Sociable Robot Systems for Real-World Problems*

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***Abstract*— Human-robot interaction research is maturing to the point where we can begin to build systems that interact with people in their daily lives and provide support for particular needs. We propose that *sociable robot systems* are systems that comprise a sociable robot, other technological devices, methods for interaction, and methods for relationship creation and maintenance. These systems can be designed as solutions to address particular needs such as health care or behavior change goals. We discuss the social support benefits of creating a relationship between a person and a robot and offer ideas for how this might be done. A system that is currently under development in our lab to help obese patients who have recently lost weight maintain their target weight is presented as an example of this kind of sociable robot system.**

***Index Terms*— Human-robot interaction, sociable robots, sociable robot systems, obesity**

I. Introduction

Researchers in robotics and human-robot interaction (HRI) are beginning to think about applications for interactive robots that are capable of assisting humans in a variety of situations. Companies are starting to capitalize on the use of robots for entertainment, such as the Sony Aibo robotic dog or Hasbro's My Real Baby, and to perform simple household chores as in the case of iRobot's Roomba and Electrolux's Trilobyte vacuum cleaners. Several Japanese companies have developed robots for therapeutic purposes as well, including the NeCoRo cat from Omron and Paro (the "Seal Type Mental Commit Robot") from Intelligent System.

Both the NeCoRo and the Paro are meant to create a bond between a person and the robot, but it is unclear how this is accomplished thus far. However, the fact that this kind of robot is interesting both to these companies and to consumers is one factor that motivates our work towards designing a robot that can create a relationship with a human partner and use the benefits of that relationship to provide advantages to the person, such as helping with health care problems, as a result. We believe that there could be a great benefit from creating robots to help people in a variety of situations that could not be achieved through other kinds of systems.

Sociable robots offer advantages not found in on-screen agents or technology embedded in the environment, such as an increased sense of social presence in an interaction (see Ref. [1]) and the capacity for touch and physical interaction. When there is a physically present, interactive robot, it opens up the possibility of creating a complex relationship which can provide the social support which has been shown to be useful in a wide variety of situations. This can be done in animated agents as well, but our earlier work shows that some of the important relationship factors are stronger in a robot [1]. Social support encompasses feelings of caring, loving, and belonging; we define it more fully in section II-C. The robot is a part of the system, serving as the interface with the people, sensors, and actuators that encompass the remainder of the system. There are two important aspects of the sociable robot component: it has the capability of creating a particular kind of relationship with the user to enable it to address, for example, health care goals or behavior change desires.

II. Sociable Robot Systems

Social and sociable robots (for a definition, see Ref. [2]) comprise a relatively new field of scientific inquiry. Many existing robots (for example Kismet [3] and Mel [4]) have been built to be used in a laboratory setting, occasionally involving humans in experiments to test various aspects of their interactions. A few robots have been built for real-world interactions (such as Pearl [5], Robovie [6], and Robota [7], and Paro [8]). There are service robots which have been designed to interact with people in a real-world setting outside of the laboratory in order to solve a specific problem (such as Sage [9] in the museum). In this paper, we propose creating a sociable robot system to assist in a particular problem, that of weight management for individuals who have lost weight and want to keep it off.

A. Definition

In Ref. [2], Breazeal defines a sociable robot as a robot that participates in social interactions with people in order to satisfy some internal goal or motivation. She notes that sociable robots rely on cues garnered from interactions with humans in order to function. These robots "model people in social and cognitive terms in order to interact with them."

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In this work, we posit that these sociable robots will use their interactions to fulfill a particular purpose. The purpose varies depending on the system being developed, but each implementation of the type that we describe will be designed so that the robot (and the entire combination of devices) has a purpose that can only be met through interaction with the user.

Here we define a *sociable robot system* as a set of technological artifacts that can communicate with one another, a robot that engages people in a social manner, the means of interaction, and the network of people involved in the interaction. The design of such a system embeds a sociable robot and other technology into an existing social system. Thus we intend to augment and build upon current means (technological or not) of addressing problems rather than replacing them with robotic methods and implementations.

