and Google Home. In such environments, smart home control hubs such as Google Home are being increasingly used to connect to, and interact with collections of other IoT devices and appliances, by multiple users (e.g. different family members living in a single home). In this paper, such systems are defined as 'IoT collectives'.

In this research, how users interact with these devices within IoT collectives and how these devices handle interactions from multiple users is referred to as multiuser-multidevice interaction (2MUDI), which is the focus of this work.

The aim of this research is to develop a system for aged care centres based on 2MUDI in IoT collectives. IoT devices (including robots) can function as sensors and actuators in an aged-care centre to help family members monitor the condition of the elderly in the aged-care centre. Recently, Australian news reports show that abuse of the elderly in aged-care centres by aged-care workers (or "carers") can happen. Hence, it is important for family members to be able to check up on the condition of their loved ones remotely. This motivates the need for a family member to have a means to communicate with not only the elderly person but also control the IoT devices (e.g., a robot) in the aged care home (e.g., via a smartphone app).

Given that smart devices are used in most aged-care centres, it would be good that they have multiple users, not just for the family member – they can be used by carers working at the centre to help with their work and even by the elderly person him/herself – motivating the need for multi-user interactions with the IoT devices. To this end, a holistic system for aged care centres based on 2MUDI using Temi[1] robots is investigating in this paper.

The rest of this paper is organised as follows. §2 provides the background of this work and reviews related work on robots in aged care centres. §3 provides an overview of the KATE system, including its concept and prototype implementation. §4 discusses further challenges and future work. §5 concludes the paper.

2 BACKGROUND AND RELATED WORK ON ROBOTS IN AGED CARE CENTRES

The world's population is aging and many of the developed countries are creating new aged-care paradigms where IoT can be utilised

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[1]https://www.robotemi.com/

to assist elderly people in living a healthy life [1]. In particular, robots are playing a crucial role in aged care by assisting elderly people in creating social interactions, managing disabilities, overcoming stress and depression, and developing remote visits to aged care centres.

There are various studies focusing on human-robot interactions. The survey [1] presents the different types of robots and their functions. For example, *AIBO* is an entertainment dog-like mobile robot that plays with elderly people to enhance the quality of their life, *Bandit* a humanoid torso robot used in cognitive games and social aid, *iCat* a catlike robot to engender facial expressions either sad or happy, *Paro* an animaloid robot to benefit elderly people with its psychological, physiological and social effects by maintaining long term communication and likewise, many other robots to assist elderly people, thus enhancing the quality of their life.

Kachouie et.al [1] pointed out some challenges with user expectations of thinking if having an interaction with a robot is worthwhile. For instance, the stakeholders (families, staff members, nurses, etc.) who have different expectations about the technology used. Therefore, it is important to build systems that are commonly acceptable to the users. Khosla et al. [2] introduced a social robot, *Matilda*, which can interact with elderly people suffering from dementia in aged care centres. *Matilda* can create a joyful environment by providing its services to elderly people such as Bingo and Hoy games, Music and Dancing, Quiz and storytelling, reminders, weather forecasts and other information. Having such a social robot can enhance the quality of life of elderly people suffering from dementia but it is also important to check if the elderly person is comfortable with having such interactions.

Some studies introduced robots that can assist elderly persons in their daily living activities. For example, Lammer and Huber [4] illustrated in their paper about Hobbit robot that can interact with elderly people to improve their participation in daily life activities. Likewise, Tanaka et al. [5] designed the *Kabochan Nodding* communication robot that can improve cognitive activities of elderly people. Tatsuno et al. [6] presented a remote visitor robot that can attend conferences and visit an aged care centre. The robot can move to a particular location and perform different tasks such as switching on the television, activating Skype calls, etc.

Besides the elderly, some research has also considered staff members in aged care centres. Koceski and Koceska [3] demonstrated a telepresence robot that can support carer staff members in their care to lessen the workload, as well as help the elderly in activities of daily living. A two-way video functionality created in the telepresence robot allows seniors having a chat with their friends and family to strengthen social interactions. Interestingly, this study evaluates user acceptance rate of the developed telepresence robot which resulted in a positive response. They collected user feedback of using the robots for both social and medical purposes.

