A Social Informatics Approach to Human–Robot Interaction With a Service Social Robot

Christine Laetitia Lisetti, Sarah M. Brown, Kaye Alvarez, and Andreas H. Marpaung

***Abstract*—The development of an autonomous social robot, Cherry, is occurring in tandem with studies gaining potential user preferences, likes, dislikes, and perceptions of her features. Thus far, results have indicated that individuals 1) believe that service robots with emotion and personality capabilities would make them more acceptable in everyday roles in human life, 2) prefer that robots communicate via both human-like facial expressions, voice, and text-based media, 3) become more positive about the idea of service and social robots after exposure to the technology, and 4) find the appearance and facial features of Cherry pleasing. The results of these studies provide the basis for future research efforts, which are discussed.**

***Index Terms*—Emotion, human–robot multimodal interaction, multimedia integration, personality, robot building tutorial, socially intelligent affective agents.**

I. INTRODUCTION

INCREASING advances in the field of artificial intelligence (AI), AI robotics [1], behavior-based systems [2], [3], robot sensor fusion [4]–[6], robot vision [7], and robot emotion-based architectures [8]–[11] have rendered feasible a variety of applications for human–robot interaction and collaboration. These include planetary exploration, urban search and rescue, military robotic forces, personal care and service robots (e.g., hospital assistance, home elderly care, robotic surgery), home appliances, entertainment robots, and more [12].

Although complete robot autonomy has not yet been accomplished, "the feasibility of integrating various robot entities into people's daily lives is coming much closer to reality. Robots now have the potential to serve, not only as high-tech workhorses in scientific endeavors, but also as more personalized appliances and assistants for ordinary people" [12].

As robots begin to enter our everyday life, an important human–robot interaction issue becomes that of *social relations*. Because emotions have a crucial evolutionary functional aspect in social intelligence, without which complex intelligent systems with limited resources cannot function efficiently [13], [14] or maintain a satisfactory relationship with their environment [15], we focus our current contribution to the study of emotional social intelligence for robots.

Indeed, the recent emergence of affective computing combined with artificial intelligence [16] has made it possible to design computer systems that have "social expertise" in order to be more autonomous and to naturally bring the human—a principally social animal—into the loop of human-computer interaction.

In this article, *social expertise* is considered in terms of 1) internal motivational goal-based abilities and 2) external communicative behavior. Because of the important functional role that emotions play in human decision-making and in human-human communication, we propose a paradigm for modeling some of the functions of emotions in intelligent autonomous artificial agents to enhance both: 1) robot autonomy and 2) human–robot interaction. To this end, we developed an autonomous service robot whose functionality has been designed so that it could socially interact with humans on a daily basis in the context of an office suite environment and studied and evaluated the design in vivo. The social robot is furthermore evaluated from a social informatics approach, using workplace ethnography to guide its design *while* it is being developed.

From our perspective, an interesting modeling issue therefore becomes that of *social relations*. In particular, we have chosen to focus our contribution to the field in addressing the technical goals of: 1) *understanding how to embody affective social intelligence and* 2) *determining when embodied affective social intelligence is useful (or not)*.

In order to determine answers to these issues, our approach is to develop a framework for computationally representing affective knowledge and expression based on cognitive modeling and to *concurrently* conduct surveys in order to investigate three areas: human social intelligence, robot social intelligence, and human–robot social interaction.

1) Human social intelligence: One may ask whether the personality of the human affects how the human interacts with the robot. If so, how? Does it arouse specific emotions or behaviors? Which ones? In what contexts does this happen? Are these effects consistently observable, predictable, positive, or negative? Can we improve on these toward the positive? If so, how?
2) Robot social intelligence: Examples of such concerns are found in quests, such as, whether a machine without emotions really is intelligent and autonomous. If not, how can emotions be modeled to increase robot autonomy? Can "no personality" in an intelligent agent (software or robot) be perceived by humans as a cold, insensitive, indifferent agent? If so, do these perceptions differ by specific groups

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of people, differentiated by age, gender, culture, subculture, etc.? Is it important to change the perceptions mentioned above in humans so that agents can be viewed as personable, helpful, even compassionate? If such is the case, can we identify the various contextual situations and applications when these agent properties might be beneficial, or even necessary? If emotions and personality are embodied in a robot, does it affect how people respond to it? If so, how and in what contexts? Should they resemble that of humans, or should they depart from them?

3) Human–robot social relationship: Finally, questions arise as to what kind of taxonomy of human–robot social "relationships" can be established, identifying numeric (e.g., one-to-one, one-to-many, many-to-many), special (e.g., remote, robo-immersion, inside), and authority (e.g., supervisor, peer, bystander) relationships [12] to determine what levels of "interpersonal skills" a robot would need in order to perform its role(s) effectively.

