Int J Soc Robot (2011) 3:443–456
DOI 10.1007/s12369-011-0115-x

Multidisciplinary Design Approach for Implementation of Interactive Services

Communication Initiation and User Identification for Healthcare Service Robots

I-Han Kuo · Chandimal Jayawardena · Elizabeth Broadbent · Bruce A. MacDonald

Accepted: 12 September 2011 / Published online: 14 October 2011

Abstract In the design of service robots, a key research focus has been on Human Robot Interaction (HRI) required in service applications. HRI is one of the critical factors that determines the acceptability of a service robot. The user acceptance of a service robot and its applications is highly related to HRI, as HRI affects the user perception and user experience related to the robot. In this paper, a new design approach is proposed for designing and implementing HRI for service robot applications designed for real scenarios in the real-world environment. The objective of this design approach is to facilitate inter-disciplinary collaborations, which are essential for HRI research and for developing successful products. The proposed design approach was used in the design of the healthcare service robot "Cafero" developed at the University of Auckland in collaboration with the Electronic and Telecommunication Research Institute (ETRI) and Yujin Robot Company Ltd. of Korea. Vital signs measurement, medication management, entertainment and falls detection were implemented as service applications of Cafero.

In the design process, UML and UMLi modelling diagrams were used to model the robot's multi-modal and interactive behaviour. Interaction design patterns were defined to represent recurring interactions or social cues in HRI using UMLi notations. The proposed design approach emphasises an iterative process to allow discovery of additional HRI requirements in the early design stage and to implement through Component-Based Software Engineering (CBSE).

The design of communication initiation and user identification by Cafero is presented as a case study, in order to evaluate the proposed design approach. In this case study, enabling a service robot to act proactively to the presence of a potential user and identifying the user prior to providing healthcare services is presented. For the implementation, Open-RTM component-oriented framework was used.

Keywords Human-robot interaction · UML · UMLi · OpenRTM · Social cues · Vital signs monitoring · Healthcare robot · Service robot · User identification · Face recognition · Communication initiation · Case study

1 Introduction

With recent advances in computer, sensor and software technologies, robotics has become a potential solution to various fast rising demands in the society. As a result of the rapidly growing older population, a huge demand for social and healthcare services has arisen, especially in developed countries [32, 33]. This demand has motivated the initiation of many research projects in the area of personal service robotics and related disciplines for helping daily lives of the aged population. The main common objective of this research is to improve the quality of life (QOL) of older people by assisting them to stay independent or with their families as long as possible, without being admitted to an aged care facility. Another common objective is to help people with disabilities using robotic technologies.

In the current research, the development of service robot applications can be identified in the following areas:

I-H. Kuo (✉) · C. Jayawardena · E. Broadbent · B.A. MacDonald
The University of Auckland, Auckland, New Zealand
e-mail: ikuo005@aucklanduni.ac.nz

C. Jayawardena
e-mail: c.jayawardena@auckland.ac.nz

E. Broadbent
e-mail: e.broadbent@auckland.ac.nz

B.A. MacDonald
e-mail: b.macdonald@auckland.ac.nz

- Physical assistance: Grasping objects, lifting people, operating existing household appliances such as microwave ovens and rehabilitation/training of human limbs are examples [11, 13].
- Cognitive assistance: These applications are usually integrated with healthcare applications, to enhance the continuity of healthcare provisioning and prevention. Vital signs monitoring, medication management, and smart homes equipped with sensor networks are examples [20, 31, 40, 47].
- Social interfaces: These are the applications that allow older people to communicate with their relatives, doctors and caregivers [35].
- Companions: The applications and robots that can provide a feeling of companionship for older people and encourage social interactions [6].

Unlike human-computer interaction (HCI), which requires users to adapt to computer user interfaces often based on the mouse and keyboard inputs, service robots must communicate and interact with human counterparts via more natural modalities, such as verbal and non-verbal modes, which have to be interpreted in a social context. Design, modelling and implementing human-like HRI are challenging research problems. These issues are especially important in the context of older people with less technical exposure, and often with deteriorated learning capabilities and decreased cognitive abilities. Typical HRI requirements of a service robot include two basic human perceptions: i.e. (i) awareness of human presence and (ii) detection of social cues such as eye gaze direction and body movements. During an interaction, a robot should respond with cues, to which a human can attribute "anthropomorphic" characteristics, thus enabling the human to understand those cues [14]. In addition to that, at a higher level of abstraction, robots need to be able to closely follow the human cognitive process to have a common protocol with the human partner, in order to establish a successful interactive session.

As different software technologies for robotic applications become mature, modularised and readily usable, there are increasingly more HRI developers and designers interested in integrating those software modules in robotic applications [17]. Software modules for robot vision, speech recognition and speech generation are some examples. Integration of different robot perception modalities is essential and critical for achieving multi-modal and natural human robot interaction and communication with a service robot.

The Healthbots project is a research collaboration between the University of Auckland/Auckland UniServices in New Zealand, with ETRI and Yujin Robot Co. Ltd., in South Korea [7, 8, 22, 28, 46]. As shown in Fig. 1, the target robot platform is the "Cafero" robot from Yujin Robot Co., with its form factor specifically designed for services in public spaces such as common rooms, lounges, waiting rooms or foyers in retirement villages as well as private spaces in personal rooms, apartments and homes. The project targets four main healthcare applications that have potential benefits to the older population. They are vital signs monitoring, falls detection, medication reminding and location monitoring. Falls detection requires the robot to attend to a fallen person upon detection of a fall signal through a sensor network whereas medication management requires the robot to visit older people in their rooms at certain medication times, according to their doctor's instructions, and prompt them to take their medications.

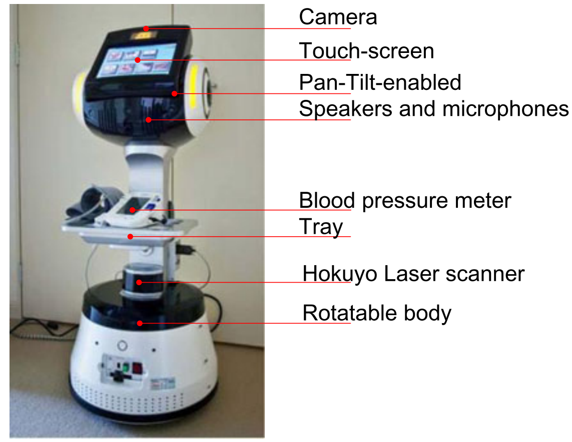

Fig. 1 The target robot platform

For the case study described in this paper, the vital signs monitoring service is the target service application and it provides the context for the case study. In this service, the robot's purpose is to encourage and help older people to take their vital signs regularly, typically in their own rooms, apartments, homes, or in a public area. The vital signs service on the robot aims to promote long term health monitoring among older people to help them stay independent longer. In addition, regular measurements and monitoring of a patient's vital signs helps doctors to provide continuity of care and to better manage patient health by detecting health concerns at an early stage [44]. For example, regular blood pressure measurements can assist a doctor and a patient with hypertension to work together to manage medication and give advice on life style changes [12].

The vital signs application development is an intersection of healthcare, robotics and aged care. Therefore, the Healthbots project, like many other HRI projects, requires interdisciplinary collaboration among experts from a wide range of disciplines including robotics, software engineering, human-computer interaction, psychology, and cognitive and health sciences. As pointed out in recent HRI research, there is a strong need for a unified methodology or design approach to facilitate communication between these diverse experts [10, 19, 25, 49]. Furthermore this design approach or methodology should also allow robot applications to be designed from the outside-in by domain experts who are not from engineering backgrounds.

In this paper, a new design approach is proposed to support a collaborative multi-disciplinary group in designing HRI application scenarios. It helps designers to model a robot's behaviour in an application, and to discover hidden requirements during the design stage. The common HRI requirements identified for the robot described in this paper are communication initiation, identifying users and then providing users with required services. The new approach will be illustrated by solving these requirements in a case study. One focus of our design is to enable the robot to autonomously detect the presence of a potential human user and take the initiative to start an interaction with the user.