We envision a sociable robot system comprising several pieces of technology that are appropriate to a given application (such as sensors and actuators either on the person, in the environment, or on the robot). Later we give an example of a sociable robot system designed for helping people keep weight off that they have lost. In this case, it is important to be able to sense amount of exercise and give users the ability to input dietary information, so the other technology in the system encompasses solutions to these needs. This use of appropriate technology is similar in spirit to Weiser's definition of *ubiqitous computing* in his 1991 article [10] where he defined the term.

The most important aspect of developing the sociable robot in this system will be creating the means of interaction. For us, the *means of interaction* encompasses what the robot knows (i.e., the information that it has access to or can gather with its own sensors), how it can process that information to present to the user or affect its interactions with the user, and what strategies it uses to create and maintain a relationship with the user over time. Much of the work from the field of HRI discussed below surrounds these issues and these are perhaps some of the most complicated portions of creating a sociable robot system.

In addition to the technological components of the system, most sociable robot systems will fit into an existing or new ecology of people. These systems will not be developed in isolation from human networks of support for the issues that they are addressing, rather they should be integrated into contemporary organizations. In the example we present later in the paper, we discuss how the system augments a current method of weight maintenance. This may be the ideal way to get a system accepted for use: integrate and extend an existing model the the user can easily comprehend and see the benefits of adopting the system.

B. Relevant work

The work that we propose in creating sociable robot systems draws on several existing areas of research. The two main technological fields we believe to be an integral part are those of human-robot interaction and ubiquitous computing (an overview of each can be found in Ref. [11] and Ref. [12], respectively). Important work also comes from psychology, social psychology, computer science, and artificial intelligence. In any given application, it is likely that other fields will be necessary for creating a successful sociable robot system. As an example, in our obesity application, we also draw from work done in the fields of bariatrics, nutrition, and behavior change.

Recent work in human-robot interaction has begun to move towards building systems that address specific problems, rather than only working on general-purpose robots in the laboratory. Several examples of this type of robot were given earlier, but none of these capture what we mean by a social robot system. They are concerned with the robot and the interaction, but do not typically integrate other pieces of technology nor the embedding of the system into a social network.

The strength of existing work in HRI is the knowledge that has been gained about how to create an interactive robot that has an internal model of itself, the world, and its interaction partner; has the ability to interact with people by reading and expressing human (or human-like) conversational gestures; and can express some of its state to the users with which it is interacting.

The field of ubiquitous computing has achieved many successes in nearly a decade and a half of work (many outlined in Ref. [12]) in domains such as the classroom [13], office [14], and the home [15]. In Ref. [12], Abowd and Mynatt argue that the field of ubiquitous computing should focus on making computing available at any time in any location. While ubicomp researchers may focus on the computing capabilities of the environment, we consider the interaction with the overall system through an embodied agent.

C. Social support

The main reason for having a sociable robot as part of this system is that it can provide social support to the user. The term "social support" has been interpreted in somewhat different ways, but we are referring here to Cobb's use (in Ref. [16]) describing social support as knowledge that leads to a person feeling that they are cared for, that they are loved and thought highly of, and that they are a part of a social network that will reciprocate their feelings and actions. The kind of interaction described in this and other work on sociable robots (e.g. Ref. [2]) leads to a robot that is capable of providing this social support. This can be provided through the creation of a long-term relationship, which we discuss in the following section.

The benefits of social support are clear and have been demonstrated for a variety of situations, such as higher cognitive functioning in the elderly [17], general cardiovascular performance [18], and general daily functioning [19]. A list of the kinds of social support that can be provided include emotional support, network support (being a part of a helping group), esteem support (increasing belief in the self to provide help), functional support (in our case, the actual physical task that the robot or system performs), informational support (for the type of systems we describe, assistance in working towards the health care goal for example), and the chance to help another (could be providing some regular service to the robot to feel needed as a part of the system).

III. Creating a Relationship

A. Important factors

There are three factors that are most important when trying to create and maintain a helpful, long-term relationship between a person and a sociable robot system. The robot must be able to engage the user so that they will begin to interact with the system in the first place and then motivate the user to carry out particular actions once they are engaged. The system must also be worthy of the trust of the user, meaning that it can carry out the actions that it has "promised" that it can do. Let us look at each of these three elements in turn.