In Section II, related research approaches are surveyed in terms of emotion modeling and emotion-based architectures, as well as, anthropomorphic avatars and social informatics approaches to evaluate designs. In Section III the paradigm used for modeling emotional intelligence in artificial artifacts is set forth. Section IV describes the actual implementation of mechanisms for endowing an autonomous mobile robot with affective social intelligence. In Section V, the results of a survey conducted to evaluate the robot design and to determine exactly when embodied affective social intelligence is useful or not are produced. In addition, a discussion about the consequences of the study's results from a participatory perspective is provided. Finally, Section VI discusses future research issues.

II. Related Research

A. Emotion-Based Robot Architectures

There have been several attempts to model emotions in software agents and robots and to use these models to enhance functionality. El-Nasr *et al.* [17] uses a fuzzy logic model for simulating emotional behaviors in an animated environment. Contrary to our approach directed toward robots, her research is directed toward HCI and computer simulation.

Velasquez's work [10], [18] is concerned with autonomous agents, particularly robots in which control arises from emotional processing. This work describes an emotion-based control framework and focuses on affect programs which are implemented by integration of circuits from several systems that mediate perception, attention, motivation, emotion, behavior, and motor control. These range from simple reflex-like emotions, to facilitation of attention, to emotional learning. Although the approach is different, its motivation is similar to ours.

The work of Breazeal *et al.* [8], [9] also involves robot architectures with a motivational system that associates motivations with both drives and emotions. Emotions are implemented in a framework very similar to that of Velasquez's work but Breazeal's emphasis is on the function of emotions in social exchanges and learning with a human caretaker. Our approach is different from Breazeal's in that it is currently focused on both social exchanges and the use of emotions to control a single agent.

In the work of Michaud *et al.* [19], [20], emotions per se are not represented in the model, but emotion capability is achieved by incorporating it into the control architecture as a global background state. Our approach which chooses to represent the emotional system explicitly (as discussed later) differs from Michaud's in that respect. Although both Michaud and our approach revolve around the notion of emotion as monitoring progress toward goals, our work explicitly represents emotion and corresponds to a formal cognitive model.

The work of Murphy *et al.* [11] uses the multilevel hierarchy of emotions where emotions both modify active behaviors at the sensory-motor level and change the set of active behaviors at the schematic level for a pair of cooperating heterogeneous robots with interdependent tasks. Our current approach builds on that work, setting the framework for more elaborate emotion representations while starting to implement simple ones and associating these with expressions (facial and spoken) in order to simultaneously evaluate human perceptions of such social robots so as to guide further design decisions.

B. Communicative Anthropomorphic Artificial Agents

Much research is currently underway on the subject of agent-based interaction [21], and agents of the future could promise to decrease human workloads and make the overall experience of human-computer interaction less stressful and more productive. Agents may assist by decreasing task complexity, bringing expertise to the user (in the form of expert critiquing, task completion, coordination), or simply providing a more natural environment in which to interact [22].

Specifically, there are a number of other related research projects that have studied the animation of computer characters/avatars in order to further the effectiveness of human-computer interaction [23]–[26]. The current research aims at furthering progress in that area.

C. Social Informatics Approaches to Evaluating Human–Robot Interaction

Formally, social informatics is "the interdisciplinary study of the design, uses, and consequences of information technologies that take into account their interaction with institutional and cultural contexts" [27]. One key idea of social informatics research is that the "social context" of information technology development and use plays a significant role in influencing the ways that people use information and technologies.

As a consequence of these findings, we take a socio-technical orientation in order to understand the specific features and trade-offs that will most appeal to the people most likely to use our system. We rely on a set of "discovery processes" for learning about preferences of people interacting with our robot, which include workplace ethnography [28]. Indeed, as made clear recently by the cognitive science community, people, the systems they use, and the interaction between the two, can no longer be studied and modeled in terms of isolated tasks and factual information, but rather in terms of activities and processes [29].

To date, few researchers use this technique in their research. Two instances were found in the literature. For example, a non-humanoid robot capable of human interaction and performing repetitive tasks is being used to test the feasibility of robots for aiding autistic patients in learning social interaction skills [30]. At Carnegie Mellon University (CMU), the importance of having an avatar and face tracking device on a social robot was tested using their robot, Vikia, by monitoring the length of interactions with the robot [23].

What is unique to our socio-technical approach is that we mix quantitative and qualitative research methods via survey research to guide our design and implementation *concurrently*. In other words, we use survey results from potential users to guide the design of our robots rather than completing our design and then gaining their feedback.

D. Personality Theory

Because of our socioinformatic approach, which is essentially to create robots that potential users will find both useful and pleasing, various individual difference factors are also of interest. In particular, does a person's age, sex, ethnicity, educational interests, or personality determine their reactions to service and social robots? Will one robot design satisfy all types of users?

