Understanding Robot Acceptance

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Table of Contents

Executive Summary

Robots are increasingly being applied to home and healthcare settings, designed to serve as personal systems. The concept of personal use implies that a robot may interact socially or collaboratively with users having little or no formal training (Breazeal, Brooks, Chilongo, Gray, Hoffman, Kidd, et al., 2004). Given that the use of personal robots may be expected to become a part of people's everyday lives and that radical technologies, such as robots, may not be as readily accepted as incremental technology (Dewar & Dutton, 1996; Green, Gavin, & Aiman-Smith, 1995), it is critical to understand the factors that may increase acceptance and adoption.

Despite the ever growing development and public interest in robotics, a theoretical model specific to robot acceptance has yet to be developed. Acceptance has been widely studied for other forms of technology. For instance in the information systems literature, a number of technology acceptance models have been developed, such as the Technology Acceptance Model (TAM; Davis, 1989), the Unified Theory of Acceptance and Use of Technology Model (UTAUT; Venkatesh, Morris, Davis & Davis, 2003), and the Chain Model (TPC; Goodhue & Thompson, 1995). These models differ in complexity and content, however, their overarching goal is to understand, explain, and model predictive variables that contribute to user acceptance.

General technology acceptance models provide guidance for understanding the variables that influence robot acceptance. With an understanding of these variables, robot developers may be able to design robots that are more likely to be adopted. The goal of this technical report is to identify potential factors that predict user acceptance of personal robots. The following categories of variables have been identified in the literature as potentially impacting robot acceptance: robot function, robot social capability, and robot appearance.

One important aspect of functionality is the robot's autonomy level. Autonomy has been described as a continuum, ranging from teleoperation to full autonomy (e.g., Yanco & Drury, 2002). Along this continuum, the nature in which the robot and human interact is expected to change. Control and interface issues, such as the appropriateness of the control method for the task, the ease of use, and user preferences, would be expected to impact user acceptance and adoption, as well.

Second, the social capability of the robot may influence acceptance. Variables such as social intelligence, emotion expression, and nonverbal social cues may influence the user expectations about the robot's social capability. A mismatch between the users' expectations and the actual social intelligence of the robot may negatively impact acceptance and use of the robot. Social cues may facilitate the believability of a robot's social capability (Breazeal, 2002), however the believability of those social cues may be crucial in acceptance, as well.

Robot appearance is also expected to influence acceptance. Human-likeness, structure or form, and gender may influence perceptions of and attitudes about a robot's appearance. Some robots are designed to be animal-like or machine-like and how users identify these characteristics may influence acceptance. More research is needed to understand what traits people attribute to robots based on their appearances, regardless of whether they were designed to be human-like, machine-like, animal-like or life-like. That is, users may make attributions, and therefore decisions about acceptance, counter to what the robot designers intended.

Based on our review, we have identified a number of open research questions. These questions represent avenues of further research to better understand user acceptance of personal robots. The field of human-robot interaction (HRI) is an exciting and open research domain, and understanding robot acceptance can inform designers in developing personal robots that will be more widely adopted.

Introduction

Due to continuing technological advancements, robots have been increasingly designed for personal use. Personal robots have been developed for domestic, healthcare, and entertainment settings. Generally, personal robots are designed to perform simple servant-like tasks (e.g., the robotic vacuum cleaner Roomba), or to be used purely for entertainment (e.g., Sony's robotic singing Elvis). However, as robot capability increases, personal use cases include a larger variety of tasks and more complex social functions. The concept of personal use implies that a robot may interact socially or collaboratively with users having little or no formal training (Breazeal, Brooks, Chilongo, Gray, Hoffman, Kidd, et al., 2004). Therefore, a critical issue that emerges is user acceptance of personal robots, given that personal robots are expected to eventually become an integral part of people's everyday lives.

What is meant by the term *user acceptance* and specifically, what does it mean to accept a robot? Does acceptance imply that the user wants to buy a robot? Or that the user is willing to interact with it? Or that users want one in their home? The technology acceptance literature provides insight about the conceptualization of robot acceptance. Generally, acceptance has been described as a combination of attitudinal, intentional, and behavioral acceptance (Davis, 1989). Attitudinal acceptance is the users' positive evaluation or beliefs about the technology. Intentional acceptance is the users' plan to act a certain way with the technology. Finally, behavioral acceptance is defined as the users' actions in using the product or technology. Although these distinctions are important, in this report we will discuss acceptance in a general sense, including all of these dimensions.

Technology Acceptance as a Basis for Robot Acceptance

The Technology Acceptance Model (TAM; Davis, 1989) is the most widely recognized model of technology acceptance. The TAM was developed to understand/explain/model prospective expectations about information technology usage. The model proposes two main variables that affect acceptance: perceived usefulness and perceived ease of use. There is strong empirical support for the TAM (Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003), in part due to its ease of application to a variety of domains. However, the model's simplicity has evoked some criticism (Bagozzi et al., 1992), and those criticisms have led to the development of other models. For example, the Unified Theory of Acceptance and Use of Technology (UTAUT) Model (Venkatesh, Morris, Davis & Davis, 2003) was developed with the intent of unifying a large number of acceptance models. UTAUT posits that technology acceptance may be determined by the follow constructs: performance expectancy, effort expectancy, social influence, and facilitating conditions. An alternative model, the Technology-to-Performance Chain Model (TPC; Goodhue & Thompson, 1995), asserts that technology adoption is impacted by the technology's utility and its fit with the tasks it is designed to support (referred to as task-technology fit).

The factors and constructs included in these models (TAM, UTAUT, and TPC) build upon one another, with UTAUT having roots in the Technology Acceptance Model, and TPC having roots in information systems literature. Table 1 organizes the key constructs as proposed by these three technology acceptance models.