Similarly, Wang et al. [7] presented robots that can assist caregivers and older adults with Alzheimer disease in their routine activities. Robots were embedded with the functionality of assisting elderly people with Alzheimer's disease, in washing their hands in bathroom, making a cup of tea in the kitchen, etc. These robots could also help caregivers in their tasks to decrease their workload or burden. Unfortunately, seniors in this study were not quite accepting these robots but caregivers were happy to use them as they helped with managing their daily workload.

Human-IoT/Robot Interaction is featured in several studies; but involving multiple smart objects to create an interaction among them with multiple human users remains a challenge. To address such a problem, this paper explores multi-user interaction with smart things (e.g., a robot) via the development of the KATE system which is described in next section.

3 KATE: THE MULTI-USER AND MULTI-DEVICE INTERACTION SYSTEM

In this section, the conceptual design and implementation of the KATE system is described.

3.1 Concept

The main idea behind the development of the KATE system is to show how complex interactions (multiuser and multidevice) can be modelled in an aged-care centre. In the KATE system, there are multiple smart devices including multiple Temi robots, smartphones and sensors. The main users of KATE are family members who have admitted their seniors in the aged-care centre, seniors who are in the centre, and the staff members who take care of these seniors. Figure 1 illustrates the various components of the KATE System.

There are three different mobile applications (apps) developed. One for the family members, the second for the carers and the third for the Temi robots. Family members who have admitted their seniors in aged care centres can use their mobile app to instruct Temi robots located in the aged care home to track their seniors. Carers can use their mobile application to instruct the Temi robot to visit them and store senior's health data that will be accessible to the family members through their mobile app. Carers can also interact with the robot directly through its interface. Family members and carer members can also retrieve tracked data stored by the Temi robots on the server.

In this context, multiple IoT devices are involved, e.g., smartphones of the carers, and family members and the robots, and potentially, other sensors in the aged care home. The system is distributed, comprising the apps on the smartphones of carers and family members to enable interaction with the robot, the app running on the robot (enabling appropriate interaction behaviors) as well as interaction with the senior, and software for additional sensor infrastructure. Developing such multi-device multi-app applications with multiple users can be complex to model.

While this paper has use the illustration of a robot in this work, the device could be any other IoT device with similar capabilities (e.g., smart camera or smart robotic arm), and sense the user, and be remotely controlled. The development of a preliminary "vanilla" prototype has been done to illustrate and demonstrate the idea discussed in this paper.

3.2 Prototype Implementation

Figure 2 shows an active Temi robot. The software version installed is 120.07 with launcher OS 13377. The Temi robot collaborates with multiple users (family members, seniors and carer members) using

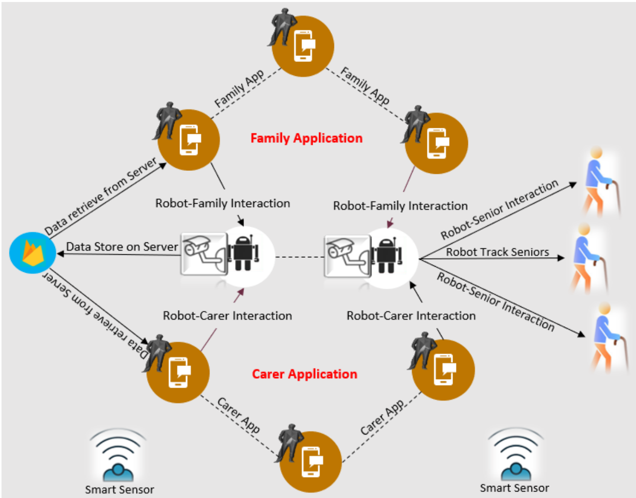

Figure 1: The KATE System

Firebase[2] database references and handles multiple requests (from family members and carers) using a simple queuing algorithm, First In First Out (FIFO) with priorities. The prototype illustrates the idea of how an Internet-connected device, i.e. Temi robot, can handle multiple users and interact with them simultaneously. It also demonstrates how users can interact with such smart connected objects using their mobile devices.