The assumptions behind personality theories are that personality traits: 1) are stable across time (i.e., moods and emotions are temporary states); 2) influence behavior, perceptions, and thought processes; 3) can be inferred from behavior. However, theorists do not agree on the number of factors. For example, Eysenck [31] found three factors, Costa and McCrae [32] found five, 16 factors were found by Cattell *et al.* [33], Gough [34] found 18 factors, and Saville *et al.* [35] found 31 [36].

Nevertheless, there is one theory of personality that has become most prominent: Costa and McCrae's [32] five-factor model, also known as the *Big Five*. There are several reasons why the Big Five has become popular. First, over the years, several theorists have independently found five factors of personality (e.g., [37]–[43], [78]). Second, longitudinal and cross-sectional studies have found support for five factors. Third, five traits appear to emerge from other personality systems. For example, Krug and Johns [44] investigated Cattell *et al.*'s [33] 16 factors and found five underlying dimensions. Finally, five factor models are found to generalize across age, sex, and cultures [36].

The dimensions of the Big Five include *extroversion*, *neuroticism*, *openness* to experience, *agreeableness*, and *conscientiousness*. An *extrovert* is described as a person who is energetic, assertive, outgoing, social, excitement seeking, and who tends to experience positive emotions. A person who is *neurotic* frequently experiences anxiety, depression, and negative emotions. In addition, he or she is described as impulsive, vulnerable, and self-conscious. Individuals who are *open* to experience enjoy new experiences, are open to ideas and values, and are often described as persons who enjoy the arts (e.g., music, theatre, etc.). *Agreeableness* is characterized as a person who is trusting, altruistic, compliant, tender-minded, and modest. Finally, a *conscientious* individual is competent, dutiful, organized, achievement oriented, self-disciplined, and deliberate [36].

III. Approach to Embodying Affective Social Intelligence

A. Embodied Social Intelligence and Decision-Making

In order to understand when social relationships are needed in human–robot interaction or when the perception of such relationships need to be changed, social relations must be modeled. Emotions have a crucial evolutionary functional aspect in social intelligence without which complex intelligent systems with limited resources cannot function efficiently [13], [14], nor maintain a satisfactory relationship with their environment [15].

Emotions are carriers of important messages which enable an organizm to maintain a satisfactory relationship with its environment. *Fear*, for example, serves the function of preparing an organizm physiologically for a flight-or-fight response (blood flow increases to the limbs, attentional cues are restricted, etc.). *Anxiety*, on the other hand, serves the function of indicating that further preparation for the task at hand is needed.

Emotions greatly influence decision making (although sometimes dysfunctionally), more often than not for improved efficiency and flexibility toward a complex changing environment. Indeed, pure reasoning and logic have proven to be insufficient to account for true intelligence in real life situations. In the real world with all its unpredictable events for example, there is not always time to determine which action is best to choose, given an infinite number of possible ones and a set of premises.

Furthermore, different personalities will incline individuals to have different mental and emotional pattern tendencies. An agent with an *aggressive* personality, for example, will be predisposed to a *fight* response when experiencing fear, whereas one with a *meek* personality will be predisposed to *flee*. Predispositions, however, can be altered by conscious repression and/or adaptation.

B. Multilevel Process Theory of Emotions

The multilevel process theory of emotions [45] diagrammed in Fig. 1 was chosen for our approach because it considers emotions as complex behavioral reactions to external events and internal thoughts and beliefs constructed from the activity of a hierarchical multicomponent processing system which parallels nicely robot architectures (as explained later).

1) The *sensory-motor level* is activated automatically without deliberate planning by a variety of external stimuli and internal changes (e.g. hormonal levels). Affective reactions based on pure sensory-motor processes are reflex-like and are coarse-grained states as described in Section III-C. Information available at that level consists of valence and intensity (see Fig. 1 lower layer).
2) *Schematic level* integrates sensory-motor processes with prototypes or scripts of emotional situations having concrete schematic representations (see Fig. 1 middle layer).
3) *Conceptual level* is deliberative and involves reasoning over the past, projecting into the future, and comparing emotional schemata in order to avoid unsuccessful emotional situations (see Fig. 1 upper layer).

The multilevel process theory of emotions is particularly powerful for artificial intelligent design in that it enables

