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Service Robot Anthropomorphism and Interface Design for Emotion in Human-Robot Interaction

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Abstract – There has been growing interest in both developing and implementing service robots for health care and home environments. In addition to a variety of functions supported by robotic technology, the interaction between a human and robot, including human emotional experiences, can affect perceived service quality and satisfaction. Based on a survey of existing service robot applications and associated interface requirements, we consider anthropomorphism as a critical characteristic of the robot interface. We propose a preliminary research framework to support identification of the exact relationship between robot interface features and user (emotional) responses in service contexts. Future experimental investigations based on the framework are to be conducted.

I. Introduction

Improvements in intelligent control systems and precision sensors have promoted a wide variety of robot applications in the health care field, including laboratory robots, surgical robots, rehabilitation robots, assistive robots for people with impaired mobility, and service robots (for an overview see [1]). In this paper, we constrain the terminology of service robots to robots developed to complement nurses in routine patient services (e.g., medicine delivery) in order to reduce nurse workload for more critical health care tasks. To achieve this goal, robots need to navigate independently in large-scale hospital workplaces or nursing home environments, and more importantly, they must support close and effective interaction with robot operators, pharmacists and nurses. In some operations, robots may also be expected to communicate with patients (especially elderly people) or hospital/home visitors for social interaction [2]. Emotions play an important role for these users in communication and interaction [3] and some research efforts have been focused on developing robots capable of affective expressions (e.g., [4]). However, few studies measured human emotional responses when interacting with the robots (e.g., [5]) for assessing system effectiveness, particularly in health care services. There is a need to understand potential patient emotional responses to service robots and to provide a design basis for future robots to facilitate positive patient emotional experiences and effective patient-robot interaction.

The objective of this paper is to present a preliminary framework for future research on human (patient) emotional responses in interacting with service robots. We first present a survey of service robots developed for hospital use. These robots were either research prototypes or implemented in actual health care environments to various degrees. We then identify important interface features of current robot implementations and review previous robot interface design guidelines as well as limitations. We identify anthropomorphism as a critical interface characteristic driving human emotions and perception of social capabilities. We discuss the design of anthropomorphic robots in the context of health care services. Finally, research on patient emotional experiences, as a measure of patient-robot interaction, is discussed.

II. Survey of Health Care Service Robots

A. Towards A Taxonomy

A literature review revealed a number of applications or tasks related to health care that service robots may contribute to, including: hospital delivery, cognitive prosthetics, social interaction, intelligent walkers and telemedicine. Robots for delivery tasks automatically perform point-to-point navigation within hospitals/nursing homes, carrying medicines, meals, medical records or lab specimens. Some delivery robots follow preprogrammed routes with the capability of taking elevators and opening electronic doors [6]; whereas, some others autonomously navigate in the environment using natural landmarks [7]. Robots as cognitive prosthetics serve as reminders for elderly patients, particularly those suffering from varying degrees of dementia [8]. These robots can help nurses in reminding patients to take medicine, eat meals, or use a bathroom, etc. Robots for social interaction can provide psychological, physiological and social effects for patients through intimate interaction and communication [2] [9]. Intelligent walkers are robots that provide mobility and navigation guidance to patients in need of walking assistance to reduce fall risk and confusion in a hospital [10]. Robots for telemedicine can transfer real-time multimedia medical information on patients to remote doctors for the purpose of consultation and examination [9].

Table I presents a summary of service robots that have been developed for health care applications (robots aimed at

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two or more applications mentioned above are labeled as "general service"). Although most of the robots listed were research prototypes, the hospital delivery robots have been implemented in real hospitals [6] [11].

Anthropomorphism is the act of attributing human-like qualities to non-human organisms or objects, particularly computers and robots [12] [13]. Such qualities include physical characteristics, like human size and shape, as well as perceivable behaviors and mannerisms. For service robots, we identified four levels of anthropomorphism, including: (1) non-anthropomorphic robots; (2) robots designed with certain anthropomorphic features as well as intentional deviations from the human "prototype"; (3) robots with uncanny resemblances to the human "prototype"; and (4) highly humanoid robots (this may be an idealized level given current robot technology). We classified the identified service robots according to these levels of anthropomorphism by considering both the fidelity of physical features and behaviors, relative to human features and behaviors.