Section 2 presents the steps of the design approach. Section 3 demonstrates the new design approach by presenting a case study. Section 4 presents the implementation details of the application used for the case study. The evaluation of the design approach is discussed in Sect. 5 and the conclusion is presented in Sect. 6

2 Proposed Design Approach

2.1 Design and Modelling in UML and UMLi

Free-form and Unified Modelling Language (UML) diagrams are the two most commonly used modelling techniques for describing software structure in a multidisciplinary group [49]. The advantage of using a free-form diagram is that it requires almost no prior knowledge of any modelling techniques from the designers and is therefore suitable for a multidisciplinary team. As the very first step of the design process, a free-form storyboard technique is utilised to visualise interactive behaviour of a system as a sequence of illustrations [48].

In the field of software engineering, UML is an industrial standard defined by the Object Modelling Group (OMG) and has been successfully applied for analysing and designing large object-oriented software systems and structures [15]. It includes a large variety of graphical notation for visual representation of different aspects of a software system. UML diagrams can be roughly categorised into two sets: structural (e.g. class and object diagrams) and behavioural diagrams (e.g. activity and use case diagram). For example, class diagrams focus on hierarchical relationships between classes and their operations and attributes whereas sequence diagrams visualise sequence and timing of processes and inter-process messages.

In combination with the storyboard technique, a UML use case model is communicates top system-level functionalities. A use case model includes a use case diagram and a use case description which describe the system functionalities in the use case diagrams in more details. These two techniques make up the first step of the process. In designing of a robot service application, the goal of this step is to encourage a brainstorming process within a group to design a robot's main functionalities for a target service scenario.

The next step is to model the required interactive behaviour for the target service application. UML's notations and diagrams are however more suited to low level controllers than for modelling a robot's interactive behaviour with a user, the UMLi extension of UML is more suitable for our current purpose. There is also a need for additional diagrams or notations for interactive task modelling, so UMLi must be further extended. HRI designers can then concentrate on the interaction and communication aspect of robot behaviour. In the HCI literature, it has also been found that UML designed interfaces often result in unnatural user interfaces and hence bad user experiences [29, 34, 36]. In other words, designing a graphical user interface for an application with UML, for example with class and sequence diagrams, does not reveal much relevant information about the user's tasks and goals, nor about the look and feel of the application; while these matter greatly to the user and can take the most of the source codes for the application [26]. As a result, many task modelling tools were proposed to assist HCI designers in designing and modelling of just the user interface. These tools are usually model-based development environments [18, 38, 45]. With the aim to maximise compatibility with existing UML and utilise advantages from existing UML diagrams, Pinheiro [36] proposed UMLi, a minimum extension to UMLs. It provides alternative methods to model interaction objects and tasks and also represent user interface and behaviour. Instead of using traditional UML diagrams which does not focus on different aspects of interaction, UMLi includes a new interface diagram to allow abstraction of interaction objects and represent them through new notations to UML activity diagrams. It simplifies behaviour modelling in user interfaces.

In the field of service robotics, UML has also been a widely used software engineering tool. However, it has often been used only when designing low-level controllers for tasks such as robot navigation and localisation and other types of controller [21, 25]. The complexity soon gets out of hand when human-robot interaction is to be modelled in actual implementation without a proper abstraction, and this is where a specialised modelling tool such as UMLi becomes useful. As a minimum extension to UML, UMLi provides a new set of abstract notations for modelling presentation and interaction objects in computer user interfaces.

Armato was the first to adopt UMLi in the development of HRI for an environmental service robot, the Dust-Cart [4]. The motivation was to apply formal modelling techniques for collaborative design of user interfaces. UML and UMLi were chosen because of their wide acceptance in industrial applications. In his work, UMLi notations were slightly

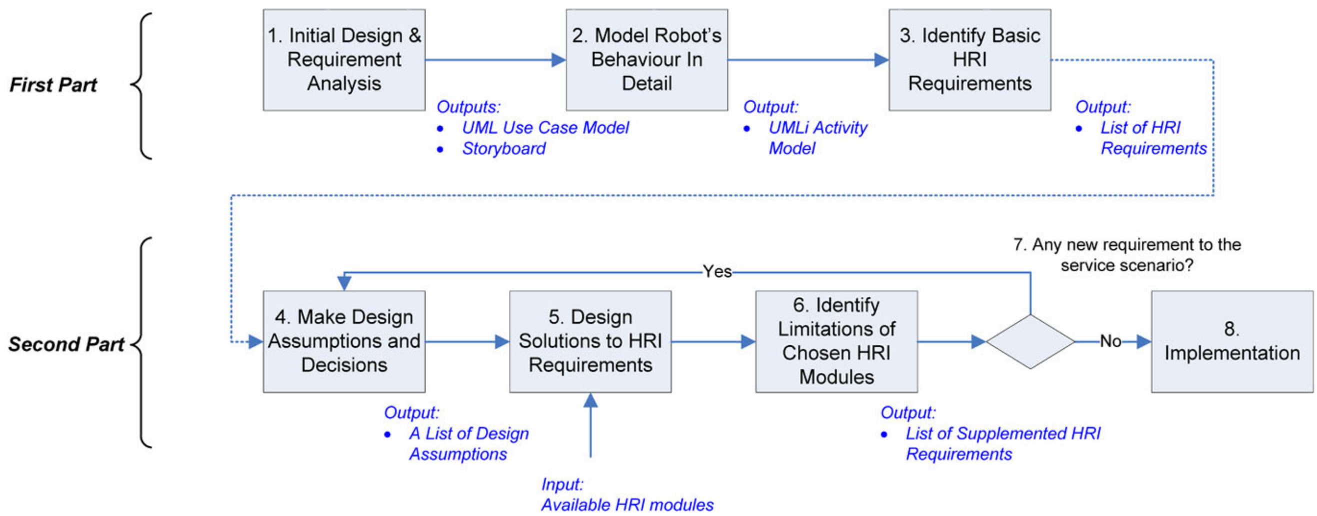

Fig. 2 Proposed design process diagram

modified and extended to better emphasise multiple modal interaction and task workflow. The Dust-Cart robot aims to provide environmental information in public places and touch-screen and speech interaction (both speech recognition and generation) are the main interaction modalities. Overall, informative interactive tasks on the Dust-Cart robot were effectively modelled to allow critical interactive design issues to be revealed.

Nevertheless, there are disadvantages and limitations to Armato's work. First, his work only addressed design and modelling issues on common multimedia interfaces (e.g. speech and touch-screen). Whereas many additional technologies must be included and integrated in the design of a service robot that is to communicate with older people who have no computer experience. Technologies such as computer vision, audio signal processing and different types of sensors such as for gesture recognition. These add to the design and modelling complexity, especially when real world robustness and hardware sensors issues are considered. Second, the interaction patterns introduced in the work are not well defined and are hard to reuse because they are task-oriented. For example, "Choose language" and "Selection" interaction patterns were used to describe different interface modalities to make a selection or choose the language of the interface on the robot. These patterns are not well designed and cannot be easily reused. One can argue that even the task "Attract attention" should be decomposed into a few interaction patterns for them to be reused because this task may involve several interaction patterns.

Alexander first introduced the concept of design patterns in analysing architectural designs [1]. Two main attributes that define a design pattern are that a design pattern should describe "the core of solution" to a problem and "you can use this solution a million times over, without ever doing it the same way twice". This concept was applied in the field of computer science as well to describe reusable software design patterns [16]. Along the same line of thinking, Kahn in [23] proposed eight design patterns for social HRI design based on observations and common interaction experiences. These patterns attempt to describe recurring patterns in social interactions between adolescents and children and robots: "initial introduction", "didactic communication", "in motion together", "personal interests and history", "recovering from mistakes", "reciprocal turn-taking in game context", "physical intimacy", and "claiming unfair treatment or wrongful harms". The humanoid robot "Robovie" from ATR was used as the research platform.