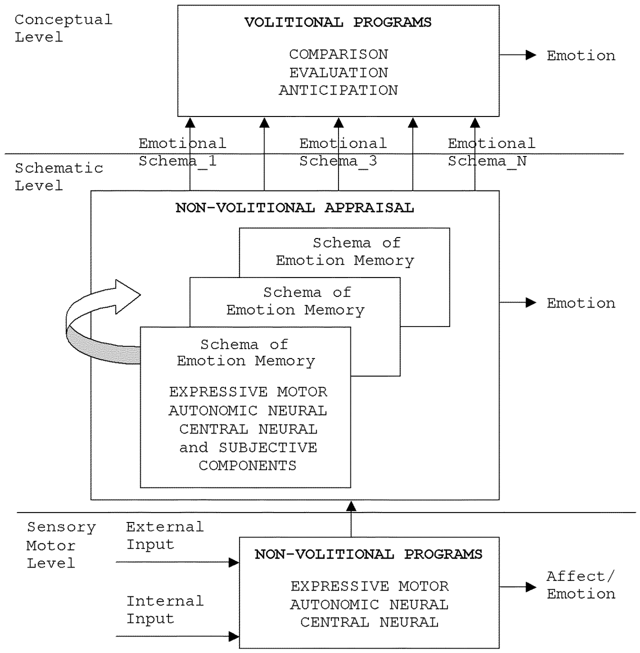

Fig. 1. Multilevel process affect/emotion generation.

various levels to be implemented, integrated, and tested incrementally. As exemplified with an emotion-based architecture for two cooperating robots [11], it furthermore matches closely hybrid/reactive deliberative architectures for robotic agents. Table I shows that relationship.

C. *Affective Knowledge Representation (AKR)*

In order to contribute to rendering artificial intelligent agents socially more competent, we combined and reconciled aspects of the main current theories of affect (e.g., [46]) and mood and emotion (e.g., [47]–[49]) into a simplified and comprehensive (but not complete) taxonomy of affect, mood, and emotion for computational affective knowledge representation (AKR). The AKR is described in further details in [50].

1) Affect, Moods, Emotions, and Personality: We created the AKR in order to enable the design of a variety of artificial autonomous (i.e., self-motivated), socially competent agents in a variety of applications such as robotics [11], user-modeling [51], human-computer interaction [52], multiagent systems, and distributed AI. The taxonomy of affective states is intended to differentiate among the variety of affective states by using values of well-defined componential attributes.

In short, in the taxonomy, each emotion is considered a collection of emotion components, such as its valence (the pleasant or unpleasant dimension), its intensity (mild, high, extreme), etc. The action tendency of each emotion [47] is also represented and corresponds to the signal that the emotional state experienced points to: a small and distinctive suite of action plans that has been (evolutionarily) selected as appropriate, (e.g. approach, avoid, reject, continue, change strategy, etc.).

Emotions are called “primary” or “basic” in the sense that they are considered to correspond to distinct and elementary forms of action tendencies. Each “discrete emotion” calls into readiness a small and distinctive suite of action plans that have been selected as appropriate when in the current emotional state. Thus, in broadly defined recurring circumstances that are relevant to goals, each emotion prompts both the individual and the group to act in a way that has been evolutionarily more successful than alternative kinds of prompting.

TABLE I
MULTILEVEL PROCESS OF EMOTIONS VERSUS HYBRID REACTIVE/DELIBERATIVE [11]

Multi-Level Process	Hybrid Reactive/Deliberative
Conceptual • reasons about past and present emotions and projects into the future regarding possible consequences of action from anticipated emotion [66]	**Deliberative Planning** • reasons about past, present, future
Schematic • emotions control which behaviors are active through prototypical schemata • can be implemented with scripts [65]	**Assemblages of behaviors** • collections of behaviors are assembled into a prototypical schema or skill [3] • can be implemented with scripts [4]
Sensory-motor • emotions modify the motor outputs of active behavior	**Reactive behavioral** • active behaviors couple sensors and motor actions

TABLE II
ACTION TENDENCIES

EMOTION	FUNCTION	ACTION TENDENCY
Fear	Protect	Avoid
Desire	Permit consummatory activity	Approach
Anger	Regain Control	Agnostic
Disgust	Protect	Reject
Anxiety	Caution	Prepare
Contentment	Recuperation	Inactivity

The number and choice of basic or primary emotions vary among different theories of emotion. We have selected the ones that seem to consistently reoccur across emotion theories. Their associated action tendencies are listed in Table II.

An emotional signal sent when a subgoal is achieved acts to prompt the individual to continue with the current direction of action. The signal sent when a goal is lost indicates a need to change the course of action or to disengage from the goal. Ensuing actions can be communicated to others in the same social group, which in turn, can have emotional consequences for the other individuals as well.

IV. SOCIAL SERVICE ROBOT IMPLEMENTATION

Enabling a computer for conversational interaction has been a vision since the creation of the first computers. While many components to a system capable of intelligent interaction with the user exist, having a believable agent capable of intelligent interaction is undoubtedly desirable. How can a *believable* emotional agent be created?

Part of the answer is to design agents whose behaviors and motivational states have some consistency. This necessitates: 1) ensuring situationally and individually appropriate internal responses (in this case, emotions); 2) ensuring situationally and individually appropriate external responses (behaviors and behavioral inclinations); and 3) arranging for sensible coordination between internal and external responses [48].

Unless there is some consistency in an agent's emotional reactions and motivational states, as well as in the observable behaviors associated with such reactions and states, much of what the agent does will not make sense to the user.