TABLE I
SUMMARY OF EXISTING SERVICE ROBOTS

Application	Robot	Type	Anthropomorphism Level
Hospital delivery	Helpmate [11]	Implemented in hospital. Not commercially available now.	Level 1
	TUG [6]	Commercially available.	Level 1
Cognitive prosthesis	Pearl [8]	Research prototype tested in one retirement community.	Level 2
Social interaction	Hug [14]	Research prototype.	Level 2
Intelligent walker	DO-U-MI [15]	Research prototype.	Level 2
Telemedicine	Sister Mary [16]	Tested in a hospital.	Level 2
General service	METI [17]	Research prototype.	Level 2
	Care-O-Bot [18]	Commercially available.	Level 2

B. *Interface Features*

The design of interfaces for service robots is dependent upon the type of interaction required. This, in turn, is dictated by: the type of application, environmental conditions, and the end-user. General forms of interaction in human-robot interaction (HRI) applications include: explicit input (keystrokes, voice commands, etc.), implicit input (direction of voice), information from the external environment (location and barriers), and output [19] [20]. A service robot may be required to support all these forms. For example, the Aethon Tug [6] supports pharmacist programming of medicine delivery routes through a simple touch-screen interface (explicit input), which also allows the pharmacist to monitor the robots progress and be aware of its success or failure in delivery tasks (information from the external environment). As robot teammates/collaborators, nurses are only required to command a "stop" of the Tug robot with a push-button, unload the robot cargo from a password protected compartment, and send the vehicle on its way with the press of a "go" button (explicit input). The interface features on the robot are designed to keep the interaction simple and intuitive while facilitating secure handling of items.

However, the most important type of robot interaction in a hospital or nursing home environment may occur with patients. Considering delivery robots again, as an example, current commercially available units deliver medicines to nurse stations throughout hospitals, but it is expected that in the near future they may deliver medicines directly to the patient. This will require additional interface features that are supportive of social interaction between the robot and patient. Based on a review of interface features implemented in existing service robots (see Table II), there appear to be three key elements: (1) illusion or presence of a face and/or head; (2) voice capabilities; and (3) the way the user interacts with the robot (e.g., keypad to acknowledge medicine delivery and touch screen to display relevant prescription information). These elements of service robot interface design have not been systematically tested to determine the impact on patient-robot interaction effectiveness or patient perception of humanness and emotional responses. Furthermore, there is no information on which combination of interface features will be most accepted by users as natural and comfortable for interaction.

TABLE II
SUMMARY OF SERVICE ROBOT INTERFACE FEATURES

Application	Robot	Interface features
Hospital delivery	Helpmate [11]	Voice output (no voice recognition); Keypad.
	TUG [6]	Voice output (no voice recognition); Keypad.
Cognitive prosthesis	Pearl [8]	Touch screen at eye height; Synthesized voice with speech recognition; Moveable humanoid head with facial expression capability (mouth and eyebrow angles); Motorized eyes for saccading (balanced color CED cameras).
Social interaction	Hug [14]	Squeezes/hugs and voice output.
Intelligent walker	DO-U-MI [15]	Camera-like head; Touch screen.
Telemedicine	Sister Mary [16]	LCD screen presenting image of doctor (similar to teleconferencing); Speakers to output doctor's voice.
General service	METI [17]	Voice and voice recognition; Gesture movements; LCD presenting computer graphic of face with expressions controlled by nurse; Head.
	Care-O-Bot [18]	Natural speech control interface; Visual touch screen commanding.

C. *Prior Guidelines for Robot Interface Design*

Drury *et al.* [21] developed four general guidelines for interface designs in HRI, including: (1) provide a map of the robot trace and relevant spatial information about the robot's immediate surroundings; (2) provide integrated sensor data information; (3) minimize the use of multiple display windows and present multiple robots in a single window, if possible; and (4) provide the operator with assistance to choose the most appropriate autonomy level of the robot. These guidelines are most applicable to direct teleoperation scenarios, such as in urban search and rescue involving navigating, monitoring and collecting remote data, and may have less relevance to semi-autonomous service robot applications. In addition, there is some focus on single operator, multiple robot control. Drury *et al.* argued that robot interfaces should be designed to achieve such goals to enhance operator awareness, lower cognitive load, and increase operating efficiency. Other guidelines (e.g., Goodrich and Olsen [22]) are also focused on designing efficient HRI involving manual control of robots.