Setting the right abstraction level for design patterns is the key to ensure reuse of the pattern and construction of more complex design patterns. It should be carefully decided and set so it is a fundamental block of HRI. In the design approach, we propose to set the abstraction to the level of "interaction cue" (or social cue) that a robot can perceive and act upon or express in an interaction. These cues can be verbal, non-verbal or a combination of both (multi-modal interaction). One HRI designer can instantiate an interaction cue-based design pattern in a slightly different way in an episode of interaction. And a complete episode of interaction should be constructed through composition of interaction cues with some common patterns repeated over the course of the interaction, e.g. awareness of human presence.

2.2 Design Process and Steps

The novelty of this design approach is that it provides HRI designers a way to model a robot's task and the HRI involved based on interaction cue-oriented design patterns. The next step after describing system functionalities through use case modelling, UMLi notations for interaction and activity diagrams are utilised for modelling of interactive behaviour of a robot. Through UMLi activity diagrams, the control flow of the robot's actions is visualised with a notion of state as well as temporal dependencies between interaction states. Parallel actions/perceptions for multi-modal interaction are also possible. In addition to modelling, the design approach (the second part of the process) aims to facilitate mapping of design patterns to implementations, through the use of HRI-related software technologies e.g. laser leg detection. The design process steps are as follows:

Step 1: Initial design and requirement analysis

1. Visualise interaction scenarios in the target service application through free-form storyboard diagrams.
2. Define the main functionalities required for the scenario in UML use case diagram.
3. Describe and develop the UML use case in detail through a use case diagram and an accompanying use case description.

Step 2: Model robot's behaviour in details

1. Define robot's behaviour further in more detail.
2. Model in UMLi activity diagrams and devise or reuse interaction patterns for visualising the robot's interactive behaviour.

Step 3: Identify basic HRI requirements

Discover and identify fundamental HRI requirements and supplement them to the use case scenario description. These requirements should be decomposed to the level of interaction cue or social cue.

Step 4: Make design decisions and assumptions

1. Analyse each HRI requirement found to determine its priority and how critical it is to the successful delivery of the robot's service.
2. Make assumptions for non-critical requirements and narrow down the use cases if necessary to reduce requirements.

Step 5: Design interaction patterns

1. Select HRI-related algorithms for integration. Multi-modal perception and expression is always more robust and better.
2. Design interaction patterns to solve each HRI requirement by matching the functionalities of chosen algorithms.
3. Define new interaction pattern if a new solution is designed.

Step 6: Test and identify limitations of HRI modules

Evaluate each selected HRI module extensively to find out its advantages and limitations. Context of use and usability of the chosen technologies and algorithm should be emphasised as well as their performance in terms of speed and efficiency. Similar approach as potential solutions should also be considered at this stage.

Step 7: Reiterate if there is any new requirement

1. Limitations found from testing may generate new requirements. Go to Step 4 to analyse new requirements and repeat Step 5 and 6.
2. Otherwise continue to Step 8.

Step 8: Implementation

If there is no new requirement, carry on to implementing the design.

In the case study, three interaction patterns were added to represent the awareness of a user's presence and user's attention to the robot's screen and robot's reciprocal actions to show attention back to the user (greeting and centre its body to user). An example illustrates issues and solutions better, the second part of the process will be introduced through a case study in the next section.

3 Use Case Study:

3.1 Communication Initiation for Interaction Engagement

From the point of view of communication, the support and assistive nature of vital signs monitoring and medication remindering services make them very different from professional medical services. The interaction between these robot services and the humans is very much deviated from the typical professional-client interaction involved in professional medical services. For example, in primary healthcare services, a patient has to approach a general practitioner (GP) or a medical centre in order to access any medical help or care. That means, when using these traditional services always the patient has to take the initiative to start the interaction. However, support and assistive services such as vital signs monitoring on a robot are designed to proactively get users engaged and provide services [39]. In another words, the robot must take more responsibility in the process of initiating an interaction with a user and fulfilling the user's needs. In certain ways, it is similar to reference services such as a librarian service. Some older people may be able to (or prefer to) manage their own health and medication, but the services would give support to people who are not confident or do not have the cognitive capabilities to do it themselves.

This particular aspect of communication in service delivery was investigated in a study which analysed the role of non-verbal communication in user's decision to initiate and use the librarian service in an academic library [39]. From this study, a librarian's verbal and non-verbal behaviours showing initiation and availability through eye contacts, body orientation, stance and explicit verbal messages were found to be critical in a user's decision to approach a librarian. This initiation behaviour is especially important for users who may be unsure of their abilities (librarian and computer abilities) and also have assumed a passive role in using librarian services. This finding provides better understanding on how to engage with a human user. A robot's behaviour of observing older people and then initialising an encounter is an important factor for successful delivery of services to people who may not be confident with new technologies [30].

In previous work, Satake et al. investigated path planning strategies to capture attention and initiate interactions with users in a public shopping mall [41]. The developed robot is capable of stopping in front of a user walking through a hall and expressing its attention by orienting its body and head toward the user. The user's intention in terms of destination and current position is estimated by behavioural classification of the user's walking trajectory. Targeting HRI for starting an interaction, Pitsch et al. in [37] and Bruce et al. in [9] studied timing and control of a robot's verbal utterance and non-verbal behaviour for engaging a user in very short interactions. In the former case, face detection, non-verbal gesture and head movement and speech were used to engage a user for a brief introduction about a painting in a museum; a pet robot was used. Whereas, in the latter case, a laser leg detection, a virtual face, body movements and speech were used. Similar to these previous studies, the case study presented here modelled robot initiation behaviour in a stepwise manner. In addition to that, the case study includes face identification, which is fundamental for starting a conversation in human-human interaction [37].

3.2 User Identification for Personal Service Delivery

Healthcare services such as medication reminding are personal and usually involve transactions of personal health information. They impose high requirements on security and maintaining privacy of sensitive information. Therefore, user identification and verification is an essential step in most healthcare services. In our application design, face recognition technology was chosen for natural and human-like interaction. In the commercialisation stage of service robot technology, other biometric technologies such as fingerprint recognition for unique identification and verification will be integrated. Face recognition technologies allow reasonable accuracy in identification for the user study [51].

In the case study, the design of HRI aims to enable a robot to autonomously detect the presence of a potential user and

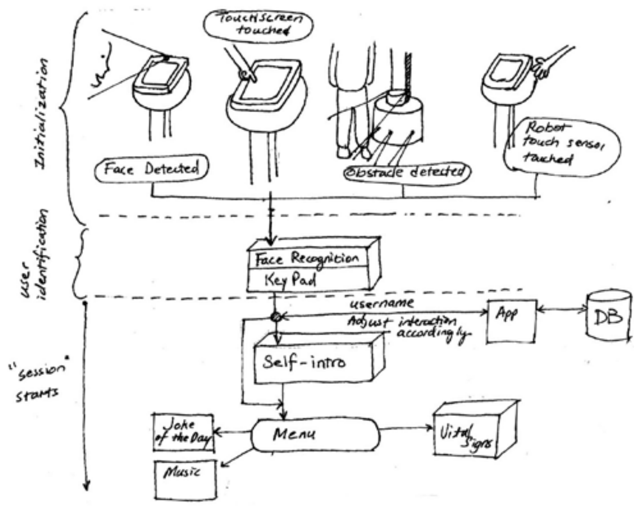

Fig. 3 Storyboard of the target application scenario

start interacting with the user by taking an initiative. If the user expresses interest in using robot services by responding to the robot's prompt, then, as the next step, the robot tries to identify the user. In designing the user identification phase, we took a different approach from widely used approaches in commercial products. In most commercial applications such as notebook computers with face recognition technologies, users are supposed to place their faces in the middle of the camera view by adjusting themselves. In our approach, we removed this constraint, since a robot user may not always be sitting in front of the camera. Unlike most commercial products, users do not have to initialise the face recognition phase. The robot takes the control of the interaction to initialise the identification phase and identifies the user through face recognition in a way that is fast, natural and transparent to the user. This design is an attempt to make this identification process as natural as possible, mimicking the process followed by humans; i.e. subconsciously recognising faces of people they have met without a direct identification interaction with the other person.