1) Engagement: Engagement is the manner in which two or more parties begin, carry out, and end an interaction in which they recognize some connection to one another. In humans, we see this in any conversational encounter when two people attract each other's attention, begin and carry on a discussion, and then disengage. (This happens in other types of encounters and with multiple people as well; this is given as an illustrative example.) The ability to draw a person into an interaction and to successfully negotiate that interaction is of great importance for a sociable robot system. Without the ability to create and maintain engagement, no other aspect of the system will be relevant. In order to carry out any other abilities of the system, the user must be willing to carry on regular interactions with the robot.

There is work focusing on different aspects of how to extend this concept of engagement beyond human-human interactions. The work of Bickmore and Picard in Ref. [20] shows a good example of a model for drawing a human into repeated interactions with an animated agent and continuing these interactions over time. They discuss the relationship literature from the social sciences and explain how strategies that have been identified in interpersonal relationships can be applied to human-computer relationships. They then show how these theories can be applied to human-computer interaction in their implementation of a health-related behavior change application. This work shows some of the necessary aspects of long-term interaction that must be considered and tracked over time.

Several projects look at specific aspects of engagement, such as gestures and looking behavior in Ref. [21] and developing proto-conversational behavior between a human and a robot in Ref. [22], both of which give insight into how to implement particular parts of an interactive system. Sidner, et al. use a conversational model that tracks progress through an interaction and is based on analysis of human dyadic interaction. Breazeal's work models lower-level interactional skills, drawing on the abilities of a human infant to conduct non-linguistic turn-taking sessions. Finally, there are a few examples that we can use for how to measure the engagement between a person and a robot, both in a laboratory setting [23] and in a real-world setting, a classroom of children [6]. Both of these studies provide concrete measures of engagement that can be used in future studies.

2) Trust: Once a person is engaged with the system, they must then initially believe that the system is going to work and then continue to believe that over the course of their relationship with the system. Thus the system must make its capabilities clear initially (the "promise" of what it can do) and follow through on this commitment over time. We do not want to develop systems in which users falsely place their trust, expecting it to do something of which it is not capable.

The concept of trust encompasses a number of factors such as reliability and credibility, which concern the function of the system over time and the quality of feedback from the system. Reliability relates to the system performing in the same way each time the user interacts with it. For these systems to be effective, we must go beyond laboratory prototypes that function most of the time; they must be completely reliable in order for a person to develop trust in them over time. Credibility has more to do with the information and feedback coming from the system. The robot must be seen as presenting correct information to the user, whether this is outside information (i.e. something it is programmed to have knowledge about) or data about the user or their interactions with the robot (health data that the system has observed over time, for example).

There is currently little work on how to create trust in human-robot relationships. The work in Ref. [20] addresses creating this aspect of a relationship. They note that while personification of an interface is helpful in increasing a user's trust, it is not sufficient to create trust. Earlier work we have done (discussed in Ref. [23]) talks about how to measure trust, perceived reliability, and perceived credibility of a robot. These measures were found to be reliable and can be used to measure aspects of trust in other work.

3) Motivation: Many of the issues that we would consider building a sociable robot system require that the user play an active part in its use. To do that, the user must be motivated to take part. There is work in understanding how to motivate a person for behavior change (smoking cessation or weight management, for example), some work in applying this to technological systems (the work of Bickmore and Picard cited above in Ref. [20] is one of the only examples we know of), but little work in applying this to sociable robots has been done.

A good overview of work done in motivation through technology and theories for developing it further is given by Fogg in Ref. [24]. He discusses this idea under the term captology (or **c**omputers **a**s **p**ersuasive **t**echn**ology**), under which he groups several ideas related to changing attitudes and behaviors of people. The claim he makes is that computers are better than people at persuasion because they can be more persistent, offer greater anonymity, can manage a lot of data, use multiple modalities to influence a person, can scale up easily, and might be welcome in situations where humans would not be. Some or all of these reasons will be relevant in any social robot system that we build.