Related to various types of service robots we characterized earlier, few end-user interface design guidelines have been developed with even fewer addressing different levels of anthropomorphism. One might ask whether multiple types of displays and controls are necessary on a service robot to achieve humanoid characteristics and promote perceptions of social capability as well as the degree to which different features dictate humanness. There is a need to complement existing robot interface design guidelines to support a broader design space, including contemporary health care applications, and to address robot characteristics, such as level of autonomy and anthropomorphic form.

D. *Challenges in Implementing Service Robots*

There are both technical and social barriers to implementing service robots in health care environments. Service robots are still in the early stages of development and safety and reliability in real, unpredictable and unsupervised operating environments needs to be tested and validated before actual implementation. For example, in congested hospital corridors, a robot may easily become trapped and remote (human) manual control must be used to return the robot to normal operation. This type of technical support can be a significant part of robot operating costs. There also remain many limitations of service robots from the human user's perspective, such as the capability for communication and interaction with patients (e.g., natural speech dialogue). Human expectations of humanness in service robots may lead to disillusions and negative experiences in interaction when the limits of current technology are revealed. More importantly, as many service robots are targeted at supporting the independence of elderly people, they must adapt to different types of user functional limitations due to aging (e.g., hearing and sight loss, memory limitations, etc.). To overcome these difficulties and effectively introduce service robots into the health care environment, research must be conducted on both technical and social issues.

III. ANTHROPOMORPHISM

In this section we focus on design for anthropomorphism to support social interaction [3], which is relevant to applications of service robots working with patients. The general hypothesis is that in order for a robot to be understandable to humans as other humans are, it must: have a naturalistic embodiment; interact with its environment in the same way living creatures do; and perceive the same things human find to be salient and relevant [3]. With respect to the human user, Epley, Waytz and Cacioppo [23] theorized that people's tendency to anthropomorphize non-human agents (e.g., robots) is based on three psychological determinants: (1) the accessibility of anthropocentric knowledge for application to agents; (2) the motivation to explain and understand the behavior of other agents (in terms of a human model); and (3) the desire for social contact and affiliation with agents. Epley *et al.* said people are more likely to perceive anthropomorphism when anthropocentric knowledge appears applicable, when they are motivated to be effective social agents, and when they lack a sense of social connection to other agents. Related to the present research, elderly patients in a hospital or nursing home are generally in great need of social communication and their desire to know the functional mechanisms of a robot is relatively low compared to younger people. Epley *et al.*'s theory predicts that elderly patients will be more likely to anthropomorphize a service robot.

A. *Design Principles for Anthropomorphism*

In general, using a humanoid design approach can facilitate certain aspects of social interaction, but may also lead to false expectations of robot capabilities and user perceptions of relationships with robots beyond what is actually possible [12]. It is therefore important to achieve a balance between features that give the illusion of humanness and necessary functionalities for social interaction with humans [24] [25]. DiSalvo *et al.* [25] contended that a robot's morphology must match its intended function. Similarly, Duffy [13] said that a robot's form should employ only those characteristics that facilitate social interaction with people, when required. He also points out that a robot's design should reflect an amount of "robot-ness" so users do not form detrimentally false expectations of the robot's capabilities [13], relative to the current state of technology. Foner [26] noted that strong anthropomorphic features in human-computer interaction (HCI) application design may inflate a user's expectations of the system's performance beyond what is possible. Therefore, a restrained degree of anthropomorphic form and function may be the optimal solution for robot applications integrating work and social interaction.

Mori [27] observed that there is a region of the anthropomorphic robot design space where the robot may have an uncanny resemblance to the human form and be perceived as "weird" by users. Mori called this the

"Uncanny Valley" in perception of anthropomorphic features. For example, strong human-like facial construction in robotics may suggest the capability of facial expression, but the minute subtleties in expression are very difficult to simulate and interaction with the robot may lead to negative impressions [13]. Mori maintained that the robot form should be visibly artificial, but interesting and appealing in appearance and effectively aim for the highpoint in perception of anthropomorphism before falling into the "Uncanny Valley".