3.3 Storyboard, UML Use Case and UMLi Design

For collaboration on robot design, a storyboard of the complete robot service application scenario for vital signs monitoring was circulated at the initial design phase, among all the domain experts involved in the project, who are from different backgrounds. Figure 3 shows one of the very first scenario designs for communication initiation and user identification. As shown in the diagram, the robot was designed to detect the user presence through four different interaction modes; i.e. touch detection, face detection, leg detection and direct user inputs via the touch screen. The robot initiates interactions with users upon detection of their feet and head or when users touch the robot's screen. Upon receiving the

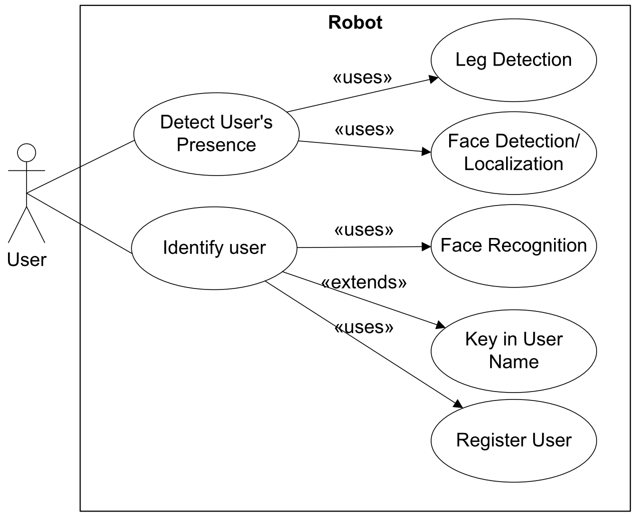

Fig. 4 Use Case Diagram for robot

user's confirmation, it carries on to identify the user and start the vital signs service.

The UML use case model depicts the basic functionalities required of the robot. The model resulting from use case analysis is shown in Fig. 4 and the main use case is simplified and described below. The actor (user) of the system is an older person. The following list is the description of the use case as part of a use case model.

1. The use case begins when a user comes near to the robot and could be detected by the robot.
2. If the robot sees either the user's face and legs, it gives action feedback including centring its upper body and tilting its screen to a better angle to the user's face.
3. The robot prompts the user with a New Zealand related trivia question.
4. If the user indicates his intention to try the robot by answering the robot's trivia question, the robot tries to recognise his/her face through its camera
5. When face recognition result returns, the robot prompts the user "are you (name)?" or "are you one of these people, (names of the 3 top candidates)" and asks the user to confirm.
6. If there is a time-out or the user rejects being the identified person, the robot falls back to ask the user to identify him/herself by entering his/her name on a keyboard on the touch screen. This use case ends when the user confirms his/her identity.

The UMLi activity diagram in Fig. 5 visualises the robot's behaviour and its concurrent process for multiple modal interaction. In the behaviour, two activities run in parallel: face recognition and speech/touch screen interaction which emulates the human cognitive process in communication, engaging in a conversation and identifying the conversing partner at the same time. To include the robots' new capabilities on perceptions and physical actions, more interaction patterns were defined in addition to the basic "inputters" and "displayers" defined in [4]. Three additional interaction patterns were defined. They are

1. User's presence detected—a fundamental interaction cue (hence design pattern) as the basis to initiate, continue on with or end an interaction.
2. User's attention to the robot's screen—provides the time instants when the user is looking at the robot. It was devised to combine with the interaction pattern to recognise the user by face. In addition, this pattern can be extended by time modulation. For example, the frequency and duration of the instants when user's attention was detected, can provide useful information on the user's engagement and other status such as the user's intention if integrated with other perception modules.
3. Pay attention—designed to show attention back to the user to establish further communication with a potential user whose leg is detected through laser or faces has been seen.

The robot's perception of the user's attention and time looking at it, is computed by a combination of user input on the touch screen and information about the user's face location and size detected by the camera. The user's presence around the robot is through a combination of input from face and leg detection. "Pay Attention" by centring on the user was created to show the robot's action upon detection of the user's face toward the robot. These are shown in the interaction container (cylinder) in the diagram. Groupings of the patterns (e.g. "Pay Attention" under "Human presence detection") represent exchanges of interaction cues between robot and user.

3.4 Iterative Process to Find Additional Requirements

Despite the recent advances in computer algorithms and technologies for HRI, still there are practical difficulties in using these technologies on a robot in real environments. First, an algorithm's description does not necessarily mean or represent what it can actually do and there are numerous conditions to apply it in real situations and realise its full advantage. There are inherent limitations in each software algorithm and technology and they can be critical if the delivery of a robot's service is dependent on it e.g. attract attention and engage a potential user. These conditions can be due to the type of sensor or feature used in a detection algorithm. For example, if the leg detection algorithm described in [50] is to be used for HRI in real environment conditions, inherent sensitivity to the environmental noises in laser sensors, the practicality of approximating legs as arcs and other things have to be considered. Secondly, a single algorithm does not suffice. A simple real world application requires