Figure 2: A Temi Robot

3.2.1 Targeted Devices and Device Features. An Internet-connected robot and multiple mobile devices are used to facilitate interactions between family members, seniors, staff members and devices themselves. It is assumed that the robot is located in an aged-care centre and can be used to track different seniors through commands provided by families (e.g., sitting at home, away from the aged-care centre) using their mobile phones over a communicating medium i.e. WiFi; tracking in this case simply means sending the robot to where the senior is and taking a photo or asking some questions, as opposed to following continually though this is possible if the senior uses the Follow-Me feature on the robot. Similarly, staff members of the aged-care centre through their mobile devices use KATE to issue commands to a robot to move and visit them to store seniors' health data – an assumption of usage made here though there are other ways to store such data. The features implemented in the Temi robot are:

- Take a senior's photo.
- Ask routine questions to seniors such as "have you done your regular exercise?", "Have you eaten?" and "Have you taken your medicine on time?"
- Store all answers provided by seniors as well as captured photo (of senior) on the server.

This prototype is based on a Temi robot but multiple robots can run the same Robot app been developed.

The features implemented in mobile applications are:

- Families can use their mobile app to ask the robot to track their seniors admitted in aged care as well as retrieve their data (seniors' photo and their routine answers).
- Carers (Staff members) can use their mobile app to ask or summon the robot to visit them in their current location where the carer will pass the health measurements to the robot and it will store those measurements on the server. A carer can also retrieve health measurements of any senior anytime.

3.2.2 Stakeholders. The intended users in this use-case scenario are aged care staff members, family members and the seniors. As mentioned earlier, aged-care staff members and families can control the robot by sending multiple commands through their mobile devices (via app). Similarly, seniors can also interact with the robot by answering questions. They can also utilise the Follow-Me feature on Temi robots to follow them. Figure 3 illustrates these interactions.

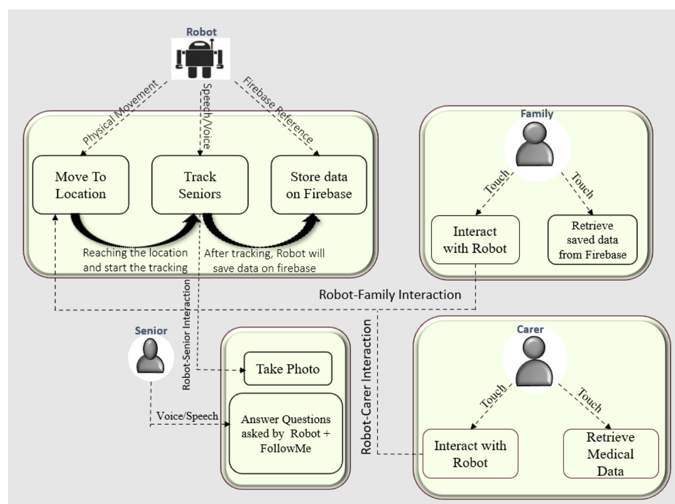

Figure 3: Prototype Design of KATE System

A video of KATE in operation (in mock-up scenario) is available.[3]

[2]https://firebase.google.com/

[3] See https://www.youtube.com/watch?v=XKd4DuQ7nMU In the video family members request Temi to track their seniors. Temi moves to the senior and asks permission to record their responses. Responses are saved to be accessible by family members. Carers send commands to Temi to come to them and store health measurements from seniors. Again Temi first takes permission before storing the measurements. If there is

3.3 Modelling Multiple Interactions in KATE

There are three different interactions created in this prototype: (i) Robot-Family Interaction, (ii) Robot-Carer Interaction and (iii) Robot-Senior Interaction. Each Interaction is modelled using State transition diagrams as showed in Figure 4 and Figure 5.