In Norman's recent book (Ref. [25]), he discusses why robots will be good in educational settings. His arguments come down to the motivational ability of robots, which means that if we agree with these arguments, then they will be good in any situation where motivation is key. The claims in this book are that robots can make learning (or other tasks) more engaging because they offer access to more information, have the ability to make issues immediate through interaction, and can be more exacting in their actions and responses than a human. Both Fogg and Norman augur for the same thing: the ability of robots to interact in engaging, motivational ways. This is exactly what we need in creating a social robot system.

B. How to create the relationship

In order to create the kind of relationship we describe here, we draw on what is known about interactions among people. Two of the systems that were mentioned above have tried to implement theories of human relationship-building into a computational system. The best of examples of this are in Bickmore's description of the Rea real estate agent and the more sophisticated Laura exercise advisor (both described in Ref. [26]). These systems encode the factors that need to be tracked when creating and manipulating a relationship over time. The main variables tracked are trust and the working alliance inventory, a measure commonly used in therapy and other helping relationships that tracks trust and belief in a common goal of helping that the therapist and patient have for one another [27].

To be successful along any of these measures, a system must be explicit and clear on what benefits it can potentially provide to the user. When a sociable robot system is introduced to a prospective user, the workings of the system, the requirements expected of the user, how it is a part of a new or existing social network, and most importantly what it offers to the user. This is analogous to the beginning of a relationship between people or transition points in the relationship when they negotiate what the nature of the relationship is (friends, student/teacher, lovers), what is expected of each partner, and other aspects of their interaction [28]. Only when a user has a clear understanding of what the system is and what it can be expected to provide can there be an opportunity for the system to fulfill those expectations.

C. Long-term relationship maintenance

A very important, but little understood, aspect of the kind of relationships that are important in creating a successful ongoing interaction with a sociable robot system is the long-term nature of the relationship. In the literature on human-human relationships, this is referred to as relationship maintenance [28], but there has been little work on either implementing relationship maintenance techniques or measuring aspects of ongoing relationships between a person and a sociable robot. The work of Kanda and others (in Ref. [6]) gives an example of a longer-term interaction than most studies (on the order of 1 month), but we clearly need more work in understanding how the relationship between a person and a sociable robot system evolves over time.

The main factor that we must be concerned with is whether the system is keeping the user engaged and maintaining (or building) trust over time. Based on the human relationship literature, we believe that this largely has to do with the system fulfilling the promises it has made to the user. This means that the system must be able to carry through on the contract established between it and the user. It must also have means of expressing what it believes that it is accomplishing and getting feedback from the user so that a common understanding may be established.

IV. Application Example: Weight Management

In the United States, the National Center for Health Statistics at the Centers for Disease Control and Prevention report that 65% of the adult population is overweight or obese (31% obese and 34% overweight, calculated using the body mass index, or BMI) [29]. According to the World Health Organization, this is an international problem, with over 1 billion of the adult population overweight, with 300 million of these considered obese [30], and they state that "almost all countries (high-income and low-income alike) are experiencing an obesity epidemic" [31]. It is also known that of those who do lose weight, 90 to 95 percent are unable to keep the weight off long-term [32].

A. Obesity and weight management

We propose creating a sociable robot system that will assist people who have recently lost weight in maintaining their target weight. We have talked to a physician whose work consists of treating overweight and obese patients about issues confronted in practice [35] and have found that one of the leading current weight management methods has patients meeting with their doctor, nurse, or other health care worker on a regular basis (from once a week to once a month) to discuss their diet, exercise, and progress. (Refs. [33] and

[34] describe recommendations to physicians on treating obese patients that give further details of current treatment methods.) In the periods between meetings, patients are asked to keep a written record of what they have eaten and how much they exercise. One difficulty with this is that most patients tend to grossly underestimate their caloric intake and overestimate their exercise time [36] even when trying to keep accurate measurements.