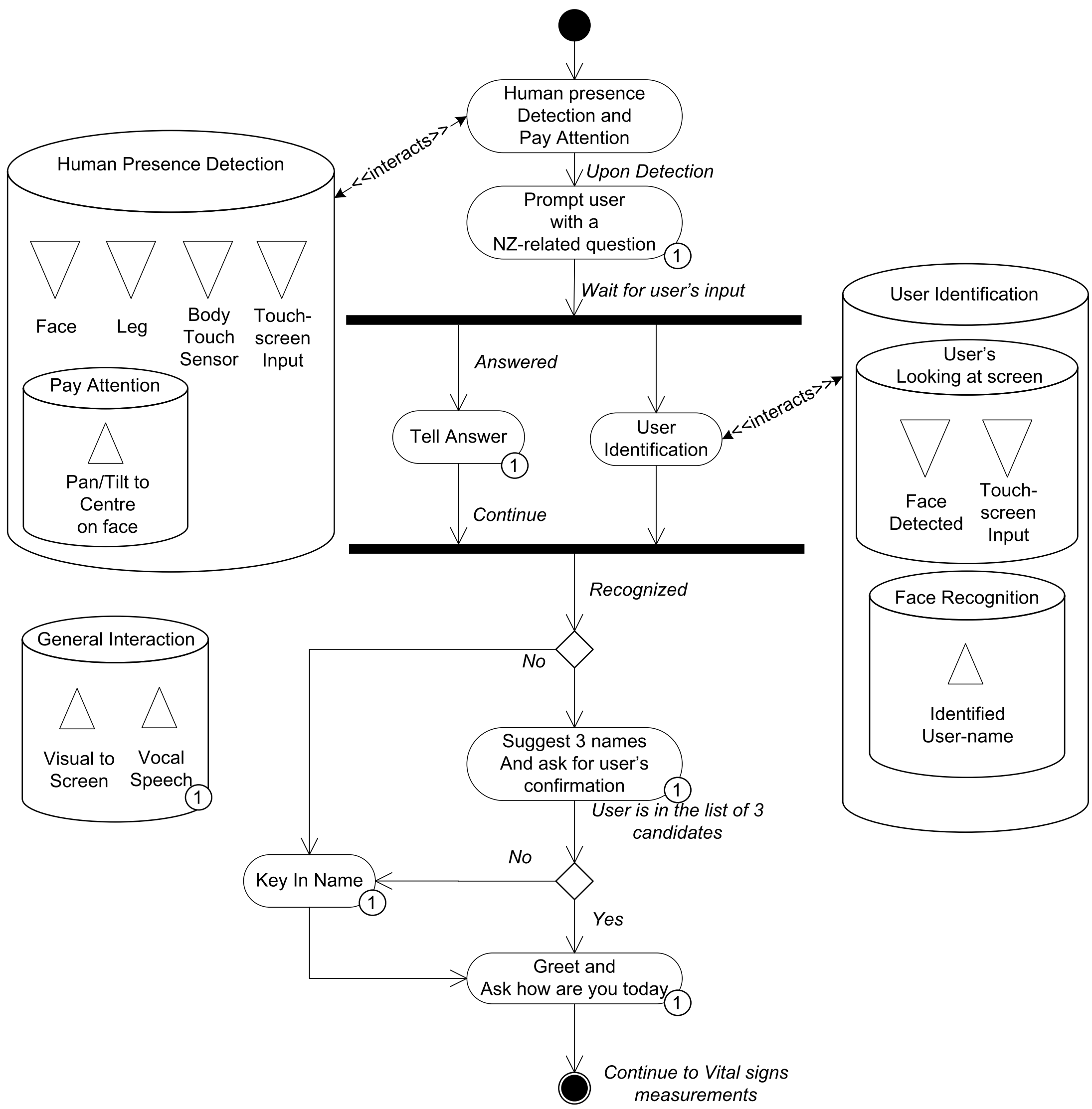

Fig. 5 Activity diagram with new HRI interaction patterns using UMLi notations

an integration of several software algorithms and technologies. A number of algorithms are required before a short and successful interaction scenario can be constructed on a robot. Due to these reasons, a number of different algorithms and technologies were tried out and briefly evaluated at the early design stage of this case study. The aim was not to benchmark them for comprehensive comparison between algorithms but to briefly evaluate them for their suitability in a general service scenario as well as their operation and performance in real environment.

For this purpose, the list of elements of a design pattern defined by Spool for interface design patterns in web applications serve as a good guideline for evaluation [43]. This list includes elements such as pattern name, description, context of use, where used, how it works, co-requisites, related patterns, competitive approaches and more were defined. For evaluation of HRI-related software technologies, the following 3 items were found to be particularly useful:

- Context of use.
- Co-requisites.
- Usability result and user feedback.

In the context of HRI design, "context of use" and "co-requisites" of a interaction cue based design pattern tell a designer whether it is suitable for the interaction being designed and the conditions under which the robot has to work. There are normally several environment conditions that have to be controlled for an algorithms to work and perform as intended. If an interaction cue is constructed from integration of several algorithms, operation conditions from them have to be clearly specified under the context of use or as co-requisites for successful design. Inclusion of usability results and user feedback from previous tests or evaluation back into design would enhance the iterative design process needed in HRI. It is essential to discover as many conditions and limitations as early as possible before implementation to bring algorithms and HRI related technologies into use and application in real environment. These conditions may impose additional requirements, therefore must be considered in the design and then solved or described as a use case condition.

3.4.1 Supplementing to Existing List of HRI Requirements

Step 4 to 7 in the design process (Fig. 2) aim to help HRI designers to fulfil the requirements resulting from the first 3 steps. By selecting appropriate HRI-related technologies and making necessary design decision and assumptions to match requirements to available solutions; design from a top-down approach (modelling) can be mapped and translated to functionalities provided by HRI-related algorithms and software technologies.

In the case study, a list of fundamental HRI requirements was produced as a result of UML and UMLi models from the first part of the design process (Step 1 to 3). See below.

To initiate an interaction with a potential user and identify him/her sitting or standing in front of the robot, the robot has to have the abilities to:

1. Detect that there is a user near the robot.
2. Detect that a user is standing or sitting down in front of the robot.
3. Search and detect where the user's head/face is in the camera view.
4. Detect whether the user is looking at the touch screen.
   (a) Detect the user's head orientation to the camera. *
5. Recognise the user by unique features on his/her face.
6. Save the user's images and register the user to the database.
   (a) Detect whether the user has left. *
   (b) Track the user's face. *

Notes: *—Additional requirements

The face detection and recognition algorithm from ETRI was chosen as the main algorithm in the design. It was evaluated, and tested with results detailed in the next section. From the test, it was found out that the accuracy of the face recognition algorithm is largely dependent on the angle of the user's face to the robot's camera. Items 4a, 6a and 6b were supplemented in consideration of the major limitations and conditions of the algorithm when applied in real environment.

Requirements 4 and 5 were satisfied by the face detection and recognition algorithm, which however depends on requirements 2 and 3 to give meaningful results. For requirements 1, 6a and 6b, a motion detector and face tracker as well as other simpler solutions were considered, to avoid issues that may arise from the user leaving and entering during an interaction. Requirement 2 could be solved, since the face detection has reasonable tolerance to a range of face angles and the robot is capable of panning and tilting. The third requirement is probably the most critical as it affects the accuracy and hence usefulness of the user identification service. There was no head rotation detection algorithm available. The first solution was devised under the assumption that the user will at least look at the screen during his/her interaction, and then the robot could take some good pictures of the user's frontal face during these times, which corresponds to the detected face size during an interaction. It was tested to be ineffective. The second solution was proposed to combine with another interaction mode. Integration with the touch-screen mode was found to be a better solution later through a short user study and it utilises the advantage of the robot's form factor that the camera is mounted together with the robot's pan/tilt touch screen. Whenever a user interacts with the robot through the touch screen, there is an short instant of time during which they have to look at the robot by nature. The assumption that most people focus on the robot's touch screen whenever they interact with the robot was tested to be valid later, a fixed angle of users' frontal faces could be captured for improving the accuracy of recognition.

4 Implementation

The service application was implemented on a robot platform "Cafero" (shown in Fig. 1). The robot hardware consists of a differential drive mobile platform, two single-board computers, sonar sensors, a microphone, speakers, a touch screen mounted on an actuated head and a camera. The overall system diagram of the final implementation is shown in Fig. 6. A message server is in the centre of the software framework on the proprietary robot platform. It handles and redirects XML-formated messages from upper-level applications to allow control and coordination of the hardware such as the actuators and motors in the robot. Most of the HRI technologies are implemented through the OpenRTM middleware.

4.1 OpenRTM—Robot Technology Middleware

OpenRTM-aist is a robot technology middleware framework implementing the OMG RT-Component specification and developed by the National Institute of Advanced Industrial Science and Technology in Japan (AIST). With vision to support rapid development of life support service robot applications, OpenRTM promotes component-oriented software engineering to encourage modularisation and reuse