Our robot, Cherry, currently has multiple internal states and external behaviors:

1) maintaining and expressing a consistent personality throughout the series of interactions;
2) experiencing different inner emotional-like states in terms of her progress toward her goals;
3) choosing (or not) to express these inner states in an anthropomorphic manner so that humans can intuitively understand them;
4) having an internal representation of her social status as well as the social status of her "bosses;"
5) adapting to the social status of the person she is interacting with by following acceptable social etiquette rules.

A. Hardware Overview

As an Amigobot from ActivMedia, Inc., Cherry's initial hardware included a Hitachi H8 processor, 1 MB of flash memory, two reversible dc motors, eight sonars, and a wireless modem. Her original functionality was limited to autonomous random wander movements or directed movements controlled by a stationary PC. As a result, many elements needed to be added to her hardware in order to increase her social interaction abilities. A small laptop was connected directly to the base of the robot to increase the programming capabilities, increase autonomy (i.e., the robot was no longer tied to a stationary computer), and allow the user interface to be displayed. Although we realize how impractical it is to have the interface at such a low level, it was not possible to create a platform at a higher level without causing her to tip over. Nevertheless, this design was implemented to begin our social robotic investigations, knowing that in the future we would be able to port the code to a different robot platform, as explained in "future research." To allow for face recognition and an eye-level vision for the operator, a FireWire camera was added to the top of an aluminum pole with a hub at its base. A detailed engineering tutorial on how she was modified is described in [53].

B. Robot Tasks and Functionality

In order to begin the inquiry on the modeling aspect of human–robot social relationships, we identified one specific application that appeared intuitively "social" enough to start generating interesting, relevant results.

Cherry was designed and programmed to participate in a number of office activities and to play a variety of social roles within an office suite. The algorithms designed for Cherry's roles include the following:

1) her master's favorite office gopher: a one-to-one master-helper human–robot relationship;
2) her department members' favorite gopher: a many-to-one masters-helper human–robot relationship;
3) her department tour guide for visitor(s): another many-to-one human–robot relationship.

Master(s)-Centered Gopher: Another important task Cherry can perform is delivering documents or bringing soda cans, which are deposited in her delivery cup, to a specific professor or staff member. A copy of the computer science map was created on Cherry's laptop interface to enable users (for now only one user at a time) to point and click to the location on the map he or she wants Cherry to go. Menu options are also available to choose a specific professor's office by last name. This feature will be described in more detail below.

Tour Guide Information for Faculty Offices and Faculty Research Interests: Another task Cherry can perform is to give meaningful and instructive tours of the faculty offices. In order to give Cherry knowledge of who works where so that she could introduce each researcher, each office on the map was linked with each professor or staff's facial image and current research interests (available from our UCF computer science web site and integrated in Cherry's software). In this way, Cherry has the capacity to introduce someone once she reaches his or her office.

C. Building Office Suite Map

ActivMedia Mapper [53] software was used to create a map of our computer science office suite in order to have the ability to create: 1) a simple point-and-click navigation system and 2) a built-in grid system used in the navigational portion of the interface.

The robot is able to use its sonars to navigate around small and moving objects. As a result, only walls and large permanent obstacles needed to be drawn into the map. The robot's vision system for collision avoidance will be described later as future research.

The map associates the layout of the office suite and each office's corresponding suite number. It also includes information relating the name of each professor and staff member to their corresponding office numbers. In this way, the user can point and click on the office in order to dispatch Cherry to the office desired.

The map therefore provides quick and simple direction for Cherry. Because the map is completely accurate, it also provides the basis for the (x, y) coordinate system.

D. Eye-Level Vision and Face Recognition

The robot interface was also integrated with Identix face recognition code [54]. Cherry has the ability to take pictures of people she encounters with her eye-level camera, and to match them to her internal database of photographs of faculty, staff, and students who work in the computer science building.

E. Social Status and Greeting

Not only does face recognition abilities enable Cherry to recognize who she encounters, but also to greet different people according to their university status. These social status codes enable her to know what greeting is socially acceptable. In general these are clearly context and/or culture-dependent.

Fig. 2. Cherry's neutral facial expression.

In the current case, they are limited to the distinction of social status within the UCF Computer Science Department: a Full Professor is greeted with more deference than a Graduate Student, by associating the title of "Professor" at the beginning of the greeting, versus addressing the person by their first name if the person is recognized as a graduate student, or yet by preceding the last name with Ms. or Mr. if the person is a staff member.

F. Avatar

The avatar created is arguably the most important aspect of the robot interface. Indeed, with new advances in graphics over the past couple of years, artificial graphical representation of animated anthropomorphic faces have become realistic enough to convey subtle facial expression changes, skin tone, etc. Given how humans have developed over century of evolution a very efficient system to perceive and interpret facial expressions in human-human communication exchanges, the current approach aims at developing a scheme for human–robot interaction that exploits the natural human capacities to understand the meaning of facial expressions as they relate to internal state.