Table 1
Overview of Technology Acceptance Models

Model	Predictor Construct	Description
Technology Acceptance Model (Davis, 1989)	Perceived Usefulness	The degree to which a person believes that using a particular system would enhance his or her job performance
	Perceived Ease of Use	The degree to which a person believes that using a particular system would be free of effort
Unified Theory of Acceptance and Use of Technology Model (Venkatesh, Morris, Davis & Davis, 2003)	Performance Expectancy	The degree to which an individual believes that using the system will help attain gains in job performance
	Effort Expectancy	The degree of ease associated with the use of the system.
	Social Influence	The degree to which an individual perceives that important others believe they should use the new system
	Facilitating Conditions	The degree to which an individual believes that an organizational and technical infrastructure exists to support use of system
Technology-to-Performance Chain Model (Goodhue & Thompson, 1995)	Technology	Tools used by individuals in carrying out their tasks
	Individuals	People using technologies to assist them in the performance of their tasks
	Task-Technology Fit (TTF)	The degree to which a technology assists an individual in performing his or her portfolio of tasks
	Utilization	The behavior of employing the technology in completing a task
	Performance Impact	The accomplishment of a portfolio of tasks by an individual

Table 1 reflects the variety of factors and constructs related to general technology acceptance models that have been researched. Do these technology acceptance models, factors, and constructs readily generalize to robotics? Currently available robot attitude questionnaires (discussed in the next section) do not adequately investigate robot acceptance, per se. Although the application of technology acceptance models to robotics has yet to be thoroughly analyzed (for an exception see Ezer, Fisk, & Rogers, 2009a), we propose that understanding acceptance of robots may require consideration of other factors not included in the above mentioned technology acceptance models.

Robot Attitude Questionnaires

Research investigating *robot* acceptance has focused in large part on user attitudes toward robots. The most widely recognized robot attitude scales are the Negative Attitude Towards Robots Scale (NARS; Nomura, Suzuki, Kanda, & Kato, 2006a; Nomura, Kanda, Suzuki, & Kato, 2004) and Robot Anxiety Scale (RAS; Nomura, Suzuki, Kanda, & Kato, 2006b), used to gauge psychological reactions evoked in humans by human-like and non-human-like robots. These scales assess the extent to which people feel unwilling to interact with a robot due to arousal of negative emotions or anxiety.

The NARS assesses negative attitudes toward robots considering three dimensions: interaction with robots, social influence of robots, and emotional interactions with robots. RAS also has three dimensions or sub-scales: anxiety toward communication capability of robots, anxiety toward behavioral capability of robots, and anxiety toward discourse with robots. It can be used to assess state-anxiety in real or imaginary interactions with robots. Bartneck, Nomura, Kanda, Suzuki, and Kato (2005) used the NARS to demonstrate that Japanese individuals may have more negative attitudes toward robots than Chinese or Dutch. Some studies using NARS have also shown that female participants have less negative attitudes toward robots as compared to male participants (Nomura, Kanda, & Suzuki, 2006; Bartneck, Suzuki, Kanda, & Nomura, 2007). Bartneck et al. found that members of online AIBO (a robotic dog created by Sony) communities had lower NARS scores than individuals who were not members of any AIBO community. However, fear reactions (or feelings of fear) and negative attitudes, as measured in NARS, only capture a portion of influential factors on robot acceptance.

Potentially limiting is that the NARS and RAS scales focus only on negative affect and lack measures of users' positive evaluations of the robot and their interactions with it. Moreover, these scales do not provide any insights into the underlying causes of negative feelings toward robots. For instance, anxiety toward a robot may be due to the nature of participants' mental models or stereotypes against robots. However, anxiety toward robots may also be due to lack of familiarity with robots in general, and thus could be eased over time as participants become more accustomed to robotic assistants. Furthermore, NARS and RAS do not measure other factors that have been shown to impact technology acceptance, such as perceived ease of use.

Understanding and predicting robot acceptance is particularly difficult because personal robots have the potential to engage in interactions with users that are more socially complex than interactions with other technologies. It is unknown whether users will place equal consideration on the perceived capability/function of a personal robot, as on its perceived social intelligence. Most technology acceptance models do not include a social variable or construct. An exception is the UTAUT model (Venkatesh, Morris, Davis, & Davis, 2003), which includes the construct of social norms/influence. However in this model, social norms focus on person-person social interaction, not person-technology social interaction.

Additionally, the technology's appearance does not play a major role in the current technology acceptance models. However, it is conceivable that robot form or appearance would influence acceptance. For example, robot appearance can take the form of a functionally-relevant design (e.g., the iRobot Roomba vacuum robot), or a socially-relevant design (e.g., emotive facial expressions of the Philips iCat). The impact of appearance on users' perceptions of robot function, intelligence, or capability is an area in need of exploration.

Finally, personal robots are a radical technology. That is, personal robots are different from traditional robots (i.e., industrial or military robots), because they can be collaborative, adaptive, and personalized. Furthermore, personal robots are radical designs because they are a rapidly developing technology in the scientific community, and newly applied to a variety of applications. Designers should be mindful of users' acceptance, because radical technologies, have been shown to not be as readily accepted as incremental innovations (Dewar & Dutton, 1996; Green, Gavin, & Aiman-Smith, 1995). Variables that have been shown to be predictive of acceptance of incremental innovations, may not apply to radical personal robots.

Identifying potential factors that affect robot acceptance can increase levels of user acceptance by ensuring that the predictive variables are considered when robots are designed and introduced. There is a need to develop a model of robot acceptance to answer a variety of research questions. What are the key variables that influence robot acceptance? Which variables are most predictive, and how do they interact? The purpose of this technical report was to identify factors that predict user acceptance of personal robots with varying function, social capability, and appearance. We identified the categories of variables that have been identified in the literature as potentially important. We discuss the relevance of these variables to robot acceptance, the empirical literature and measurement approaches, and open research questions.

Robot Characteristics and Acceptance

Robot Functionality

Tasks. Service robots have been designed for work settings (e.g., Willow Garage Texai http://www.willowgarage.com/pages/texai/overview), and healthcare (e.g., Nursebot http://www.cs.cmu.edu/~nursebot/). The home setting is increasingly being considered as a potentially large market for service robot applications.

People require assistance in home-based tasks for a number of reasons. For example , limitations in physical capabilities may be caused by a birth-defect or an injury, and be persistent (e.g., loss of a limb) or temporary (e.g., a broken arm). In addition, some physical limitations are associated with aging. In cases where declination in physical health creates a need for assistance, people employ service of informal or professional caregivers (CDC, 2004). However, there is the potential for robots to help with home tasks as well as home healthcare.