In addition to design guidelines in the literature, one way to elicit design suggestions on anthropomorphism is through survey studies regarding how people generally perceive and internally represent robots. For example, Khan [28] conducted a survey to investigate people's attitudes towards intelligent service robots with results indicating a strong influence of science fiction literature. Two important findings for design include: (1) a robot with a machine-like appearance, serious "personality", and round shape is preferred; and (2) verbal communication using a human-like voice is highly desired. It is interesting to note that the preferences for physical appearance and vocal capability were not in agreement relative to addressing anthropomorphism through robot design, which may suggest the perception of anthropomorphism in technology is always partial in nature.

B. *Pros and Cons of Designing Anthropomorphic Robots*

There has been continuing debate of whether, or how to use anthropomorphic forms in robot design. Disalvo and Gemperle [12] contended that anthropomorphism in (robot) design can be useful for four purposes: (1) providing human users with the sense their interactions with the product are comparable to human-human interaction; (2) providing users with some basis to mentally explain or understand unfamiliar technologies; (3) reflecting particular humanlike attributes in products; and (4) reflecting human values. Related to this, the humanoid form has traditionally been seen as an obvious strategy for effectively integrating robots into physical and social environments with humans [13]. Opposite to the above perspectives, Shneiderman [29] stated that designers using anthropomorphism may create issues of system unpredictability and vagueness – i.e., users are not certain of what the system can actually do.

From a practical perspective, both negative and positive consequences may result from applying anthropomorphic features to robots that assist elderly patients. An important purpose of creating anthropomorphic robots is to reduce cognitive load by making HRI as natural as possible. Anthropomorphism is also supposed to help create trust between the patient and robot while establishing a feeling of partnership or assistantship. To achieve this goal, many service robots are designed using Natural Language Processing (NLP) in an attempt to reduce the amount of human learning required to use a robot interface [30]. However, for service robots targeting elderly persons, speech recognition using NLP is a major challenge. The robot may have difficulty recognizing language when users have unclear or low speech. Furthermore, for elderly people with hearing loss, using a speech interface may not always be the optimal way to communicate. In addition, some robots do not present intuitive cues to let users know whether the robot is thinking and preparing to answer, or it simply did not hear the question [9]. Thus, anthropomorphism should be designed with target user expectations and capabilities in mind.

IV. Research Framework

Based on the review of literature, we propose a research framework (Fig.1) addressing both the robot and the human user in the context of service applications. First, there may be psychological factors [23] and individual differences (in experience, attitude, arousal, and expectation, etc.) that drive the tendency of anthropomorphizing robots during HRI. Opposite to this, a robot's physical appearance and interface features also affect perceived anthropomorphism and the quality of the HRI. The underlying hypothesis is that anthropomorphism in robot design serves to mediate the perception of functional capacity, social capability (cf., Duffy [13]) and, consequently, system outcomes.

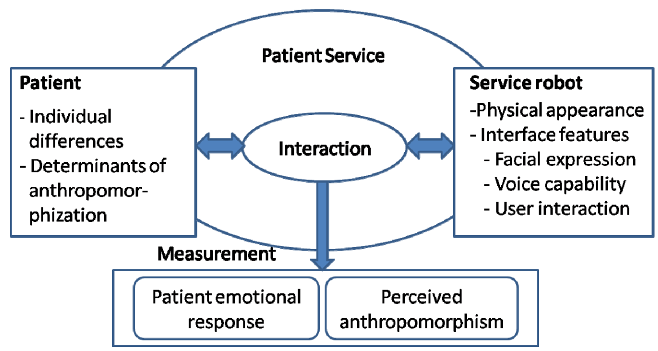

Fig. 1. Research framework.

In the health care service context, we consider patient emotional experiences activated by perceptions of a robot to be a critical measure of patient-robot interaction effectiveness, in addition to the traditional metrics of accuracy and efficiency in performance. From a design perspective, there is a need to objectively quantify the relationship between manipulation of robot interface features and user emotional responses to create quality patient interaction experiences. The research framework is intended to motivate analysis of emotional responses as a measure of patient-robot interaction, in general, and assessment of the effect of varying interface features of service robots and characteristics on emotional responses, in particular.