Cherry's face, shown in Fig. 2, was created using Haptek's People Putty [55] and was designed to be a 20-something year-old young woman who is both attractive and able to believably demonstrate being upset or angry. The avatar was designed to mimic human movement by incorporating random head and eye movements as well as lip movements as she spoke.

In order to facilitate Cherry's social interactions with humans, the avatar is present on the laptop (e.g., Cherry's user interface) and has voice capabilities, which allow her to speak to the user in natural language. As mentioned before, as a tour guide, her current tasks are to explain a variety of facts, i.e., who she is, what her mission is (namely the UCF computer science tour guide), which professor works in what office, what a particular professor is researching, what a professor's office hours are, and so on.

G. Speech and Voice

Haptek not only provides the means to create an avatar, but also to equip a robot with an appropriate voice. Selections include various male, female, and robotic voices, including voice simulations in space, in a stadium, on a telephone, and whispering. Because we wanted the avatar to be as human-like as possible, we decided to incorporate the standard female voice.

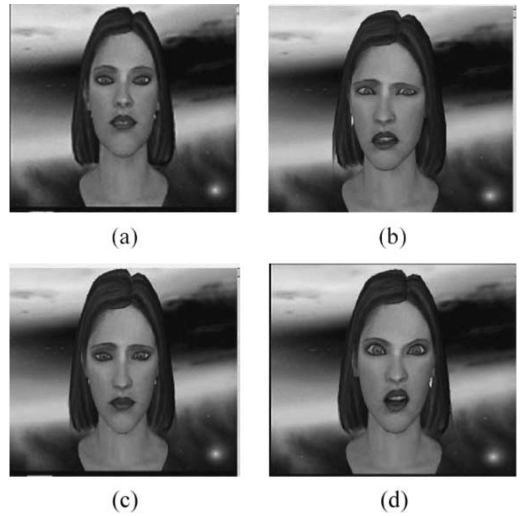

Fig. 3. (a) Neutral facial expression. (b) Frustrated facial expression. (c) Sad facial expression. (d) Angry facial expression.

H. Facial Expressions for Effective Communication

As surveyed in Lisetti and Schiano [56], since Darwin [57], the central preoccupation of researchers interested in the face has been to correlate movements of the face primarily with *expressions of inner emotional states*. The advocates of this view, the "emotion view," are not all homogeneous in their opinions, but they do share the conviction that emotions are central in explaining facial movements [58], [59].

The "behavioral ecology view," on the contrary, derives from accounts of the evolution of signaling behavior, and does not treat facial displays as expressions of emotions, but rather as *social signals of intent*, which have meaning only in social contexts [60], [61].[1]

These observations motivated the inclusion of facial expressions in our interface, with the intuition that humans would relate to and understand better a robot with an anthropomorphic face able to express internal states in a manner consistent with the one naturally used and understood by humans.

Currently, Cherry can display different facial expressions with different intensities, which, as explained later, correspond to her different inner states, i.e., neutral, frustrated, sad, and angry, as shown in Fig. 3(a)–(d).

I. Expression of Culturally-Independent Semantic Descriptions of Emotion Concepts

In order to enable our robot to express its internal emotional states in natural language as well, we adapted the semantic meta-definitions of emotion concepts using a limited set of language-independent primitives developed by Wierzbicka [49]. The semantic meta-definitions have the advantage of being culture-independent as they describe the causal chain that led to that emotion. A causal chain of events describes the subjective cognitive experience components that are associated with the emotion, the beliefs, the goals, and the achievement of (or lack of) those goals. These components are associated with each emotion and

[1]More recently, facial expression has also been considered as an *emotional activator*—i.e., as a trigger—contrary to being viewed solely as a response to emotional arousal [62]–[64].

are spoken via speech synthesis so that the agent can *verbally* express and describe the cognitive interpretation of its state. For example, the causal chain for *frustration* is "I want to do something, I cannot do it, and because of this, I feel bad." More examples can be found in [65] again derived from Wierzbicka's work [49], and although slightly unnatural, we chose to use them in order to avoid ethnocentric language for our artificial agent. Furthermore, we also want to later be able to easily complete the uttered sentences with the actual objects of emotions, goals etc., and replace primitives like "something" (as above) with the actual object of frustration. For example, the robot will be able to identify the "something" that it is unable to accomplish in the *focality* of the causal chain. It will then say "I am frustrated because I want to deliver a message to Dr. So-and-so, and I cannot do it; because of this, I feel bad."

J. Internal States

Both a bottom-up and a top-down approach were adopted to design Cherry's architecture. She has the beginning of some social expertise in terms of associating a variety of *external expressive behaviors* with her various *inner states*.

