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Robots at Home: Understanding Long-Term Human-Robot Interaction

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***Abstract*— Human-robot interaction (HRI) is now well enough understood to allow us to build useful systems that can function outside of the laboratory. We are studying long-term interaction in natural user environments and describe the implementation of a robot designed to help individuals effect behavior change while dieting. Our robotic weight loss coach is compared to a standalone computer and a paper log in a controlled study. We describe the software model used to create successful long-term HRI. We summarize the experimental design, analysis, and results of our study, the first where a sociable robot interacts with a user to achieve behavior change. Results show that participants track their calorie consumption and exercise for nearly twice as long when using the robot than with the other methods and develop a closer relationship with the robot. Both are indicators of longer-term success at weight loss and maintenance and show the effectiveness of sociable robots for long-term HRI.**

I. Introduction

Humans have been interacting with robots and other automata for many years. In the past decade, the methodical, scientific study of this interplay between man and machine has matured into the field of human-robot interaction. Much of the work thus far has looked at aspects of development and learning (e.g. Breazeal's Ph.D. thesis and subsequent work [1]); human perceptions of various portions of a robot's appearance, personality, and behaviors (work in Dautenhahn's lab [2] or Carnegie Mellon University's HCII group [3], for example); or short-term interactions in laboratory-based settings (such as previous work we carried out using a variety of robots [4], [5], [6], [7] and others at the University of Washington on children interacting with robots[8] and at Hertfordshire on how comfortable people may be near a robot [9]).

The vision of the field of HRI, however, has been to create and study robots that exist in our everyday lives. The objective shared by many is to build robots that will assist us in anything from the mundane tasks of cooking and cleaning to more intellectual and social endeavors of entertainment and caregiving. The enormous challenges presented in surmounting the scientific, engineering, and interaction difficulties has kept the field from creating systems capable of autonomous, sustained interaction in the real world, leaving us to build systems and study the resulting interactions in the microcosm of the laboratory. We have completed the first long-term study where a sociable robot interacts with a person over time to effect long-term behavior change.

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A. Overweight and obesity

Increasing rates of overweight and obesity has brought us to the point where two-thirds of the US adult population falls into one of these categories. The National Health and Nutrition Survey in 2002 shows 65% of the adult population in these categories, with 30% obese and 35% overweight [10], with similar trends seen in children and adolescents [11]. (Overweight is defined as a body mass index (BMI) of 25 up to 30 kg/m^2 and obese as greater than 30 kg/m^2.)

This excess weight leads to a significant increase in many comorbid conditions including type 2 diabetes mellitus, heart disease, high blood pressure, and some cancers [12]. It is noted that a reduction of even 5% to 10% of initial body weight can lead to a significant reduction in risk to these concomitant conditions [13].

There is a long history of treatments trying to effect weight loss in patients. For much of this history, overweight or obese patients were given instructions or short-term treatment and expected to lose weight and maintain that loss independently. Only in recent years has the medical community developed an understanding of obesity as a chronic condition that must be managed on an ongoing basis [14]. Current practices include behavioral therapy [15], lifestyle modification [16], pharmacotherapy [12], and surgical interventions [17], as well as combinations of these methods [18].

These improvements in health and reduction in risk is negated when an individual regains lost weight. Unfortunately, nearly everyone who loses weight using current treatments gradually regains at least all of the weight that was lost during the subsequent months and years [19]. Nearly every study following up on weight loss shows the gradual regain of weight after the cessation of intervention. An exception is the group of people who are a part of the National Weight Control Registry, a database of over 5,000 people who have lost at least 30 pounds and kept it off for over a year [20]. While the methods of weight loss and maintenance vary across this group, common factors among those successful at maintaining their weight loss is a modification of their food intake and daily exercise [21].

B. Why use sociable robots for weight loss?

The series of experiments we have conducted over the last 7 years has led to the desire to explore long-term HRI as well as helped to develop the reasoning for why a robot can be a more effective interaction partner in certain settings. Together, they showed the power of a robot in conducting

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an effective interaction and the stronger responses that our robots elicited from many study participants.

We have written about the application of sociable robots to real-world problems as we have begun exploring the design and construction of such systems. An earlier discussion on the important factors in creating a relationship [22] noted three factors that are most important: engagement of the user, trust of the system, and motivation to use the system. An early implemented system design is presented in a conference paper [23] that shows many of the design decisions that underly the relationship model in this system.