Older adults prefer to age in place (AARP, 2005). There are many tasks that older adults must perform to maintain their independence and health, including self-maintenance, instrumental, and enhanced activities of daily living (Lawton, 1990; Rogers, Meyer, Walker, & Fisk, 1998). Self-maintenance activities of daily living (ADLs) include the ability to toilet, feed, dress, groom, bathe, and ambulate. Instrumental activities of daily living (IADLs) include the ability to successfully use the telephone, shop, prepare food, do the housekeeping and laundry, manage medications and finances, and use transportation. Enhanced activities of daily living (EADLs) include participation in social and enriching activities, such as learning new skills and engaging in hobbies. Age-related changes in physical, perceptual, and cognitive abilities may make performing these tasks more difficult or challenging for older adults.

Even for individuals, of all ages, who are physically fit, robots may play a beneficial role in saving time and effort. Moreover, high workload in people's professional lives may prevent them from regularly taking care of some or many household activities, such as vacuuming, cleaning, lawn mowing. Well-designed, functional robots can facilitate timely maintenance of the home and its surroundings. A variety of robots are under development that may potentially assist with everyday living tasks (for review, see Smarr, Fausset, & Rogers, 2011); however, it remains unclear what type of home-tasks people would be most willing to accept a robot performing or assisting with.

To better understand the potential for home-based assistive robots, Ezer et al. (Ezer, 2008; 2009a; 2009b) sampled 60 younger and 117 older adults, in a questionnaire designed to examine the characteristics and functionality of a robot participants were asked to imagine in their home. Table 3 presents the percentage of each type of task mentioned in participants' robot descriptions and drawings out of all task types mentioned.

Table 3
Specific Tasks Younger and Older Adults Reported Wanting a Robot to Perform

Task	**Percentage of participant responses**
Cleaning/Chores	35
Security	10
Physical Aiding	9
Working on other machines	8
Cooking	7
Maintenance/Repairs	5
Service	3
Entertainment	3
Health-related activities	3
Cognitive Aid	3
Company/Conversation	3
Other	11

The tasks listed in Table 3 were analyzed further to examine how they varied along the dimensions of interaction-level and criticality. Interaction level is the amount of human-robot interaction the task entails. That is, some tasks may be highly interactive tasks whereas some may involve infrequent interaction between the user and the robot. The second dimension of criticality relates to a measure of how serious the nature of the task being performed by the robot is. Younger and older adults showed the most willingness to have robots perform critical, infrequent tasks (Ezer, 2008). Participants least preferred to use a robot for tasks that involved a lot of interaction with the robot or to form friend-like relations with the robot, a finding consistent with previous surveys (e.g., Dautenhahn et al., 2005). Ezer and colleagues also found that older adults were more willing than younger adults to have a robot's assistance in critical monitoring tasks and in emergency situations. However, older adults reported being as willing as younger adults to have robots perform service and interactive tasks.

The results of the Ezer et al. (2009a, 2009b) studies provide insights into what tasks individuals might want a robot to perform. In particular, the results indicate that there were age-related differences in the nature of the tasks and services that respondents desired a robot to perform. This is an important consideration for robot acceptance; particularly because service robots will interact with users of all age groups. However, it is important to note that their questionnaire did not specify a particular robot. Therefore, a caveat to consider when interpreting these results is that participant views were limited by their imagination of what a robot could do for them.

Autonomy. Robot autonomy is an important factor of human-robot interaction (Yanco & Drury, 2002). More than any other area of study, roboticists have strived to empower their technology designs – their robots – to make decisions and actions. Autonomy may be defined generally as a robot's capability to accommodate to variations in the environment (Thrun, 2004). A more detailed definition of autonomy identifies the environment, the task, and the level of human interaction to be three major characteristics determining the autonomy level (Huang, Messina, Wade, English, Novak, & Albus, 2004). That is, any combination of the complexity of the environment (e.g., obstacles in navigation), the difficulty of task (e.g., one goal vs. many goals), and/or the nature of human interaction (e.g., team dynamic) may require a robotic system to demonstrate a specific level of autonomy to function proficiently.

Autonomy may be thought of as a continuum. For example, Huang and colleagues (2005) proposed an 11 stage autonomy model, ranging from teleoperation (full human control) to a fully autonomous agent (full robot control). Similarly, autonomy has been defined as having an elastic relationship with human intervention. If autonomy is defined as the time that the robot is carrying out a task on its own, and intervention is defined as the time that the human is carrying out a task on his/her own, then the two measures should sum to 100% (Yanco & Drury, 2002). For instance, for a teleoperated system autonomy would be 0% and human intervention would be 100%. For robots with full autonomy (i.e., delivery robots that can localize themselves) autonomy would be 100% and human intervention would be 0%.

In between teleoperation and full autonomy is a continuum of shared control between the robot and human. Any autonomy/intervention ratio where either endpoint does not equal 100, is considered to be within the range of shared control (e.g., robot autonomy = 75%, human intervention = 25%). Although traditionally shared control is usually studied as a fixed point, in practice there may be instances where the robot may slide up or down the autonomy continuum to modify its autonomy level to match the requirements of the task or the performance level of the human. Much like levels of automation (Endsley & Kaber, 1999; Parasuraman, Sheridan, &

Wickens, 2000), this sliding autonomy has been referred to as adjustable autonomy (Sellner, Heger, Hiatt, Simmons, & Signh, 2006).

It is important to note that *intervention* does not necessarily equate to *interaction*. That is, even if the human intervention equals zero, human-robot *interaction* (e.g., social interaction with an autonomous personal robot) may still take place. The nature of robot use and interaction with users changes as a function of robot capability. The autonomy level of the robot determines the types of tasks the robot is capable of performing, in addition to the level and nature of the interaction between the robot and human. Additionally, the required autonomy level may depend on the variability of the task environment. For example, personal robots, which operate in an environment with people, may require a higher level of autonomy because people are less predictable than stationary objects (Thrun, 2004).

Why is robot autonomy relevant to acceptance? A robot's autonomy level may affect the perceived usefulness of the robot. It is critical that the robot's autonomy level meets the expectations of the user. If a required level of autonomy is not met for a given environment, task, or interaction, then the robot may be deemed as not useful. For example, if a home robot was incapable of navigating accurately through the home environment (e.g., it runs into obstacles), the robot may be perceived as useless, even if its capability to perform other tasks (e.g., medication reminders) was reliable. The level of autonomy is expected to affect the nature of the interaction between robot and user, by impacting the users' perceived intelligence and social intelligence of the robot.