1) **Frustration**: Cherry reaches a state of frustration when she finds that an office to which she was send to has a closed door, or she cannot recognize the faculty or staff member inside the office. She expresses her internal frustration with the facial expression shown in Fig. 3(b) and with speech "I want to do something, I can't do this, because of this I feel bad."
2) **Anger**: Cherry reaches an angry state when, after waiting for a long time, an office door still remains closed, and the action tendency activated will "motivate" her to change her current relationship with the environment and regain control. Anger is expressed with facial expression (Fig. 3(d)) and with speech "Something bad happened, I don't want this, because of this, I want to do something, I would want to do something bad to this object."
3) **Discouragement**: Cherry reaches a discouraged state when, after waiting for a while, an office door still remains closed. She expresses sadness with the expression shown in Fig. 3(c) and with the speech "Something bad happened, I would want this did not happen, if I could I would want to do something, because of this I can't do anything."

The initial choice of specific internal states for Cherry was, on one hand, motivated by a desire to test how her different behavior affect real people behavior and their reaction to her (depending on their own personality, age, gender etc.), and on the other hand, to later be able to study the design of artificial agents in collaborative human–robot group settings.

These inner states—dynamically measured in terms of her current relationship with her environment and goals—will need to be integrated with the external behavior for a consistent system [48]. Currently, each level functions separately. For the current application, the robot action tendencies (AT) associated with its emotion are related to its tasks and shown in Table III.

TABLE III
CHERRY'S ACTION TENDENCIES

EMOTION	AT for Cherry	ACTION TENDENCY
Happy	Guide/Deliver	FreeActivate
Neutral	Guide/Deliver	ContinueNormalActivity
Frustrated	ReturntoMaster	ChangeCurrentStrategy
Angry	RemoveObstacle	RegainControl
Discouraged	GiveUpTask	ReleaseExpectations

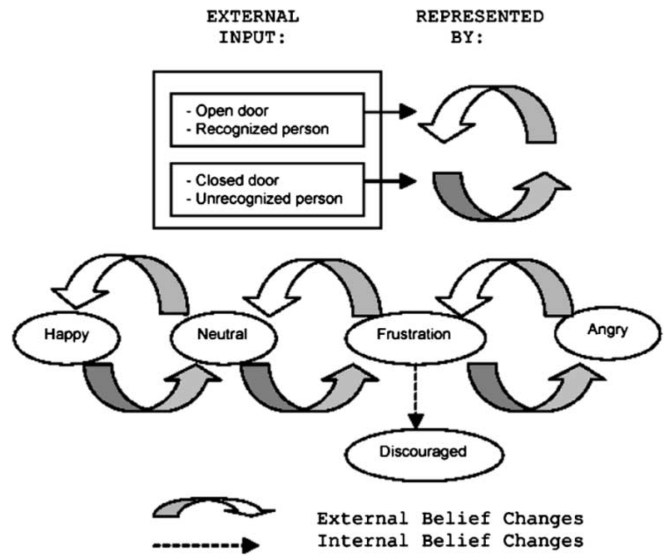

Fig. 4. Transitions between emotional states.

K. Emotion Dynamics

1) External Events as Inputs: Transitions among the various emotional states are caused by environmental inputs or responses to the system, and they are divided into categories of positive progress toward goals and negative progress toward goals. Using this dynamic model, we can predict that an agent that is in a HAPPY state will remain HAPPY given positive inputs and could become FRUSTRATED given a series of negative inputs toward its goal (e.g., obstacles of some sort depending on the context).

Currently, Cherry has a limited number of states to transit to and from: happy, neutral, frustrated, discouraged, and angry as shown in Fig. 4.

Transitions are based on negative or positive inputs from the environment in terms of her success in: 1) finding the door to the office that she was sent to open and 2) in recognizing someone in that office.

2) Internal Beliefs as Inputs: An individual's emotions can change in reaction to an event, and these changes may also be the result of their own efforts, not simply the result of an independent process directed by external events or social rules. Emotional changes indeed occur as a result of a number of processes.

A simple example is one where a negative internal belief regarding the subjective perception of *modifiability* of the current situation such as "I can't do this" keeps the agent in its current DISCOURAGED state forever. Should the agent manage to change its internal belief to a positive input in the form of an