In this paper, we focus on the design and implementation of the system used to create and maintain a relationship for long-term HRI. For a complete discussion of the hardware and software system design and implementation; the study design, protocol, and analysis; and evaluation of the overall system, see Kidd's Ph.D. thesis [24].

II. Autom: A Weight Loss Coach

A. Sociable Robots

A sociable robot is one that is "capable of engaging humans in natural social exchanges" ([1], page 40), according to Breazeal's 2000 thesis, which was one of the early users of the term. There is psychological grounding for this concept described in the introductory chapter of her thesis that relates to Reeves and Nass' 1996 book on social aspects of human-computer interaction [25]. They posit that as a result of evolutionary behaviors the more social cues a piece of technology exhibits, the more human-like people will find it. While their work dealt mainly with traditional computer interfaces, Breazeal's work extends this theory to humanoid robots and states that using social cues in interactions between people and robots offers an attractive alternative to traditional methods of communicating with robots.

B. Autom: A Weight Loss Coach

In setting out to study long-term HRI, the initial intent was to use an existing robotic platform and design a study or series of studies around the chosen robots. However, we found no suitable robots available commercially that would allow us to create interactions for a large long-term study.

There are several key features that are desirable for robots to be used in a long-term study of HRI. The ability to look at the user (or appear to do so) is important for drawing a person into the interaction. A robot in which the software that controls the human interaction is easily modifiable is vital, as many aspects of the interaction will need to be adjusted as user tests are conducted. Some set of features that enable social interaction (e.g. eye contact; look-at behaviors; head, arm, and hand gestures; speech; and speech recognition) are needed, but the exact set depends on the type of interactions expected.

One of the seventeen robots that we created is depicted in Figure 1. Called Autom, it is a four degree of freedom robot based on easily available PC components, motors, and motor controllers. It has a moving head and eyes, a camera for vision to allow for face tracking, and a full-color touch screen display for user input. The robot is designed to sit on a counter top and is not mobile. Seventeen identical robots were constructed to allow for a long-term study with multiple simultaneous users.

Fig. 1: The Autom robot built for our study.

The robot is designed to have a once- or twice-daily interaction with the user with each interaction lasting approximately five minutes. The nature of the interaction is helping an individual track information related to their weight loss program. The robot talks to the person and guides them through the interaction, making small talk along the way. The discussion is varied, changing with each interaction based on variables including time of day, estimated state of the relationship between the robot and person, time since last interaction, and data that the user has input in recent days.

III. Software Design and Implementation

There are five main pieces of software that create the interactions between the weight loss coach system and the user. The main piece of software coordinates all input and output, maintains the overall state of the interaction and relationship with the user, and handles interaction flow based on user input. There are four peripheral pieces of software: the motor control system, vision system, speech output server, and user interface controller. Each of these components is discussed in this section.

A. Control system architecture

The main software system handles the control flow of an interaction and the communication between all subsystems. The overall architecture is depicted in Figure 2. This central piece of software is written in Java and either instantiates subsystems as other Java classes (as with the motor control and user interface) or uses sockets to communicate with them (the face tracker and speech output).

The basic control flow is driven by the user. The user can select an option from the initial menu, which chooses the appropriate script to be run. There are five options on the main screen: start the daily interaction, update goals, view data, show a demo, and shutdown the robot. The first, *Start Daily Interaction*, is what the user does most frequently. This

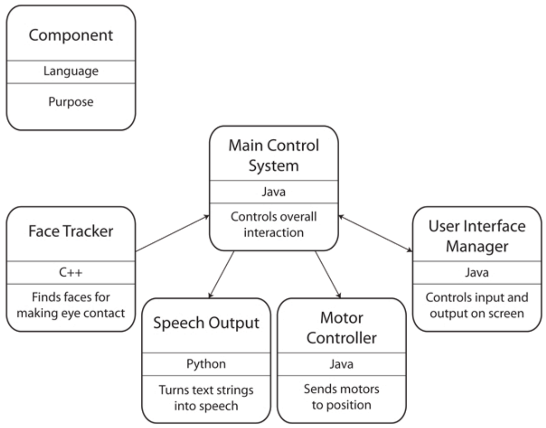

Fig. 2: High-level software architecture.

interaction is described below. *Update Goals* allows the user to enter or modify their daily exercise and calorie goals. The *View Data* option lets the user go directly to graphs of their exercise or calorie entries for the previous seven days. *Start Demo* lets a person show off the capabilities of the system without revealing their personal data. Finally, *Shutdown the Robot* is a button which exits the software and powers down the entire hardware and software system.