The system that we propose has two purposes. The first is to help in automating some of the current treatment methods in order to improve patients' ability to track their own progress and behavior. We are building a system that will allow patients to more easily and more accurately track their behavior. Improvements can come in two ways. Automation of some record-keeping (such as time spent exercising) will allow individuals to keep a running total of exercise time without having to manually record every instance. A system that helps keep track of their eating and exercise will allow them to share this information with their doctor, which is a currently accepted method of improving record keeping, by having their health care practitioner review their eating logs accompanied by pictures and teach them to more accurately estimate calories consumed.

The second is to take advantage of the benefits we have described in coming from sociable robots to engage the patient more in their care and make them more aware of their own progress. We believe that a sociable robot will be able to create a relationship with the person that will allow them to become more engaged in their own long-term progress. In our system, the robot will have both a functional and a relational rôle. Functionally it will serve as a "mirror" of the person's behavior. (More details are provided in the following subsection on the implementation.) Relationally, the robot will interact with the person on an ongoing basis, providing some of the social support interactions we described earlier.

B. System design

A brief description of our design includes the robot, other sensors, technology, and people that comprise the sociable robot system. We are using a commercial, off-the-shelf robot (the Sony Aibo) to prototype the interactions between a person and the robot in our system. We are using a wireless pedometer on the person's shoe to track exercise occurrences and durations. There is a PDA-based form that can be carried with the user for recording everything they have eaten. All of the devices can communicate via wireless technology (both Bluetooth and 802.11), giving the robot access to all of the information it needs for its interactions with the user.

After establishing an initial relationship with the user, the robot will perform two functions. It will serve as the "face" of the system; the portion with which the user can engage and maintain an ongoing relationship. This is its relational rôle. We believe that the interactions that we are using from the Aibo and the interactions that we are creating will create engagement between the user and the robot. Users will be asked to interact with the robot at least once a day and perform some "caregiving" tasks for the robot, such as recharging it. These are some of the aspects of the interaction that will be measured through a long-term interaction experiment that we will perform.

It will also serve a functional rôle, demonstrating to the user how he is doing at meeting his exercise and and calorie goals on a regular basis. The person and robot might carry out a routine interaction each day where the robot serves as a "mirror" to the person's behavior. When they are meeting the goals that they have set for themselves, the robot will interact in a lively and energetic fashion. If they have not achieved their exercise goal or exceeded their self-imposed calorie limit, the robot will then perform this interaction in a more lethargic fashion, demonstrating the longer-term effects of the user's short-term lapse. The readability of these expressions is of utmost importance to the system, so we plan to iterate the design of the interactions until users report that they show what we intend.

C. Ethnographic research

We are currently conducting ethnographic research on current methods for treating obesity and the weight management process. We are working with a local doctor whose practice consists of treating overweight and obese patients. Now we are also starting to spend time in other venues to learn about the issues that are confronted both by those trying to keep weight off and those in the medical profession who are helping with this problem. In order to successfully build a system, it will be necessary to spend time with physicians on rounds, in clinical group settings where people discuss their progress in managing their own weight, and in non-clinical settings such as Weight Watchers groups.

D. Initial technical work

In parallel to the ethnographic work, we are working on implementing some of the necessary relational behaviors in the robot and integrating the separate pieces of the system. A first step in evaluating the usefulness of the system will be measuring the readability of the behaviors on the robot. In order to create the kind of relationship that is desired in this system, the robot must be able to express several states to the user. Before deploying this on a full test of the system, we are studying this aspect of the interaction to make sure that it works as we expect. Once all pieces of the system are integrated, we will also run short-term user tests to verify the technological aspects of the system before deploying in a long-term trial for its actual weight management use.

V. Conclusions and Future Work

We have presented our definition of a sociable robot system and described the parts that make up such a system. Work in psychology, social psychology, human-robot interaction, and computer agents leads us to believe that such a system could be beneficial in creating useful applications for long-term interaction with humans. A framework for creating such a system is described along with the outline of a system that we are currently in the process of building and deploying. It is our hope that the description offered here will be useful for developing sociable robot systems for other purposes.

We are currently building a prototype of the robotic interactions and the interfaces for data entry and viewing. We will run an initial experiment to determine whether the robot's actions are readable and iterate the experiment and behavior creation until they are. We then plan to run a pilot study of the entire system before introducing it to our target population to determine its effectiveness in a longer study.

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