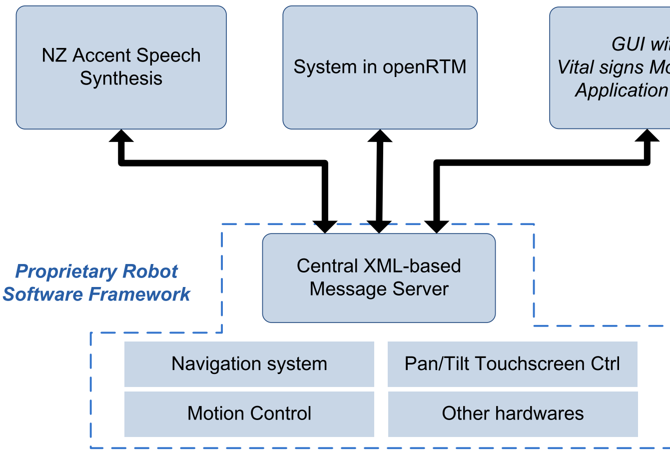

Fig. 6 Overview of the complete system implementation

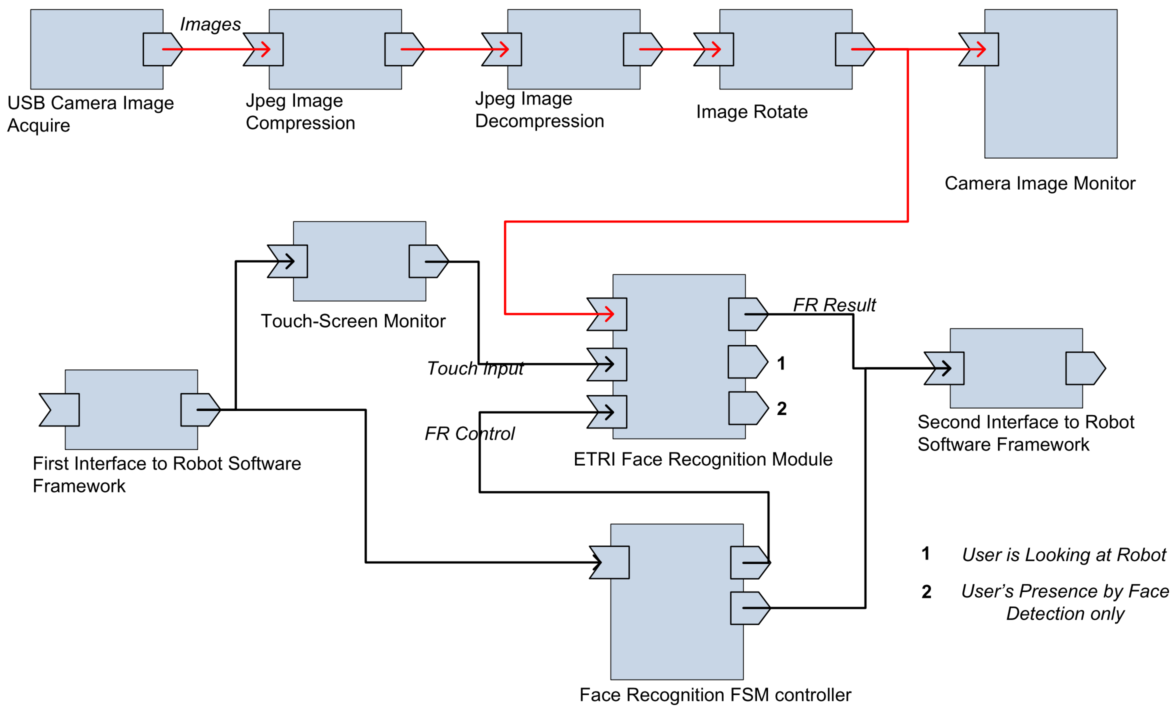

Fig. 7 Simplified data-flow diagram of the HRI system implemented in OpenRTM middleware

of robot's functionalities and provide a flexible distributed framework for system composition and interoperability between different OS and communication protocols [2, 3, 42]. The robot system resulting from the design was implemented through the OpenRTM development tool chain.

4.2 HRI System in OpenRTM

As shown in Fig. 7, the complete system is composed of 10 components. Due to limited processing power on the robot, an additional remote PC is networked with the robot for the image processing resources required. Four components were used for image streaming across the network, responsible for four stages of image streaming: image capture, image compression, image decompression and image display. This model of distributed computing is the intended deployment where many robots communicate with a central, powerful server. One component was developed to perform image rotation as the camera on the robot was rotated to allow a wider vertical view to accommodate to older people sitting on a sofa with lower height.

The face recognition algorithm developed by ETRI was encapsulated into a single component and a separate controller was developed to automate and control the sequence of face detection, face recognition and face registration for user identification required in the scenario. As shown in

Fig. 8 a finite state machine was implemented in the component. Touch screen input is monitored through another component that calculates frequency and duration of a user's touch.

The duration of user's input is used with the ETRI face recognition component for detection of the user's attention duration to the robot's screen. The face recognition module uses images captured during the instants when the user touches the screen, to capture the user's frontal face images, in order to improve recognition accuracy. Two additional wrapper components are used to translate message format and data type in between the OpenRTM components and the hardware controllers on the Cafero robot platform. The components translate XML-formatted messages for communications to monitor and control the robot's hardware and other functionalities including mapping and navigation.

The main interaction modes of the robot system are the touch screen plus verbal speech and the face recognition system that run in parallel on the robot and a remote PC. The face detection and recognition algorithms used in this design are provided as dynamic linked libraries (DLLs). The algorithms uses gamma intensity correction (GIC) method and is reasonably robust to illumination changes in the environment [24]. The face detection is able to detect a person's face robustly against head rotation up to about 30 degrees to both sides. This advantage however is traded-off during face recognition. The face recognition algorithm's confidence and accuracy are very much dependent on head rotation and drop significantly when the person turns his or her head more than about 10 degrees to the sides.

The GUI on the robot's touch screen was implemented in Adobe Flash and Actionscript. To facilitate customisation and on-site modification of the GUI for the user, Actionscript was used to automate the process of creating flash screens and buttons and texts on it from an XML script. Through this automation, designers were able to focus on the application flow of the user interface rather than other details on the GUI such as pictures and buttons.

It was tested with both the students and staff in the Healthbots project in the University of Auckland and was later deployed in a retirement village in New Zealand for a user study. The robot was tested in private apartments for personal use and also a public foyer. The result of the study will be separately reported.

5 Discussion

In this paper, a design approach is proposed as an attempt to model and design HRI which is inherently of high complexity if human-like interaction is to be achieved. In this respect, design concepts and methodology for task modelling (UML and UMLi) and designing software system (design patterns) in the field of HCI were borrowed and applied. As a demonstration, the approach was used and applied to improve interaction between the "Cafero" robot (by Yujin Robot Co.) and users. The implementation resulting from the case study enabled the robot to actively prompt and start interaction and its service instead of passively waiting for the user to initialise by pressing a start button on the robot [27]. Compared to the previous work done by the author in [27], this paper gave more focus to translation of HRI design to actual implementation (connection between the first and second part of the design process). It is proposed to design HRI in units of interaction cues and the author argues that this level of abstraction is better than previous approaches [23] because it facilitates mapping to implementation with current software technologies e.g. computer vision. As the next step, the robustness and effectiveness of the interaction design patterns for perception/expression of natural interaction cues should be evaluated. The result will feedback to the existing design to allow better HRI and interaction experience.

As was intended in the design, the HRI system implemented for the case study was used for other health care service applications in the Healthbots project including the medication reminder and management services [22, 27]. During application of the design approach in these developments, several limitations were found. Some aspects of HRI are not visible in the modelling diagrams used in the design approach and are critical in user experience and acceptability. For example UMLi activity models are very limited in visualising timeliness of the robot's expression or physical actions upon detection of an interaction cues. Although temporary dependency between interaction states could be visualised, issues on time-out on face recognition and the waiting time for recognition result (described in Steps 4 and 5 in use case description) could not be emphasised as we wished. From our observations and video analysis in the past trials, the older people are sensitive to the timing of the robot's

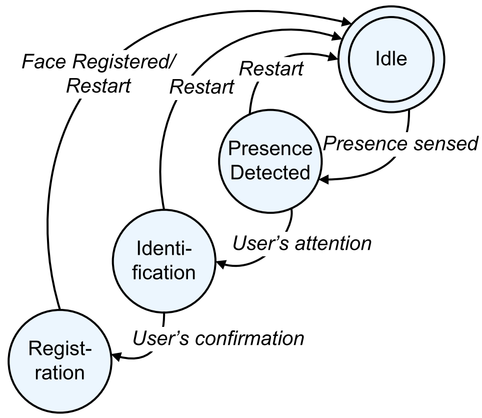

Fig. 8 Simplified finite state machine implemented for face recognition sequence control

feedback through verbal utterances and visual display [37]. Longer than the usual timing between a human-human interaction does affect their interaction experiences. This also points out the role of expectation in HRI. A more satisfying HRI experience can be achieved if user's expectations during an interaction can be met or adjusted by the robot's expression of its internal status and intention [5, 28]. However some of these design issues are sometimes revealed only through user study and evaluation with its intended users. In this respect, the importance of completing the loop from design to implementation to evaluation and design iteration to incorporate user feedback back to the design should be emphasised.

The robot's application logic to instruct and take users through measurements of their vital signs with different devices is inherently synchronous, i.e. there is a sequence of steps that the robot follows to show, instruct and take users to take their vital signs. In the current implementation, it is run concurrently with the perception and action modules in the system such as speech recognition, speech synthesis and face recognition and it was found mandatory to devise handshaking protocols for any communication between these concurrent processes and the main application logic. In another words, the main application will require synchronous service requests and responses to/from these processes in order to give timely responses to the user.