Daily Interaction – implementation

The control flow of the interaction is the most complex part of the software system created for the robot. The basic flow is written to be easily modifiable, which allowed for rapid changes based on early and ongoing feedback that was solicited on the interactions with the system. There are a number of factors that can change what the robot says or does at a given instant.

Fig. 3: Spoken text is also shown on the screen.

All interactions are driven based on scripts and data in several databases. When a user selects an action from the main menu, the system chooses a script appropriate to that particular interaction. Scripts are made up of a set of tags that recursively generate the full, detailed interaction script. A tag either performs some action, generates a screen to interact with the user, or stores a user response to the database.

The decision of what a particular tag will create is based on several factors. Simple ones are time of day (e.g. "Good morning" versus "Good evening") and time since last interaction (e.g. "Good to see you back again. I'm glad we're getting a chance to talk" versus "Thanks for coming to talk to me today.") More complex is the state of the relationship, which is calculated to be in one of three states based on user responses. This state can be either initial, normal, or repair, and the calculation of the state is described below. It the state is initial, the system uses language that is more explanatory in nature. For example, instead of simply saying "Can you tell me how much you have eaten and exercised today." the robot might add something like "It will help us to reach your goals if we keep track of what you do each day." In the normal state, the system uses relatively short forms of dialogue as in the example interaction given above. In the repair state, it will uses meta-relational dialogue with the user.

Calculating relationship state: The relationship state can be either *initial*, *normal*, or *repair*. *Initial* is used for the first few days of interaction, so there is no calculation to be made. The Working Alliance Inventory (WAI) – Short Form (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, as described by Horvath and Leslie [26]) consists of eight questions and the robot rotates through the questions, asking two each day, thus repeating every four days during daily use. The full WAI of 36 questions is also used in paper form at the conclusion of the study. Currently the *initial* state is used for four days. The *normal* state is then used for four days. Starting at the ninth day (or ninth interaction), the system calculates a score based on the following formula:

$$WAI_{state} = \frac{\sum_{day=-3}^{0}(WAI_{day})}{8} - \frac{\sum_{day=-7}^{-4}(WAI_{day})}{8}.$$

The result is an average difference in responses on a scale of 0 to 600 (the range for any one question). If the WAI_{state} is greater than -25 (allowing for minor variation in responses or UI input error), the relationship state is deemed *normal*. If the result is less than -25 (i.e. the responses to questions are in general lower over a period of time), the relationship state is set to *repair*.

Aspects of the interactions

As a result of these calculations and generation of interactions, the dialogue that is generated between the robot and the user is extremely unlikely to be the same for any two interactions during the six-week study. This variety makes the system seem more capable of interacting with the user and much less likely to bore the user during the weeks of continuing interaction.

The robot also performs small gestures throughout the interaction in addition to looking at the user. When introducing a part of the interaction where a response on the screen is expected, the robot will look away from the user and glance down at the screen as a subtle indication to the user that their attention is expected there at that particular time.

Every response from the user – data on calories and exercise that is entered, WAI-SF questions answered, and responses to each piece of dialogue – are recorded in an interactions database. Some of this is used later, such as in calculating the relationship state. All of it is available post-experiment for analysis of the interactions and correlation with other information collected in questionnaires before and after the study.

Example interaction

Autom's daily interaction with a user lasts from three to five minutes. She starts off by greeting the user and making small talk; "Good afternoon. Thanks for coming back to talk with me," is an example. She utters each phrase aloud while showing the text on the touchscreen display, allowing the user to press a button on the screen to respond and continue the dialog. She then introduces the topic of gathering information, saying something like "Can you tell me about how much you have eaten and exercised so far today?" The user inputs information using a series of dialog screens and Autom continues with offering suggestions and advice about the user's recent progress. Finally, the robot makes a little more small talk and exhorts the user to return again, finishing with dialog like "Thanks for coming to talk with me today. Good luck on your diet and I hope to see you again tomorrow."

IV. Study and Results

There were two major goals in designing and running the study with the robotic weight loss coach. The first is to better understand how to run a long-term HRI study, what data to collect, and how to analyze it. The second is to understand whether such a sociable robot system might be useful to people who are trying to lose and keep off weight. The study had forty-five participants: 36 female and 9 male with an age range of 18 to 72 and average age of 50 years.