Control and interfacing. An additional factor that may influence acceptance is the nature in which the human controls and interfaces with the robot. Scholtz (2003) described five roles in which the human may partake while interacting with a robot: supervisor, operator, teammate, mechanic/programmer, and bystander. A supervisor monitors the robot's behavior; however, the supervisor does not necessarily need to directly control the robot. For example, in a search and rescue context a supervisor may command a robot to go to a specific location, but the robot plans and navigates to that location on its own. An operator, on the other hand, may directly control the robot. Whether the robot is teleoperated (full human control) or some form of shared control is required, the operator needs to manipulate the robot's behavior to some degree. Alternatively, a teammate collaborates with the robot to complete a task. The teammate and robot may have shared subtasks or separate subtasks, but it is important that they are working toward the same end-goal. Finally, a bystander does not control the robot, but may be in the same environment as the robot. For example, an individual in the same room as the robotic vacuum cleaner, Roomba, must have an understanding of the robots' task to avoid disrupting it.

Control refers to a situation in which a user/operator gives a robot a command, and the robot executes that command. Depending on a robot's level of autonomy and capability, the nature of the human control may vary considerably. Table 2 highlights teleoperated and shared control methods found in the literature. This overview provides a sense of the range and scope of robot control methods. Each control method is likely to impact human-robot interaction. Additionally, each method of control is likely to have a variety of human factors-related challenges in both implementation and acceptance. The way in which the user interfaces with the robot may impact their perceived and actual usefulness and perceived ease of use.

Table 2
Descriptions of Robot Control Methods and Related Work

Control Method	Description of Control Method	Related Work
Computer input/output control devices	Operated remotely using interfaces similar to radio controlled cars, gaming counsel controllers, mouse and keyboard, joystick, etc.	• Duran, Fernandez-Carmona, Urdiales, Peula, & Sandoval, 2009 • Csencsits, Jones, McMahan, Iyengar, & Walker, 2005
Demonstration and Direct Physical Interfaces	Human performs the task, while monitored by the robot. The robot then learns the strategy for performing task. Similarly, human may physically manipulates robot (e.g., moves robot arm). These physical commands are then interpreted by robot.	• Billard, Calinon, Ruediger, & Schaal, 2008 • Nicolescu, & Mataric, 2003 • Chen, T. L. & Kemp, C. C., 2011
Gesture Recognition	Robot monitors the physical movements of the user and either mimics movement, or uses movements for communication/interaction purposes.	• Charles, Qixin, Zhu Xiao, & Zhang, 2009 • Bremner, Pipe, Melhuish, Fraser, & Subramanian, 2009 • Gielniak, M. & Thomaz, A., 2011
Laser Pointer	Laer-based point and click interface that enables a human to select a 3D location in the world and communicate it to a mobile robot.	• Nguyen,Jain, Anderson, & Kemp, 2008 • Kemp, Anderson, Nguyen, Trevor, Xu, 2008
Speaking	Human verbally provides commands to robot.	• Asyali, Yilmaz, Tokmakci, Sedef, Aksebzeci, & Mittal, 2011 • Ceballos, Gomez, Prieto, & Redarce, 2009 • Hyun, Gyeongho, & Youngjin, 2007
Telepresence	The human fully controls the robot (either remotely or in same physical presence).	• Michaud, Boissy, Labonte, Briere, Perreault, Corriveau, et al., 2010 • Takayama, Marder-Eppstein, Harris, & Beer, 2011

Research has documented preferences for robot interaction. Findings from questionnaires administered to a range of age groups have suggested that speech is the preferred method of control for service robots (Ezer, 2008; Khan, 1998). However, there is a need to consider the capabilities and limitations of the software and the users when designing input methods. For instance, older adults have expressed a preference for speech control of a robot

(Ezer, 2008), yet speech recognition software has limitations in understanding and interpreting language (e.g., Roy et al., 2000). In addition, if the robot is capable of speaking to the user then older adult auditory limitations (i.e., difficulty hearing high pitches) should be taken into consideration. Finally, the robot's speech capability may provide a false perception of intelligence or influence the perceived social relation with the robot (Torrey, Powers, Marge, Fussell, & Kiesler, 2006), potentially creating a mismatch between the robot's actual capability and the users' expectations. Mismatches such as these may have a negative impact on the perceived usefulness of the robot.

Moreover, there are situations in which speech may not be an ideal form of control, such as in a search and rescue context where the robot and human operator may not be located in the same space or in the case of a service robot assisting a stroke victim with limited speech capability. Hence, a variety of considerations such as the appropriateness of the control method for the task, the ease of use, and user preferences should be taken into account when designing robot controls and interfaces. These considerations would be expected to impact user acceptance and adoption.

Robot function: Open questions.

1. What methods (e.g., training) should be implemented to ensure the users' expectations of robot autonomy match its actual autonomy level?

2. To what extent will control and interfacing change as a function of task? Some forms of control may be more applicable to only certain types of tasks.

3. The relation between control methods (Table 2) and their effects on perceived ease of use is relatively undefined.

4. Many studies investigate "proof-of-concept" of robot control; however, more work is needed in actual user testing of various control methods.

Robot Social Ability

Social intelligence. Making effective intelligent agents is not only about improving the task-relevant functionality of the robot. Additionally, the social characteristics of robotic agents may influence human-robot interaction. It is generally accepted in the research community that people are willing to apply social characteristics to technology. Humans have been shown to apply social characteristics to computers, even though the users admit that they believe these technologies do not possess actual human-like emotions, characteristics, or "selves" (Nass, Steuer, Henriksen, & Dryer, 1994). Humans have been shown to elicit social behaviors toward computers mindlessly (Nass & Moon, 2000), and treat computers as teammates and having personality, similar to human-human interaction (Nass, Fogg, & Moon, 1996; Nass, Moon, Fogg, Reeves, 1995).

The emotion-expressive abilities of an agent may play a role in the development of advanced *intelligent* technology. In fact, Picard (1997) stressed that emotion is a critical component and active part of intelligence. More specifically, Picard stated that "computers do not need affective abilities for the fanciful goal of becoming humanoids; they need them for a meeker and more practical goal: to function with intelligence and sensitivity toward humans" (p. 247). However, effective and intelligent social interaction requires more than simply applying social characteristics to a robot. The level of social intelligence needs to meet the users' expectations for acceptance to take place. Social intelligence constructs such as situation-relevant expression, believability, and recognition should be considered to understand and predict robot acceptance. According to Breazeal (2003), when designing robots, the emphasis should not be whether people will develop a social model to understand robots. Rather, to facilitate acceptance, it is more important that the robot adhere to the social models the humans expect.