One common goal of component based software engineering (CBSE) is to maximise reusability of existing software technologies by enforcing a strict encapsulation model to modularise robot functionalities. This very concept behind CBSE facilitates design and development of interaction design patterns for HRI. The core idea presented in this paper is to decompose HRI into interaction cue-oriented design patterns and then compose again interactions by implementing or reusing design patterns on a component-based framework such as OpenRTM [42]. This approach is different to common approaches that decompose and build robot system into components by functionality. One of the our future directions is to develop a methodology to evaluate and validate developed interaction design patterns. This will inform how perception or expression of interaction or social cues can be better built for efficiency, robustness and hence natural user interaction.

For healthcare services that require unique user identification, the face recognition in the implementation does not have the verification functionality that is needed. The high accuracy required to achieve unique identification and verification, could only be satisfied through unique recognition devices such as palm print recognition. However, an accurate face recognition algorithm does have the potential to be used for increasing the robot's interactivity and making the interaction more engaging, and for enriching the user's experience. Unlike other biometric devices that require users to conform to a certain procedure or form factor, the face recognition in this design could be used to generate events such as "oh I just saw you this morning" when the robot sees the person the second time in the afternoon. If these asynchronous social cues can be added to an interaction according to the context the robot is in, they could enrich HRI significantly.

6 Conclusion

In conclusion, a new design approach was proposed, described and demonstrated through a vital signs monitoring service application on a robot Cafero. This design approach helps researchers and designers involved in HRI design to (a) model a robot's multi-modal interactive behaviour to reveal critical design errors or clarify necessary assumptions to make a target robot service application possible, and (b) decompose and match interaction requirements to interaction cue based design patterns. An iterative process is used to evaluate chosen HRI-related algorithms and then find out additional requirements for implementation of the design patterns. As a case study, the complete development of a robot's interactive behaviour to initiate communication with a human user and perform user identification was presented from design to implementation.

For the HRI design in the case study, three new interaction patterns were designed and implemented for the awareness of a user's presence around the robot, a user's attention to the robot's screen, and the robot's expression to show its attention to user. These interaction patterns for perception and expression in an interaction are multi-modal by nature and were built through composition of components in a component-oriented framework OpenRTM. Future work is planned to expand the existing set of interaction design patterns to compose meaningful interactions of longer length and validate the existing interaction design patterns to improve their robustness, efficiency and user experiences.

Acknowledgements This work was jointly supported by the R&D program of the Korea Ministry of Knowledge and Economy (MKE) and Korea Evaluation Institute of Industrial Technology (KEIT). [KI001836], Development of Mediated Interface Technology for HRI] and the New Zealand Foundation for Research, Science and Technology IIOF (13635). We thank Electronics and Telecommunications Research Institute (ETRI) for their valuable contributions and help with the research. We would also like to thank Yujin Robot for their technical support and our colleagues of University of Auckland HealthBots research team for their ongoing support.

References

1. Alexander C, Ishikawa S, Silverstein M, Jacobson M, Fiksdahl-King I, Angel S (1977) A pattern language. LISP50, vol 132. Oxford University Press, Oxford. doi:10.1145/1529966.1529967

2. Ando N, Suehiro T, Kitagaki K, Kotoku T, Yoon W (2005) RT-middleware: distributed component middleware for RT (robot technology). In: Intelligent robots and systems (IROS 2005), IEEE/RSJ international conference on, pp 3933–3938. IEEE, New York
3. Ando N, Suehiro T, Kotoku T (2008) In: Carpin S, Noda I, Pagello E, Reggiani M, Stryk O (eds) Simulation, modeling, and programming for autonomous robots. Lecture notes in computer science, vol 5325. Springer, Berlin, pp 87–98
4. Armato A, Salvini P, Laschi C (2008) Adapting UMLi to design interfaces for human-robot interaction (Poster). In: ACM/IEEE international conference on human-robot interaction, Amsterdam
5. Breazeal C (2004) Social interactions in HRI: the robot view. IEEE Trans Syst Man Cybern, Part C, Appl Rev 34(2):181–186. doi:10.1109/TSMCC.2004.826268
6. Breazeal C, Takanishi A, Kobayashi T (2008) In: Social robots that interact with people, pp 1349–1369. Springer, Berlin. doi:10.1007/978-3-540-30301-5_59
7. Broadbent E, Kuo IH, Lee YI, Rabindran J, Kerse N, Stafford R, MacDonald BA (2010) Attitudes and reactions to a healthcare robot. Telemed J E-Health: The Official Journal of the American Telemedicine Association 16(5), 608–613. doi:10.1089/tmj.2009.0171
8. Broadbent E, Lee YI, Stafford RQ, Kuo IH, MacDonald BA (2011) Mental schemes of robots as more human-like are associated with higher blood pressure and negative emotions in a human-robot interaction. Int J Soc Robot 3(3):291–297. doi:10.1007/s12369-011-0096-9
9. Bruce A, Nourbakhsh I, Simmons R (2002) The role of expressiveness and attention in human-robot interaction. IEEE, New York. doi:10.1109/ROBOT.2002.1014396
10. Burke J, Murphy R, Rogers E, Lumelsky V, Scholtz J (2004) Final report for the DARPA/NSF interdisciplinary study on human-robot interaction. IEEE Trans Syst Man Cybern, Part C, Appl Rev 34(2):103–112
11. Ceccarelli M (2011) Problems and issues for service robots in new applications. Int J Soc Robot 3(3):299–312. doi:10.1007/s12369-011-0097-8
12. Chobanian A, Bakris G, Black H, Cushman W, Green L, Izzo Jr J, Jones D, Materson B, Oparil S, Wright Jr J, et al. (2003) Seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure. Hypertension 42(6):1206
13. Dario P, Guglielmelli E, Laschi C, Teti G (1999) MOVAID: a personal robot in everyday life of disabled and elderly people. Technol Disabil 10(2):77–93
14. Duffy B (2003) Anthropomorphism and the social robot. Robot Auton Syst 42(3–4):177–190. doi:10.1016/S0921-8890(02)00374-3
15. Fowler M (2003) UML distilled: a brief guide to the standard object modeling language. Addison-Wesley/Longman, Boston
16. Gamma E, Helm R, Johnson R, Vlissides J (1995) Design patterns: elements of reusable object-oriented software. Addison-Wesley Professional Computing Series, vol 206. Addison-Wesley, Reading
17. Glas D, Satake S, Kanda T, Hagita N (2011) An interaction design framework for social robots. In: Proceedings of robotics: science and systems, Los Angeles, CA, USA
18. Griffiths T, Barclay P, Paton NW, McKirdy J, Kennedy J, Gray P, Cooper R, Goble C, Da Silva P (2010) Teallach: a model-based user interface development environment for object databases. Proc. User Interfaces Data Intensive Syst 14(1):86–96
19. Guiochet J, Tondu B, Baron C (2003) Integration of UML in human factors analysis for safety of a medical robot for tele-echography. In: Intelligent robots and systems (IROS 2003), Proceedings, 2003 IEEE/RSJ international conference on, vol 4, pp 3212–3217. IEEE, New York
20. Hashimoto H, Sasaki T, Jeni LA (2010) Current status of intelligent space. J Meas Sci Instrum doi:10.3969/j.issn.1674-8042.2010.01.18
21. Iborra A, Caceres D, Ortiz F, Franco J, Palma P, Alvarez B (2009) Design of service robots. IEEE Robot Autom Mag 16(1):24–33. doi:10.1109/MRA.2008.931635
22. Jayawardena C, Kuo I, Unger U, Igic A, Wong R, Watson C, Stafford R, Broadbent E, Tiwari P, Warren J, et al. (2010) Deployment of a service robot to help older people. In: Intelligent robots and systems (IROS), 2010 IEEE/RSJ international conference on, pp 5990–5995. IEEE, New York
23. Kahn PH, Freier NG, Kanda T, Ishiguro H, Ruckert JH, Severson RL, Kane SK (2008) Design patterns for sociality in human-robot interaction. ACM Press, New York. doi:10.1145/1349822.1349836
24. Kim D, Lee J, Soh J, Chung Y (2003) Real-time face verification using multiple feature combination and a support vector machine supervisor. In: International conference on multimedia and expo, vol 2, pp 145–148
25. Kim M, Kim S, Park S, Choi M, Gomaa H (2009) Service robot for the elderly. IEEE Robot Autom Mag 16(1):34–45
26. Kovacevic S (2004) UML and user interface modeling. The Unified Modeling Language. UML'98: Beyond the Notation
27. Kuo IH, Jayawardena C, Tiwari P, Broadbent E, MacDonald BA (2010) User identification for healthcare service robots: multidisciplinary design for implementation of interactive services. In: Second international conference on social robotics, pp 20–29
28. Kuo IH, Rabindran J, Broadbent E, Lee Y, Kerse N, Stafford M, Macdonald BA (2009) Age and gender factors in user acceptance of healthcare robots. In: Proceedings of 18th IEEE international symposium on robot and human interactive communication, pp 214–219. Toyama, Japan
29. Markopoulos P, Marijnissen P (2000) UML as a representation for interaction designs. In: Proceedings of OZCHI 2000, pp 240–249
30. Marquie JC, Jourdan-Boddaert L, Huet N (2002) Do older adults underestimate their actual computer knowledge? Behav Inf Technol, 21(4):273–280. doi:10.1080/0144929021000020998
31. Mattern F, Naghshineh M, LaMarca A, Brunette W, Koizumi D, Lease M, Sigurdsson S, Sikorski K, Fox D, Borriello G (2002) Pervasive computing. Lecture notes in computer science, vol 2414. Springer, Berlin. doi:10.1007/3-540-45866-2
32. NZIER (2004) Ageing New Zealand and health and disability service: demand projections and workforce implications, 2001–2021
33. Ogawa N, Retherford RD (1993) Care of the elderly in Japan: Changing norms and expectations. J Marriage Fam 55(3):585–597. doi:10.2307/353340
34. Paterno F (2001) Towards a UML for interactive systems. In: Little R, Nigay L (eds) Engineering for human-computer interaction, vol 2254. Springer, Berlin, pp 7–18
35. Paulos E, Canny J (1998) Designing personal tele-embodiment. In: Proceedings 1998 IEEE international conference on robotics and automation cat No 98CH36146, vol 4, pp 3173–3178. IEEE, New York. doi:10.1109/ROBOT.1998.680913
36. Pinheiro P, Paton NW (2000) UMLi: The unified modeling language for interactive applications. In: 3rd International conference on the unified modeling language, pp 117–132. Springer, York
37. Pitsch K, Kuzuoka H, Suzuki Y, Süssenbach L, Luff P, Heath C (2009) "The first five seconds": Contingent stepwise entry into an interaction as a means to secure sustained engagement in HRI. In: Proceedings of the internatinal symposium on robot human interactive communication RoMan 2009, pp 985–991
38. Puerta AR (1997) A model-based interface development environment. IEEE Softw 14(4):40–47. doi:10.1109/52.595902
39. Radford M (1998) Approach or avoidance? The role of nonverbal communication in the academic library user's decision to initiate a reference encounter. Libr Trends 46(4):699–717