A. *Measures of Perceived Anthropomorphism*

We argue that anthropomorphism of robots should not be measured strictly in an engineering way (e.g., counting numbers of features or measuring dimensions of certain features), but by observing how users perceive the anthropomorphism during HRI. The perceived anthropomorphism of a robot can be assessed using, for example, subjective rating scales, narratives, word counts, or people's behavior, as they interact with a robot. Among these measures, subjective rating scales are easy to implement and can yield quantitative data. Anthropomorphism is generally believed to be a multi-dimensional construct [31], and there is no general agreement in the literature regarding the nature and the content of the dimensions. Based on the review of characteristics of service robots, we identified a set of underlying qualities of perceived anthropomorphism, comprising: physical appearance, expressiveness, task performance, and enjoyment. Physical appearance refers to the degree to which a robot physically looks like a human; expressiveness refers to the degree to which the robot can clearly express its states and intentions; task performance is the degree to which the robot can perform intelligent assistance and take initiative in interaction with humans; and enjoyment refers to the degree to which the user enjoys interacting with the robot and thinks that "(s)he" is smart. Different service robots may differ in these dimensions due to different interface features, different HRI contexts, or different user characteristics, which result in different overall levels of anthropomorphism as identified in Table I. The qualities of anthropomorphism may be subjectively rated by robot users as a basis for overall assessment of the humanness of a design.

B. Measures of Emotional Response in HRI

Using emotional responses to evaluate patient-robot interaction requires an effective technique of identifying specific emotion states within an emotional space. Russell [32] [33] and Lang [34] suggested that emotion states are not independent, but rather are interrelated. They defined a two-dimensional emotion space including: *pleasuredispleasure* (Lang called this valence), and *arousal-sleepiness*. Russell said the typical course of an emotion involves: (1) an event, or some combination of events (internal or external), producing a noticeable change in an individual's state; (2) the individual automatically perceiving this change in their core affective state in terms of pleasure-displeasure and arousal-sleep; and (3) the individual seeking to label the emotional state. For example, a state of high pleasure/high arousal might be labeled as excitement; displeasure/low arousal might be considered depression; displeasure/high arousal can be considered distress; high pleasure/low arousal can be considered serenity. In line with this theory, methods have been proposed for assessing emotional state from both subjective [35] and objective (i.e., physiological) responses [36].

Previous studies of human emotion responses in HCI applications (e.g., [36]) have used physiological measures (e.g., galvanic skin response, facial EMG, and heart rate) for inferring emotion states using fuzzy set classification. Such measures may also be useful and readily accessible for assessing patient emotion states when a service robot is providing care. Related to this, the empirical process for study of our research framework may involve five steps: (1) specify interface features represented in a certain anthropomorphic form of a robot; (2) allow the participants ("patients") to interact with the robot and expose them to the interface features; (3) collect physiological responses during the interaction; (4) use the two-dimension emotional space [34] [35] to identify any possible emotion states; and (5) use subjective measurements (surveys of user emotions) to validate the results generated from the physiological responses. This process must be based on a comprehensive understanding of the service tasks under study, the hospital environment, and the patient characteristics. Because of space limitations, the detailed steps of this process are not presented here.

V. Conclusion

There is a wide range of service robot technologies currently available and being used in health care and nursing home facilities. In the near future, applications will likely involve increased direct patient-robot interaction, particularly in medicine delivery tasks. This will potentially add to the complexity of interface design for such technologies. The interface requirements of existing users, including nurses, pharmacists and support operators, include programming, monitoring, data collection and navigation. Robot interaction with patients poses additional requirements, including social interaction. With this in mind, the degree of anthropomorphism in service robot design, and patient perceptions of social capabilities, are considered to be critical aspects of design. Interface design guidelines have been formulated for HRI applications but they tend to focus on teleoperation-oriented applications and few guidelines address anthropomorphism. Research on anthropomorphism in design suggests that human perceptions of device functionality are largely influenced by anthropomorphic features. Consequently, we believe anthropomorphism may mediate the role of fundamental robot features, such as interfaces, level of autonomy, etc., in the quality of patient-robot interaction. We also contend that one of the most important response measures for assessing the quality of patient-robot interaction is patient emotion state. Future research should make use of physiological and subjective measurements of emotion as an evaluative tool for HRI in service contexts in order to assess various interface designs and to formulate affective design guidelines. We have proposed a simple framework by which to organize future research.

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