Emotion expression. Facial expression in particular is one of the most common non-verbal cues used to display emotion in on-screen agents (Cassell, Sullivan, Prevost, & Churchill, 2000), and has been applied to a variety of robots, such as MIT's Kismit (Breazeal, 2003) and the Philips iCat (e.g., Bartneck, Reichenbach, & Van Breemen, 2004). Facial expressions are an important means for conveying emotional state (Collier, 1985), and a critical component in successful and natural social interaction. Emotion expression is thought to create a sense of believability by allowing the viewer to assume that a social agent is capable of caring about its surroundings (Bates, 1994) and creating a more enjoyable interaction (Bartneck, 2003).

The role of social cues, such as emotion, is not only critical in creating intelligent agents that are sensitive and reactive toward humans, but also impact the way in which people respond to the agent. Previous research has shown that participants' accuracy of recognizing facial emotion of robotic characters and virtual agents is similar (Bartneck, Reichenbach, & Breemen, 2004). Furthermore, simulated visual and visual/audio affective displays of emotion are reported to be perceived as convincing, or believable, as human faces (Barneck, 2001), further supporting the assumption that humans will apply social attributes to technology (e.g., Nass et al., 1996; Nass & Moon, 2000; Nass et al., 1995; Nass et al., 1994).

The ability of a *robot* to perceive and respond to human emotional displays may also be a critical component to effective social interaction, as well as acceptance. Humans convey a great deal of meaning in their facial expressions, and a robot's ability to interpret those expressions could greatly improve human-robot communication. Ways in which robots could use image processing and face pattern recognition techniques (Lee, Park, & Park, 2006) to recognize emotion as a means of friendly interaction is a promising area of study.

Although expressions of emotion, particularly facial expressions, play an integral role in human-human interaction, the extent to which equal consideration of social quality may be placed on a robot's emotion expression capability is relatively an open question. As mentioned earlier, a social variable or construct is missing from most technology acceptance models. However, emotion expressions may impact acceptance.

Robot non-verbal social cues. Like facial expressions of emotion, other non-verbal social cues influence the way in which people will interact with an agent. Such non-verbal cues include nodding in agreement, shaking head to disagree, shifting weight, eye movement, blinking, and eye-tracking to name a few. A robot that is able to use natural dialog, as well as gesture, and non-verbal social cues creates a more cooperative relationship between the robot and human (Breazeal et al., 2004).

Applying non-verbal social attributes to robots is likely to impact the interaction of humans and robots in a team-like collaborative system. Breazeal, Kidd, Thomaz, Hoffman, and Berlin (2005) investigated how a robot's non-verbal explicit behavior (i.e., head nod, gesturing) and implicit cues (i.e., eye gaze) affected human-robotic teamwork. They found that implicit behavior was positively associated with human-robot task performance, more particularly in understanding of the robot, efficient teamwork/performance, and alleviating miscommunication. Furthermore, optimal human-robotic interaction may be dependent on the robot's ability to demonstrate a level of believability by displaying behaviors such as attention and reactivity (Breazeal, 2002). The believability of such cues may be crucial in acceptance. For example, a robot lacking dexterity in movement (e.g., jerky versus flexible limb/head movements) may be considered careless or even dangerous by the user.

Social ability: Open questions.

1. How do social intelligence constructs such as situation-relevant expression, believability, and recognition play a role in acceptance?
2. How are the users' mental models of social ability developed, and how are they refined to meet the actual capability of the robot system?
3. What role does a robot's emotional expression play in the development of acceptance by humans?
4. How do such factors as the users' age, experience, and expectations affect interpretations of social ability, such as the robot's facial expressions?

Robot Form and Appearance

Why appearance matters. People form quick impressions about an entity even when little information about it is available in the environment (Bar, Neta, Linz, 2006; Kelley, 1950). In the lack of more concrete data, people often extract certain cues from the outer appearance of their target of analysis. Such cues can range from physical attractiveness, gender, clothing, facial symmetry, and skin-textures to expressive non-verbal behavior (Weibel, Stricker, Wissmath, & Mast, 2010). These cues are organized and interpreted based on pre-existent schema, mental-models, or belief-systems (Smith, 1984; Snyder & Cantor, 1979). This is a top-down approach of cognitive processing. The overall impressions built about an entity by means of a top down process may vary across individuals depending on the type of expectations they have.

A robot is a complex machine. Although many service robots are meant to interact with humans, the human users are usually not expected to know the complicated engineering details of the system. However, the robot's physical form can help users develop some idea about its nature and capabilities. People may be prone to judge the overall characteristics of a robot by merely assessing its external features. Thus, to ensure a successful human-robotic interaction, it has been proposed that the robot be given a form that enables people to intuitively understand its behavior (Kanda, Miyashita, Osada, Haikawa, & Ishiguro, 2008). Furthermore, it has been suggested that an appropriate match between a robot's appearance and its task can improve people's acceptance of the robot (Goetz, Kiesler & Powers, 2003).

As an interactive, assistive technology, a robot should have an appearance that is suitable for its target user group and the system should fit with the expectations of the population it is designed to assist. However, there may be differences among people in the assessment of robot appearances depending on their age, health, personality, or culture (MacDorman, Green, Ho, & Koch, 2009). An appearance that arouses negative emotions in one individual can receive a neutral or positive evaluation from another. For example, children in the age range of three to five were scared of the Repliee R1 child android whereas one-year old babies were attracted to it (Minato, Shimada, Ishiguro, & Itakura, 2004).

Human-likeness of robots. Human-likeness of a robot can be analyzed by finding similarities between its physical structure and a human body. A robot that has a human form or bears human features such as a face, arms, and legs is generally considered more human-like than a robot that has a distinctly mechanical appearance. Research is ongoing to assess to what extent people would want a robot to resemble a human, nevertheless at a generic level a robot's appearance should not be scary, repulsive, or anxiety-provoking for the user. The design should be such that the user feels comfortable in initiating and maintaining interactions with the robot (Disalvo, Gemperie, Forlizzi, & Kiesler, 2002).