40. Sasaki T, Hashimoto H (2009) Design and implementation of distributed sensor network for intelligent space based on robot technology components. In: Human system interactions, 2009 (HSI'09) 2nd conference on, pp 400–405. IEEE, New York
41. Satake S, Kanda T, Glas DF, Imai M, Ishiguro H, Hagita N (2009) How to approach humans? Strategies for social robots to initiate interaction. In: HRI 09 Proceedings of the 4th ACM IEEE international conference on human robot interaction, pp. 109–116. ACM, New York. doi:10.1145/1514095.1514117
42. Shakhimardanov A, Paulus J, Hochgeschwender N, Reckhaus M, Kraetzschmar GK (2010) Best practice assessment of software technologies for robotics. Tech rep, Bonn-Rhein-Sieg University (BRSU)
43. Spool J (2006) The elements of a design pattern. Academic Press, New York
44. Stergiou GS, Bliziotis IA (2011) Home blood pressure monitoring in the diagnosis and treatment of hypertension: a systematic review. Am J Hypertens 24(2), 123–134. doi:10.1038/ajh.2010.194
45. Szekely P (1996) Retrospective and challenges for model-based interface development. In: Bodart F, Vanderdonckt J (eds.) Design specification and verification of interactive systems, vol 96, pp 1–27. Information Sciences Institute, University of Southern California, Citeseer
46. Tamagawa R, Watson CI, Kuo IH, MacDonald BA, Broadbent E (2011) The effects of synthesized voice accents on user perceptions of robots. Int J Soc Robot 3(3):253–262. doi:10.1007/s12369-011-0100-4
47. Tapus A, Chetouani M (2010) ROBADOM: the impact of a domestic robot on the psychological and cognitive state of the elderly with mild cognitive impairment. In: Proceedings of the second international symposium on quality of life technology intelligent systems for better living, Las Vegas, CA, USA
48. Truong K, Hayes G, Abowd G (2006) Storyboarding: an empirical determination of best practices and effective guidelines. In: Proceedings of the 6th conference on designing interactive systems, pp 12–21. ACM, New York
49. Wrede S, Lütkebohle I (2008) Integration expertise in HRI research: a first survey. In: ICRA'08 workshop on software engineering for robotics III. Applied Informatics Group
50. Xavier J, Pacheco M, Castro D, Ruano A, Nunes U (2005) Fast line, arc/circle and leg detection from laser scan data in a player driver. In: IEEE international conference on robotics and automation, vol 4, pp 3930. Citeseer
51. Yun WH, Kim D, Song BY, Yoon HS (2008) Face recognition using HOG features. In: The 5th international conference on ubiquitous robots and ambient intelligence, Urai

I-Han Kuo received a BE (1st class) in computer systems engineering from the University of Auckland, where he is currently studying for a PhD in Human-robot interaction (HRI) and service robotics. Research interests include HRI design methodology and development of human-like, mixed-initiative communication for robot service applications.

Chandimal Jayawardena received his BScEng(Hons) and MEng degrees in Electronics and Telecommunication Engineering from the University of Moratuwa, Sri Lanka, in 1999 and 2003 respectively. From 1999 to 2001, he was with Sri Lankan Airlines and from 2001 to 2003 he was with Sri Lanka Telecom as an Engineer. In 2006, he received his PhD from Saga University, Japan in the area of Robotics and Intelligent Systems. From 2006 to 2009, he was with Sri Lanka Institute of Information Technology and currently he is a postdoctoral research fellow in the University of Auckland, New Zealand. His research interests include intelligent robotics, swarm robotics, robot software frameworks, and machine learning. He is a chartered engineer, and a member of the IET, IEEE, BCS and IESL.

Elizabeth Broadbent received her BE (Hons) in Electrical and Electronic Engineering from the University of Canterbury, Christchurch, New Zealand, and her MSc and PhD degrees in health psychology from the University of Auckland, New Zealand. Elizabeth is currently a Senior Lecturer in Health Psychology at the Faculty of Medical and Health Sciences, the University of Auckland. Her research interests include human robot interaction, with a particular interest in emotional reactions to robots and perceptions of robots.

Bruce A. MacDonald received a BE (1st class) and PhD in the Electrical Engineering department of the University of Canterbury, Christchurch, New Zealand. He spent ten years in the Computer Science department of the University of Calgary in Canada then returned to New Zealand in 1995, joining the Department of Electrical and Computer Engineering Department at the University of Auckland. He is director of the Robotics Laboratory. The long term goal is to design intelligent robotic assistants for that improve the quality of peoples' lives. His research interests include human robot interaction and robot programming systems, with applications in areas such as healthcare and agriculture.