3.3.1 Robot-Family Interaction: The state machine in Figure 4 illustrates a number of actions and states of robot-family interaction.

Family states and actions: To start an interaction, the family member has to open the mobile app. The state *waiting for user input* will start on action of opening the app. Next, the *senior name selection* is a state that will allow the family member to select a senior name and send the request to track this senior to the robot. Once the request is sent to the robot, *waiting for robot* state will allow the family member to wait till the robot completes its job of tracking the senior. After this, the *robot responding* is a state that will send a message to the family member about the robot's job completion status. At this stage, in case the family member wants to retrieve tracked data, then, *date inputting* is a state where the family member can enter a date of the day they want to retrieve the tracked data and will then, be able to see data in the *data showing* state. Lastly, the family member can either close the app or issue another command.

Robot states and actions: When a family member sends a request to the robot to track a senior the robot will start actions that will change its state accordingly. On receiving a family request, the *robot activating* state will begin that will take robot to the next state which is *examining request*. The robot has to examine the requests it has in the queue. In case it is a family request, the robot will start executing it in the *processing family request* state. To process a family request, the robot will start moving to the senior's location, but where a condition is set which is, if senior is not located then, the robot needs to come back to the *examining request* state where it can see the next request to execute. Otherwise, when it finds the senior, it can move to the next (super-)state which is an *interaction*. In the interaction, the robot will start asking some questions. Here *waiting for the senior answers* is a state where the robot waits for the senior to answer. On receiving senior answers, it will start another state i.e. *processing senior answers* that will allow the robot to store and save all answers in the database so that, family can retrieve this data later. In case the senior wants to command the robot to move with him/her, then the robot needs to be in the *robot following* state followed by waiting for senior's command state. If *robot following* state aborts, then the robot will move back to the *examining request* state and continue with executing the next request.

3.3.2 Robot-Carer Interaction: The state machine in Figure 5 illustrates a number of actions and states of robot-carer interaction.

Carer states and actions: Carer member needs to open the app to start an interaction. The state *waiting for user input* will start on opening the app. Carer member can retrieve data or interact with the robot after the *Carer ID selection state*. To interact with the robot, the action of ID selection will send a request to the robot in *request sending* state. Next, the *waiting for robot* state will let the carer member wait for the robot's response in which the robot will move to carer's location. Once the robot responds, the state of the *robot responding* will start that will take the carer member to *data retrieving* or move back to *waiting for user input* state. To retrieve data, carer member has to make a selection of senior's name and start inputting a date.

Robot states and actions: When the carer sends a request to the robot, then the robot will start taking some actions that will change its state accordingly. On receiving carer's request, *robot activating* state will begin that will take the robot to next state which is *examining request*. The robot has to examine the requests it has in the queue. In case of a carer request, then the robot will be in the *processing carer request* state. To process carer's request, the robot needs to start moving to the carer's location. If the carer is not located in his/her location, then the robot will move back to the *examining request* state. Otherwise, it will move into the next state which is an *interaction* with the carer. In an interaction state, the robot will wait to receive data from the carer and then move into next sub-state which is robot collecting data. Once completed, the robot moves back to the *examining request* state for the next request.

3.3.3 Robot-Senior Interaction: The state machine for this interaction is similar to Figure 4. In this example here, there is little difference between robot-family and robot-senior interaction as it is clear from the state machine diagram that the family will interact with robot to command it to track the senior and to have an interaction with the senior. The only difference in both interactions is that the senior can also command the robot to follow him/her, where the robot goes into the *robot following* state.

3.4 Mobile applications

There are three mobile applications are developed in Android: Family App, Carer App and Robot App (Temi uses the Android OS). Family-app and Carer-app run on mobile devices while the Robot-app runs on the Temi robot. Screenshots of the interface of each application is shown in Figure 6.