The Uncanny Valley Theory (Mori, 1970; translated by MacDorman & Minato, 2005) is a popular theory that tries to relate human-likeness of a robot with the level of familiarity evoked in the person interacting with the robot. Mori hypothesized that, as robots appear more and more human-like, people's familiarity with them increases until a point where this relationship ceases. Beyond this critical point, the appearance of the robot increases in human-likeness but the appearance no more evokes a feeling of familiarity. The robot instead is perceived as strange in appearance.

According to Mori, a prosthetic hand exemplifies this situation. With improvement in technology, a prosthetic hand has become indistinguishable from a real hand, especially when viewed from a distance. However, when an individual shakes the hand, he or she is surprised by the lack of soft tissues and cold temperature. Thus, after a tactile interaction, the prosthetic hand does not feel familiar anymore despite its real hand-like appearance. This may be due to a disparity between the appearance of the object and the expectations of the person. Mori also argued that if the robot's human-likeness can be further increased to almost entirely match the appearance of a human, familiarity will rise again and will be maximized when the robot cannot be distinguished from a healthy person. The region of dip in familiarity with increasing familiarity is called the uncanny valley (see Figure 1).

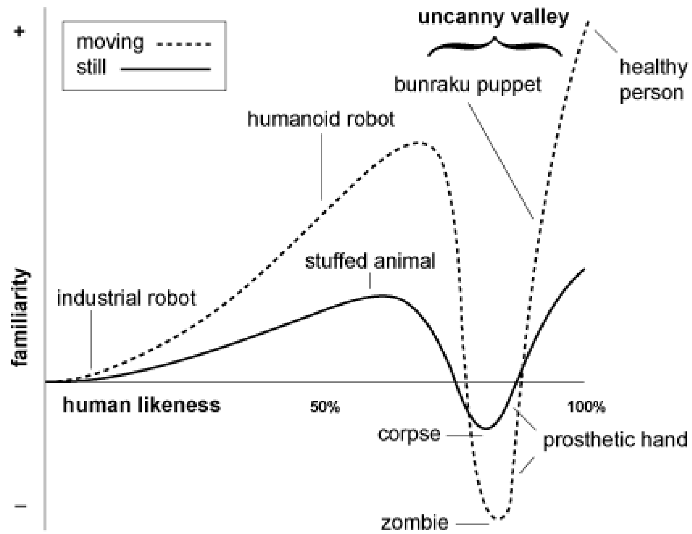

Figure 1. Mori's hypothesized uncanny valley diagram (translated by MacDorman & Minato, 2005)

Studies investigating preferences for the human-likeness of robots have provided mixed results. Overall, young adults (university undergraduates) have been found to have a preference for a human-like appearance of robots (Walters, Syrdal, Dautenhahn, Boekhorst & Koay, 2008; Ezer, 2008). However, as compared to others, introverts and individuals with low emotional stability are more likely to prefer mechanical looking robots (Walters et al., 2008).

Robot appearance not only affects preference, but also people's perceptions of the robot's personality. For instance, in an examination of the relationship between robot appearance and personality, one study found that children between the age of 9 and 11 considered robots with mixed human-robot features to be friendlier than completely mechanical looking robots (Woods, 2006). However, they judged pure human-like robots (i.e., robots modeled after human form and features) to be the most aggressive of all other robots. Robins, Dautenhahn, Boekhorst, and Billard (2004) investigated the effect of robot's human-likeness on the level of interaction with it by children with autism. By measuring the duration of eye gaze, touch, imitation, and physical closeness with the robot, the authors inferred that children with autism in their initial response preferred to interact with a plain, featureless robot to a more human-like robot.

Additionally, appearance has been shown to affect the way in which adults interact with a robot fulfilling the role of a peer. An experiment was conducted to examine people's response to robot's human-likeness when the robot played the role of a co-worker (Hinds, Roberts & Jones, 2004). People felt more responsible when working with a machine-looking robot than when working with a human-looking robot, particularly when the robot was in a subordinate position. Based on this finding, Hinds et al. suggested that robots should be made mechanical-looking when assisting in environments where personal responsibility is important. However, this conclusion is premature based on a single study.

Researchers have also attempted to compare people's reactions toward a realistic looking robot compared to an actual human. Bartneck, Kanda, Ishiguro, and Hagita (2009) assessed whether people liked the human more than the robot, which had a similar appearance to that of the human. The robot used was a Japanese android named Geminoid H1-1, which is a replica of Hiroshi Ishiguro, one of the researchers. Hiroshi Ishiguro served as the human stimulus. Participants viewed the android and Ishiguro from a distance of one meter. The findings showed that although participants were able to differentiate between the android and the human (i.e., human-likeness ratings were significantly higher for the human-stimulus as compared to the android stimulus), their likeability for the two stimuli were not significantly different. This implies that people can like a human and a human-looking robot to the same degree. However, at a cognitive level, *how* people decode a robot's human-like appearance versus a human's appearance still needs to be explored.

In summary, attitudes toward human-like robots seem to be influenced by factors such as the individual's age and personality, and the robot's role. However, given that research in this domain is still in an exploratory stage, we have to be careful in drawing general conclusions from the studies conducted so far. Most of these studies involved a limited range of human-robotic interaction, such as viewing the robot from a distance or interacting with it in an unfamiliar setting for a limited time. Therefore, the results cannot be easily generalized to contexts and types of interaction other than those assessed in the experiments. However, it can be assumed that people's attitudes toward robots, as influenced by the robot appearance, affects acceptance and adoption.

Robot structure. It is important to assess which body features people would like a robot to have so that it could be designed not only to appear more functional but also more likeable and acceptable. It is also worthwhile for robot designers to know the appropriate size a robot should be and if the size should be adjustable. Ezer and colleagues (2008; Ezer et al., 2009a, 2009b) asked participants to imagine a robot that was given to them to have in their home. Participants were then asked to write a description of this imaginary robot and also draw a picture of it. The descriptions and drawings were analyzed based on a coding scheme that assessed salient features of robot appearance and differences between human-like and machine-like robots. The findings were as follows:

<u>Height:</u> Only one participant in the study indicated the robot to be taller than an average adult person. The majority of participants (81%) indicated the robot to be of a lesser or the same height as that of an average human adult. Most others (15%) described the robot to have multiple or changeable height(s).