A. Hypotheses

In the weight loss application experiment, there are four sets of hypotheses. These are:

- Participants using the robot will stick with it longer than those using the computer or paper systems. This measure can be determined through analysis of interactions.
- Participants using the robot will like using their system more and feel a closer relationship with it. This will be measured using mainly the working alliance inventory, but also measures of trust in the system, perceived reliability, and perceived information quality of the system.
- Participants using the robot will relate to their system more and develop a stronger affinity to it. This will be analyzed mostly through post-experiment interviews with participants.
- Participants in all three conditions will lose weight and the difference between systems will not be statistically significant. This is because we can expect anyone participating in such a study to lose weight and that the effects of using the system for longer periods of time only become important and differentiable in terms of weight loss after a much longer period.

B. Study design

The evaluation of the sociable robot weight loss system was carried out using a between-subjects, longitudinal study where people who were attempting to lose weight used the system for six weeks. One-third of the participants received the sociable robot system described in earlier chapters. An equal number in a second group received a computer running identical software with the same touch screen that is on the front of the robot. This system was not capable of looking at the participants, as it had no camera or eyes. This system also did not speak text aloud; all text appeared only on the screen. A third group, with an equal number of participants to each of the first groups, received a paper log that was based on the log currently used in the Nutrition and Weight Management Center at Boston Medical Center.

C. Protocol

The four components of the study were recruitment and qualification, initial visit and setup, study period, and final interview. Each of these is described here.

Recruitment and qualification: Participants were recruited using flyers in area restaurants and gyms and by request from a physician in a medical weight loss clinic. After a potential participant expressed interest, they would then complete an intake screening questionnaire to get subjects who were overweight, ready to start a diet, and who did not have uncontrolled medical problems.

Initial visit and setup: During the initial visit to participants' homes questionnaires were administered and they were given a pedometer and showed its use. The experimenter explained the need to set daily calorie and exercise goals and asked the participant if they had goals. If they did not, the experimenter suggested general guidelines and asked the participant to choose an initial goal and explained that the goal could be changed at any time and as frequently as desired during the course of the study. Finally they were shown the record-keeping system they were given and went through a brief explanation of its use and tried it once with the experimenter answering any questions. Participants were asked to use the system that they had been given at least once a day and left with contact information for the experimenter in the event that they encountered any problems while using the system.

Study period: During the initial period of the study, the experimenter initiated no contact with participants. At approximately five days before the end of the four-week period, participants were contacted and told that they were being given the opportunity to continue the study for an additional two weeks. If participants chose to continue, they were advised to continue using their system in the same way they had been. Participants who chose not to continue were asked to schedule a follow up visit for as soon as possible after the conclusion of their four weeks. Participants who continued for a full six weeks were contacted a few days before the end of the six week period and asked to schedule a follow up visit for as soon as possible after the conclusion of the study.

Final interview: The final visit to participants' homes consisted of questionnaires, an interview, and debriefing the participant on the purposes and design of the study.

D. Experimental Results

We developed and tested eleven hypotheses using the robot, the computer, and the paper logs. The central hypotheses concerned the length of time participants would use the system and their relationship with the system as measured through the WAI and through observation of their behavior. Table I summarizes the overall results of the experiment. The analysis of hypothesis 2 shows that participants with a robot kept up with tracking their diet and exercise for longer than did participants using the computer or the paper log. Hypotheses 3 and 4 deal with the relationship question and the analysis of these three show a clear difference in the relationship that is developed with the robot when compared to the computer or the paper log. (Results of many of the other hypotheses were confirmed and are reported in [24].)

Hypothesis	Confirmed	Synopsis
1	Yes	Participants with a robot used the system for significantly longer.
2	Yes	Participants had a closer alliance with the robot shown with the short WAI.
3	Yes	Participants had a closer alliance with the robot as shown with the full WAI.
4	Yes	As expected, the difference in percent of body weight lost was minimal.

TABLE I: Summary of experimental findings.

E. Hypothesis 1: Usage

The analysis of the data shows that this hypothesis is supported. Participants with a robot used their system on average 50.6 days (continuing use even after their six-week period concluded), while participants with a computer used their system for 36.2 days on average, and participants with a paper log reached an average of 26.7 days. A one-way ANOVA shows a significant difference among groups: $F(2,30) = 11.51, p < 0.001$. The post-hoc Tukey HSD shows a significant difference between the robot group and the computer group ($p < 0.05$) and a highly significant difference between the robot group and the paper log group ($p < 0.01$).