Firebase Database: Seniors admitted to aged care centre are registered in a Firebase database. Similarly, the carers' (staff members) data is also stored in the Firebase database. Figure 6 shows the database structure.

Family App: A family member can use the family app installed on their mobile devices to track a selected senior using KATE via a robot located in the aged care centre. On receiving a family request, one of the robots will start moving to the location where the senior is located (note that it is assumed that there is a positioning system for seniors, which is not detailed here). If the senior is found on location, then the robot will first take the Senior's photo proceeding with some questions (e.g., Have you done with your regular exercise? Have you eaten? Have you taken your medicine on time?). The senior will answer each question and Kate will record those answers using its built-in voice recorder to store them on the server. Next, the status of request completed will be sent out to the Family app that can be accessible through the button i.e. "check status" on the mobile interface. If status is "completed" then the family member can enter the date to retrieve the tracked data saved on the server.

a hurdle on the way, it notifies this to family members. An implementation of a queuing algorithm with priority is shown to work as well as sending messages to family members about the request completion status. Temi is handling multiple requests and operating as required.

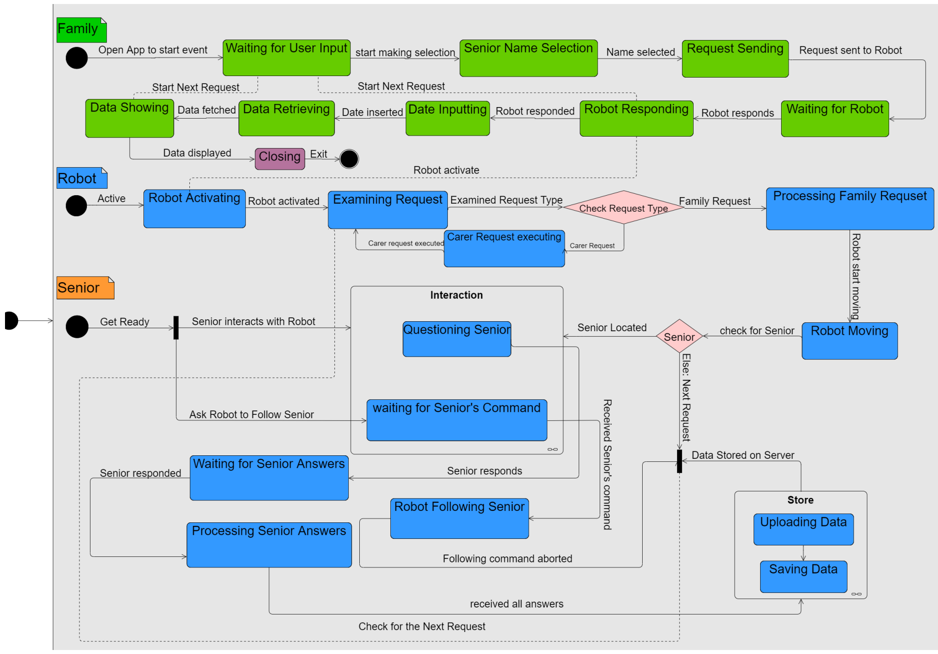

Figure 4: Robot-Family Interaction

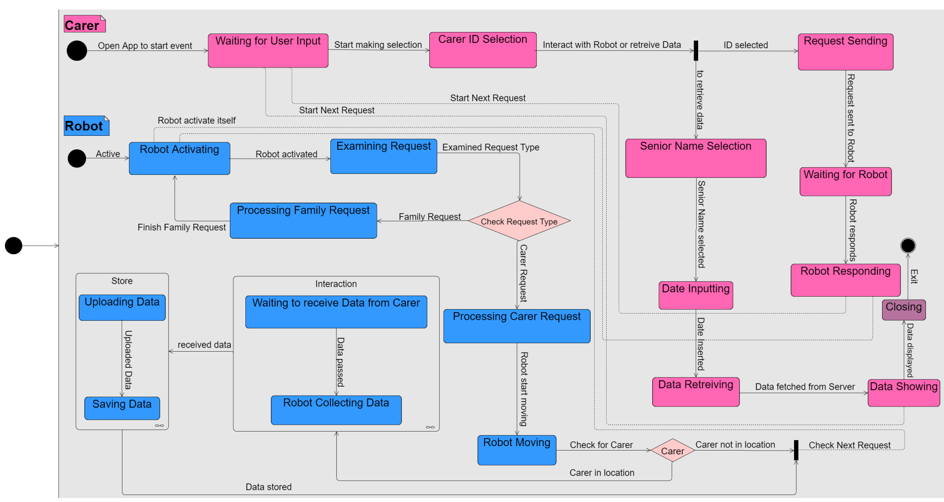

Figure 5: Robot-Carer Interaction

The camera button will let the family see the photo of their senior captured by the robot and the remaining play buttons will let the family hear the voice notes of their loved-ones recorded by the KATE system during a robot-senior interaction. The family member can also retrieve previous interaction data.

Carer App: Carer or staff member of aged care centre can use the carer app to summon the robot. Once the carer ID is selected via the app, the system will check where the staff member is located and send a robot to that location. Next, if KATE is processing a family request then carer requests will be moved to the waiting queue to be processed after the family request finishes - KATE prioritises family requests before carer requests. To execute a carer request, the robot will start moving to the carer's location and check if the carer is there, and if so, then it will start collecting data (eg: senior's blood pressure and sugar levels) from the carer and save the data on the server.