Body features: More than half of participants indicated that the robot had a head and 40% ascribed a face to their robot. The most common facial features indicated were (in decreasing order of frequency) eyes, mouth, nose and ears. Almost all participants described their robots to have two arms. Most imagined their robot as mobile and to have two legs (55% of people who indicated imagining a mobile robot), wheels (39%), or treads/tracks (5%).

This study also provided some evidence that younger adults imagine their robots to be more human-like in overall appearance as compared to older adults. Younger adults also specified their imaginary robot to have more facial features than did older adults. Presence of facial features plays a role in making a robot more human-like. A study on the design of humanoid heads found 62% of the variation in the perception of human-likeness of a humanoid head to be accounted for by the presence of facial features (Disalvo, Gemperie, Forlizzi, & Kiesler, 2002). Nose, eyelids and mouth were found to be the facial features that correspond with a robot being perceived as having high human-likeness.

Creating human-like robots that individuals will adopt may require more than simply adding human facial features or form. From an aesthetic approach of designing, consistency in a robot's structure affects its appearance and thereby, may influence people's acceptance of the robot. Unity and prototypicality are important visual aspects of a product design (Veryzer & Hutchison, 1998). Unity refers to how well the various elements of a product aesthetically match with each other. Prototypicality is the degree to which a product represents a category (Barsalou, 1985). There are many examples of humanoid robots that do not fulfill the unity and prototypicality criteria of design. For example, Robot hand H-type is a very realistic-looking arm but is attached to a headless body; Albert Hubo is a robot that has a face that closely resembles Albert Einstein's but its body is distinctly mechanical-looking. Despite a close resemblance to certain human features, these robots may not be perceived as highly human-like due to their structural inconsistencies.

If a robot head is wider than it is tall, it is perceived as more robot-like (and therefore, less human-like) in appearance (Disalvo, Gemperie, Forlizzi, & Kiesler, 2002). Moreover, the appearance becomes less human-like if the proportion of head-space for forehead, hair, or chin is reduced (Disalvo et al., 2002).

Robot gender. Although androids and some humanoids are modeled either after a man or a woman, many existing robots do not have an apparent male or female gender. Some studies have attempted to examine if people would attribute gender to a robot even when its appearance was not clearly indicative of one. One such study used robot pictures to evaluate children's perceptions of robots and found that most children between the ages of 9 and 11 assigned gender to robots, particularly male gender (Woods, 2006). Children ascribed female gender to some robots that they also rated high on primarily positive traits, such as friendliness and happiness. However, robots that were assigned male gender were associated with both positive and negative traits. This study, therefore, recommended designing female gendered robots for children; but again this is a premature conclusion based on a single study.

Bumby and Dautenhahn (1999) also found that children were more likely to assign male than female genders to robots. Moreover, adults have been found to associate a gender with Roomba, a vacuum cleaning robot, despite its distinctly non-humanlike appearance (Sung, Grinter, & Christensen, 2009). In Ezer's (2008) study with adults, few people described their robot to have a gender. Overall, the research on gender assignment for robots is inconclusive and more research is needed to understand when and why children and adults assign male or female gender to a robot.

Nevertheless, when the gender of a humanoid robot is clearly evident, it may influence how people evaluate the robot. Siegel, Breazeal, and Norton (2009) found that people tend to rate the robot of the opposite sex of themselves as more credible, trustworthy, and engaging. Is it because people perceive different gendered robots differently? Potential differences in how men vs. women make character attributions based on a robot's gender is another area that needs to be further delved into to understand how it might influence robot acceptance.

Non-humanlike robots. There are many robotic toys and pets modeled after animals (e,g., AIBO, Furby) rather than humans. Although owners of AIBO, a robotic dog, did not consider AIBO as a live dog, they did associate with it concepts such as mental states and sociability (Friedman, Kahn, & Hagman, 2003). However, people tend to anthropomorphize, that is, they attribute human-like characteristics to non-human agents (Epley, Waytz, & Cacioppo, 2007). Thus, people's perception of a robot's appearance may depend on the extent to which they anthropomorphize a robot and ascribe human-like-traits to it, even if the robot was designed based on a non-humanlike model (e.g., animal).

Another example of how people anthropomorphize robots involves a vacuuming robot. Roomba users were found to associate names and genders with their vacuuming robots (Sung, Grinter, & Christensen, 2009), which exemplifies how people can humanize even highly mechanical-looking robots. Additionally, there may be gender differences associated with the level of anthropomorphization. Schermerhorn, Scheutz and Crowell (2006) found that during brief interactions, men tended to think of an autonomous robot used in the experiment as a social entity whereas women considered it as more machine-like.

However, not all robots are designed to have a human-like appearance. In an internet survey designed to assess people's attitudes toward zoomorphic (i.e., animal-like) robots as compared to humanoid and machine-looking robots, 100 individuals viewed videos of four robots: BARTHOC (a humanoid), BIRON (a machine-looking mobile robot platform), AIBO (a dog-like robot, and iCat (a robot with a cat-like face; Lohse, Hegel, Swadzba, Rohlfing, Wachsmuth, & Wrede, 2007). The participants responded to questions such as, “which robot would you like to own?”, and “which robot is most likeable?” The majority of participants found AIBO and iCAT to be most likeable. Over half of participants considered AIBO as most enjoyable to interact with.

In sum, although people are prone to associate some human-like traits to non-humanlike robots, the underlying processes that evoke such associations are not well understood. Moreover, people’s acceptance of zoomorphic robots is also understudied. In some cases people may prefer interacting with zoomorphic robots over humanoids and machine-like robots. Therefore, to understand people’s preference for robot appearance, zoomorphic appearances should also be taken into account. Most studies have only looked at the continuum of human-likeness-machine-likeness, which excludes the scope for studying zoomorphic appearances.

Together these findings suggest that more research is needed to understand what traits people attribute to robots based on their appearances regardless of whether they were designed to be human-like, machine-like, animal-like or life-like. That is, users may make attributions, and therefore decisions about acceptance, counter to what the robot designers intended.