F. Hypothesis 2: Alliance (WAI-Short)

This hypothesis was clearly shown to be true. Questions were presented to uses as a continuous scale anchored at three points ("Strongly Agree," "Neutral," and "Strongly Disagree"). The scale was discretized on a scale of 0 to 600 for coding responses, with 0 correlating with "Strongly Agree." The average response for participants in the robot group was 68.2, while the average score in the computer group was 234.1. A double-sided t test shows $t(17) = -5.1$ with $p < 0.001$.

G. Hypothesis 3: Alliance (WAI-Long)

Analysis showed that participants developed a closer alliance with the robot than either of the other systems. A one-way ANOVA for independent samples shows a significant difference among cases ($F(2,30) = 5.54, p < 0.01$). Tukey HSD tests report no significant difference between the computer and paper cases, but a significant difference between the robot and computer cases ($p < 0.05$) and the robot and paper cases ($p < 0.01$).

H. Hypothesis 4: Weight

The results bear out the hypothesis of similar weight loss. (One-way ANOVA: $F(2,29) = 0$). The mean percentage of starting body weight lost per group was: robot = 2.2%, computer = 2.0%, paper = 2.4%. (If we exclude one extreme outlier in the study who happened to be in the robot group who gained 10 pounds during the study, the robot group is 3.2%, still resulting in no significant difference: $F(2,28) = 0.44$.)

V. Discussion

A. Relationship Requirements

Having a clearly defined model of the relationship made the development of a cohesive system possible. Two aspects of this model were necessary to understand. The first is the trajectory of the relationship. As described previously, we developed a model based on human psychology. This model is relatively simple, but an understanding of the differences in how the system relates to the user at each stage can be nuanced. Drawing on social psychological models of relationships, we look to examples of how people behave in such a situation and model the robot's behavior off that.

The other important part of the relationship model is the type of relationship that we were trying to create. Using the interactions between caregivers and weight loss patients gave a clear focus to all aspects of the interaction. In this case, this is a relationship where the caregiver is always supportive, positive, and helpful. Thus everything that the robot says in interactions with the user was created with this in mind. Based on participant feedback, it is clear that this model worked well. Users found the suggestions and the overall tone of the system to be helpful to them and told us so.

B. Target Audience Requirements

Designing with end users in mind was easier after spending time with the target population before beginning to create the system. Even with that, however, it is difficult to anticipate how individuals will respond to a system. Each person has widely divergent ideas about what is good or bad and useful or intrusive in such a system. We did some user testing along the way, but to create a more useful system, a more intensive iterative testing approach would be highly recommended. Our testing was brief – having people use particular aspects of the system once or twice – rather than giving people systems to use for a week or two as a test and then making changes and improvements before repeating that process.

Finally, the design challenge of making this robot system as simple and intuitive as possible was clearly worthwhile. Taking advantage of the robot's ability to guide people through the interaction, along with creating software that supported this notion, made the system easy to use for even novice computer users. We managed to strike the right balance between explanation and terseness that allowed individuals at all levels of competence use the system. This relates to the relationship stages as well and the ability of the robot to estimate the user's need for more or less explanation at appropriate times worked well.

VI. Conclusions

The effectiveness of our weight loss coach sociable robot system gives an early glimpse at the possibilities for sociable robot systems. Participants in our study enjoyed working with this robot and many did not want to give it up at the end.

We hope that the creation, deployment, and study of this robot is a precursor to many other sociable robot systems that will soon enter our everyday lives. The possibilities for creating these type of robots that we will interact with on such a regular basis that they become part of our lives has entered the popular culture long before now. We are finally capable of beginning to create robots that will live up to these ideas. Previous robots have shown the promise of HRI, now we have begun to take these capabilities out of the microcosm of the laboratory and bring them into our lives.

The relationship that was formed between people and their robots is clearly a significant step towards developing an understanding of the relationships that are possible between us and our robotic creations.

We also see here that there is clear applicability to one of the big challenges that is presented to us in the health of much of the population. One of the biggest difficulties for the many tens of millions of people who are struggling to lose weight is keeping with their diet and exercise program and keeping that weight off over time. The robot that we deployed clearly has promise in helping people to do just that. Sociable robots are now a reality; it's time for us to put these engaging technologies to work in ways that we find helpful and productive.

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