Robot App: All requests move to the queue for KATE, which processes each request one after the other based on priorities. Moreover, seniors located in the aged care centre can use a button on the robot's screen, i.e. Follow-Me, that will make the robot follow the senior and have a conversation with them. Once the senior aborts the Follow-Me feature, the robot can move back to examining its queue for the next request to execute.

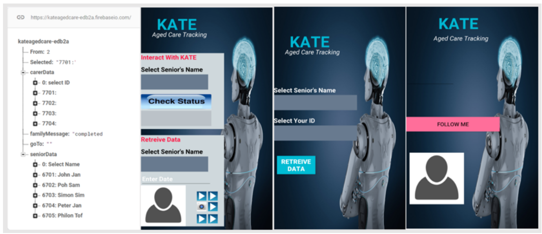

Figure 6: Firebase database structure, Family, Carer and Robot mobile application interface

4 DISCUSSION AND CHALLENGES

The vanilla prototype implementation illustrates how smart devices (e.g., robot, mobile phones) can manage multiple requests from multiple users (families, carer staff members) but there is a need to add functionalities as noted below.

Device/robot decision-making transparency. Robots need to make decisions in their daily operation given that they can be used by different family members or carers, as well as by the elderly person him/herself. For example, if there are six elderly people who need to be tracked by multiple robots throughout the day then the robots have to make a decision on which elderly person they have to track first or if the tracking can be interleaved, and if so, in what way. Also, conflicts can happen where the family member, carer and senior want the robot to do different things. The robot will also need to keep its users (e.g., family members who are using the robot via remote connections, carers etc.) informed of its decisions and decision-making processes, and be transparent to human users about its behaviors.

Device/robot behavioural robustness - handling of uncertainty and hindrances in task completion and network/device failures. The robots need to deal with uncertainties and hindrances to accomplishing certain tasks, or if there are network failures. For example, a robot is starting to track an elderly person, and facing some uncertainties and hindrances to them accomplishing the task, such as the door to the location where the elderly person is to be tracked is closed, the robot needs to handle such situations, have a means to fail gracefully or to feedback appropriately to the person (e.g., family member) issuing this directive; the robot will need to keep its users in the loop in such circumstances. A robot might also delegate its task to other robots when it cannot accomplish a task due to some constraints.