Robot appearance response measures. Most studies investigating the uncanny valley theory measure participants’ responses to different human-like, non-human agents. The original paper on the uncanny valley theory, which was written in Japanese, used the term *shinwakam* for the dependent variable (Bartneck, Kanda, Ishiguro, & Hagita, 2009; MacDorman et al. 2009). There has been a lack of consistency on how *shinwakam* is translated. The most common translation used is “familiarity” (e.g., MacDorman & Ishiguro, 2006). According to MacDorman et al. (2009), it roughly means rapport or comfort level. However, Bartneck et al. (2009) pointed out that *shinwakam* is not a standard Japanese word and is not found in any Japanese dictionary. The word is a combination of two separate Japanese words *shinwa* (“mutually be friendly” or “having similar mind”) and *kan* (“the sense of”). Even with these meanings of the two components of *shinwakan*, it is unclear how to map its nuance into an English term. Therefore, different researchers have used different dependent variables to measure participants’ reactions to robotic agents and virtual characters.

Probably because the translation of Mori’s original article (Mori, 1970; translated by MacDorman & Minato, 2005) used “familiarity”, researchers investigating the uncanny valley have attempted to measure how familiar people find robots based on their appearances (MacDorman, 2006). However, it is an ambiguous construct. Familiarity is likely to change with increased interactions. What appears strange initially may become familiar after a few encounters. Moreover, high familiarity may not necessarily imply liking or acceptance. Similarly, low familiarity may not always imply disliking or rejection because if it does, it will mean that people do not ever like innovations or creativity.

Other subjective measures used to evaluate people’s opinion of robots’ appearances are likability (Bartneck, Kanda, Ishiguro & Hagita, 2009; Groom et al., 2009, Mathur & Reichling, 2009), attractiveness versus repulsiveness (Schneider, Wang, & Yang, 2007; Chen, Russel, & Nakayama, 2010), and perceived eeriness (MacDorman & Ishiguro, 2006). Researchers have also measured affect evoked by robots, such as fear and anxiety (Nomura, Suzuki, Kanda, & Kato, 2006). None of these measures can independently provide a holistic view of people’s attitudes toward the robot’s appearance, particularly when evaluated without taking the context of interaction into account. How humans and robots interact, in what situation, and for what purpose will also influence attitudes and acceptance.

Robot form and appearance: Open questions. Although many studies have assessed the human response to robot form, more research needs to be done to provide clearer answers to the following questions:

1. Do people want robots to be at all human-like? If yes, then how much human-likeness is desirable? Are people willing to have a robot that is indistinguishable from a human in appearance? Would they prefer that?

2. Are there age-related, experience-related, or personality-related differences in people's preference for a robot appearance?

3. How do preferences for robot appearance interact with the functionality of the robot or the tasks it is intended to perform?

4. What are people's views about machine-looking robots? What do they think of robotic pets' appearances and of other robots with life-like but non-humanlike appearances?

General Discussion

Understanding user acceptance of robots is a critical component of designing robots that will be adopted by a variety of users. Robots have been a topic of science fiction literature and film for decades. Rosie from the Jetsons, C3P0 and R2D2 from Star Wars, and Robbie the Robot from Forbidden Planet, are all beloved science fiction characters and they have influenced the way in which the general public thinks about robotics. This media exposure may create preconceived expectations about robots, even for individuals who have never interacted with a robot directly. In fact, research has found that most people have ideas or definitions of what a robot should be like (Ezer, 2008). Moreover, robot design has been modeled in part by science fiction portrayals of autonomous systems (Brooks, 2003). Hence, there is a possibility that users' preconceived notions of how robots should behave would be reinforced by interacting with a robot that matches their expectations. Any mismatches between user expectations and a robot's actual capability, however, would be expected to negatively impact acceptance. Additional research is needed to explore these preconceived expectations further and to fully understand how they impact robot acceptance.

Despite the ever growing development and public interest in robotics, a theoretical model designed specifically to explain robot acceptance has yet to be fully developed. Traditional technology acceptance models such as the Technology Acceptance Model (TAM; Davis, 1989), Unified Theory of Acceptance and Use of Technology Model (UTAUT; Venkatesh, Morris, Davis & Davis, 2003), and the Chain Model (TPC; Goodhue & Thompson, 1995) can provide guidance for developing an understanding of robot acceptance. Although TAM has been suggested as a potentially robust predictor of acceptance of performance-directed robots (Ezer, Fisk, & Rogers, 2009), more research is needed to investigate what and why certain aspects of existing technology acceptance models do and do not predict robot acceptance.

In this report we reviewed the literature and identified a variety of robot characteristics that may influence acceptance. These variables include the robot's function (e.g., tasks performed; autonomy level; control and interfacing), social ability (e.g., social intelligence; emotion expression; speech and dialog; non-verbal social cues), and form (e.g., human-likeness; gender; physical structure). Some of the characteristics identified, such as social ability and robot form/appearance, are not included in traditional technology acceptance models. However, these characteristics may play a role in acceptance due to the expected social interaction robots may engage in with humans.

Based on our review, we have identified the following questions as potential open research avenues. These questions represent avenues in need of further research; the results of which can be used by designers to develop improved service robots that have greater potential to provide assistance for a wide user demographic.

Overview of Open Research Questions

Robot Function

1. What methods (e.g., training) should be implemented to ensure the users' expectations of robot autonomy match its actual autonomy level?

2. To what extent will control and interfacing change as a function of task? Some forms of control may be more applicable to only certain types of tasks.

3. The relation between control methods (Table 2) and their effects on perceived ease of use is relatively undefined.

4. Many studies investigate "proof-of-concept" of robot control; however, more work is needed in actual user testing of various control methods.

Social Ability

5. How do social intelligence constructs such as situation-relevant expression, believability, and recognition play a role in acceptance?

6. How are the users' mental models of social ability developed, and how are they refined to meet the actual capability of the robot system?

7. What role does a robot's emotional expression play in the development of acceptance by humans?

8. How do such factors as the users' age, experience, and expectations affect their interpretation of social ability, such as the robot's facial expressions?

Robot Form and Appearance

9. Do people want robots to be at all human-like? If yes, then how much human-likeness is desirable? Are people willing to have a robot that is indistinguishable from a human in appearance? Would they prefer that?

10. Are there age-related, experience-related, or personality-related differences in people's preference for a robot appearance?

11. How do preferences for robot appearance interact with the functionality of the robot or the tasks it is intended to perform?

12. What are people's views about machine-looking robots? What do they think of robotic pets' appearances and of other robots with life-like but non-humanlike appearances?

This list is not meant to be exhaustive but instead to provide a starting point for developing a predictive model of technology acceptance that pertains to human-robot interactions. Understanding robot acceptance is a critical step in ensuring that robots designed for human support reach their full potential.

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