Device/robot socially appropriate interaction behaviours. The robots need to interact with humans in the aged care home appropriately. For example, a robot needs to be privacy-respecting, when a robot wants to track an elderly person but if the elderly person does not want to be tracked then the ethical behaviours around robot actions need to be triggered. Each action must trigger a consent-seeking process, e.g., to seek approval before actually tracking or taking a picture of the elderly person. Also, if a robot is tracking a senior then the senior must have awareness of the robot's actions (e.g., that it is tracking the senior at that time, even if the senior previously approved of it) as cooperation and awareness need to be considered. Also, while a robot is moving through the aged care home, it might need to be polite and say "excuse me" and warn others along its way and move in a safe speed, slowing down or stopping when needed. Note that privacy-respecting and politeness are two behavioural modules that the device/robot needs to trigger in such circumstances in their interactions with people in the aged care home. Apart from a robot, similar socially appropriate behaviours are also needed for smart devices, e.g., a fixed smart camera might be instructed to take photos of a senior, but will be better if it asked the senior first for permission in doing so, e.g. "your daughter wants to take a photo of you, is that ok?" and so on.

IoT devices in the aged-care home might be remotely controlled by family members outside of the aged care home and by different users, and so, there is a need to manage such control, supporting principles such as privacy respecting, social norms (e.g., politeness), device behaviour transparency and device robust behaviours. While the prototype robot app can handle decision making transparency at some level by reporting status of tasks as well as asking permission from the senior before taking any action (e.g., tracking them), there is a need for a more comprehensive approach.

5 CONCLUSION

The KATE prototype shows how different devices can interact with multiple users, and brings out a range of issues to consider. Smooth interaction across devices and users in IoT collectives is important. Placing robot(s) as a mediator between family members and seniors, while allowing them to be used by carers can be useful. Seniors could ask the robot to contact a family member as well, and so on. But they need to work together with other smart devices, and the use by multiple parties (senior, family members, carers) should be to maximise the utility of such devices. Using Temi robot(s) is useful as it has reduced installation of multiple cameras in each room. Further work is needed to handle uncertainty, increase decision-making process transparency, and realise privacy respecting behaviours.

REFERENCES

[1] Reza Kachouie, Sima Sedighadeli, Rajiv Khosla, and Mei-Tai Chu. 2014. Socially Assistive Robots in Elderly Care: A Mixed-Method Systematic Literature Review. *International Journal of Human–Computer Interaction* 30, 5 (2014), 369–393. https://doi.org/10.1080/10447318.2013.873278 arXiv:https://doi.org/10.1080/10447318.2013.873278
[2] Rajiv Khosla, Khanh Nguyen, and Mei-Tai Chu. 2017. Human Robot Engagement and Acceptability in Residential Aged Care. *International Journal of Human–Computer Interaction* 33, 6 (2017), 510–522. https://doi.org/10.1080/10447318.2016.1275435 arXiv:https://doi.org/10.1080/10447318.2016.1275435
[3] Saso Koceski and Natasa Koceska. 2016. Evaluation of an Assistive Telepresence Robot for Elderly Healthcare. *Journal of Medical Systems* 40 (2016), 1–7.
[4] Lara Lammer, Andreas Huber, Astrid Weiss, and Markus Vincze. 2014. Mutual Care : How older adults react when they should help their care robot.
[5] Masaaki Tanaka, Akira Ishii, Emi Yamano, Hiroki Ogikubo, Masatsugu Okazaki, Kazuro Kamimura, Yasuharu Konishi, Shigeru Emoto, and Yasuyoshi Watanabe. 2012. Effect of a human-type communication robot on cognitive function in elderly women living alone.
[6] K. Tatsuno, T. Kawai, M. Nako, Y. Yasuda, T. Fukuta, and H. Murata. 2010. Development of a remote visitor robot system — Attending a remote conference and visiting to an aged care center. In *Proceedings of SICE Annual Conference 2010*. 3616–3617.
[7] Rosalie H. Wang, Aishwarya Sudhama, Momotaz Begum, Rajibul Huq, and Alex Mihailidis. 2017. Robots to assist daily activities: views of older adults with Alzheimer's disease and their caregivers. *International psychogeriatrics* 29 1 (2017), 67–79.