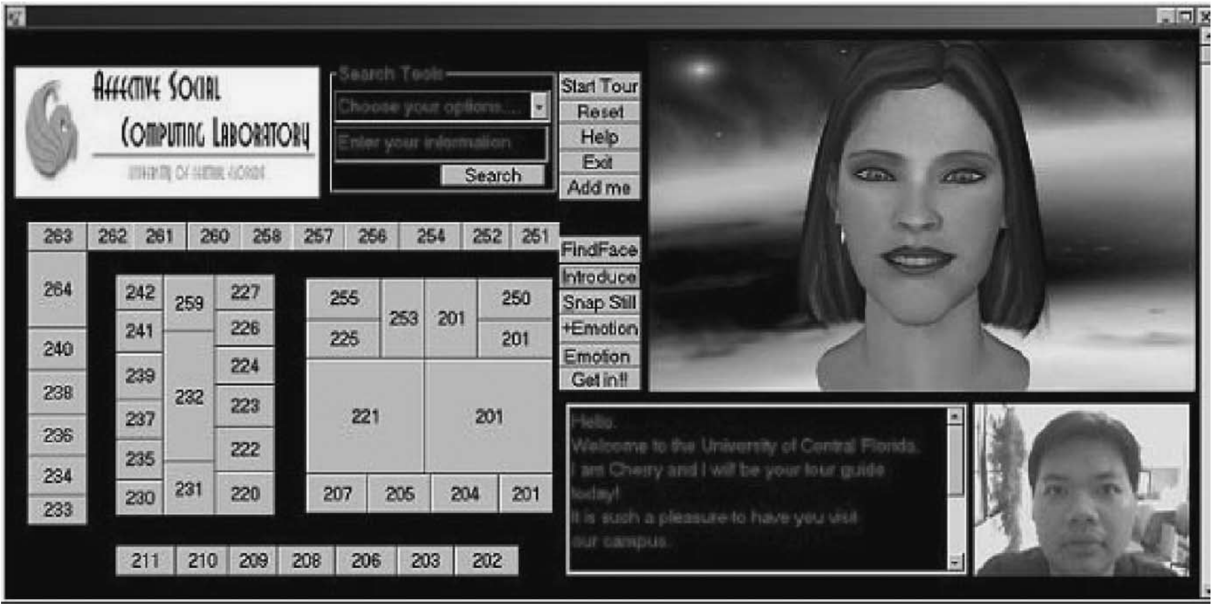

Fig. 5. Cherry's complete integrated interface.

enabling belief (e.g., "I can indeed do this"), the agent would switch to a HOPEFUL state. Other examples of such internal self-adjustments abound [66].

These mental modal beliefs described in [50] are part of an affective knowledge representation scheme, which enables such transitions to occur. Currently, Cherry's internal beliefs such as *modifiability*, *certainty*, and *controllability* are not active in this version of implementation. Furthermore, depending upon the programmed personality traits, the agent can experience various tendencies toward specific sets of emotions.

L. Web-Based Command-and-Control

To allow users the ability to control Cherry from their desktops (rather than having to stoop toward the floor to manipulate Cherry's laptop), the laptop was connected to the university network via a wireless Ethernet card.[2]

M. Cherry's Web-Based Eye-View of the World

Because a robot may take a "wrong turn" or intrude upon someone unintentionally, a vision aspect was integrated into the user interface. Not only is the image of what the robot can "see" (with the camera at eye-level) displayed on the user interface, but the image can be broadcasted via the Web to allow multiple users to view her actions at once.

This aspect of the complete user interface is partly for user interest, but mostly to prevent the robot from failing to reach an intended goal or advancing to an unsafe region, such as a stairway, due to inaccurate navigational systems during the testing process.

Using TeVeo webcam video streaming software, images can be broadcasted from Cherry's camera to the Web. Cherry's eye-level camera, and potentially another camera mounted nearer to her base, can provide a "Cherry's-eye-view" of the world to users via access to the Web.

N. Complete Integrated Robot

Cherry's interface was written in Visual C++ and incorporates the avatar, speech, video, face recognition, and navigational map elements. We believe that the layout and simplicity of use will make the robot more accepted as a service robot and provide an easy and enjoyable way for people to interact with her. The avatar, map, eye-level vision, and menu options can all be seen in the integrated user interface in Fig. 5.

Finally, to create a nonintimidating genre of technology, and to give her an aesthetically pleasing appearance acceptable for a home, Cherry was dressed with feathers, Fig. 6. This also has the advantage of avoiding issues such as raising user's expectations about her current abilities and limited intelligence.

V. Design Evaluation for Social Robot

Taking a social informatics co-evolutionary approach to the study and design of technology and social structures, this bi-directional approach enables us to start testing and evaluating the interface with human subjects *while* Cherry's functionality is being designed. We believe this approach helps to ensure maximum success in her functionality, interface design, and acceptance.

A. Study One: Preliminary Investigation

The first study was a preliminary investigation to determine whether our robots' features needed to be adjusted. Specifically, the objectives of the first study were to assess

1) whether Cherry's avatar and voice features were acceptable;
2) whether the avatar of a second robot under development, Lola, was acceptable;
3) opinions toward service robots;
4) opinions toward robots with personality and emotion capabilities.

[2]We are searching for better ways to display the web interface in order to 1) reduce potential interferences and 2) get a better refresh rate and color display than WinVNC can provide. The subtle coloration and frequent subtle facial movements of our avatar caused by WinVNC will be described later.

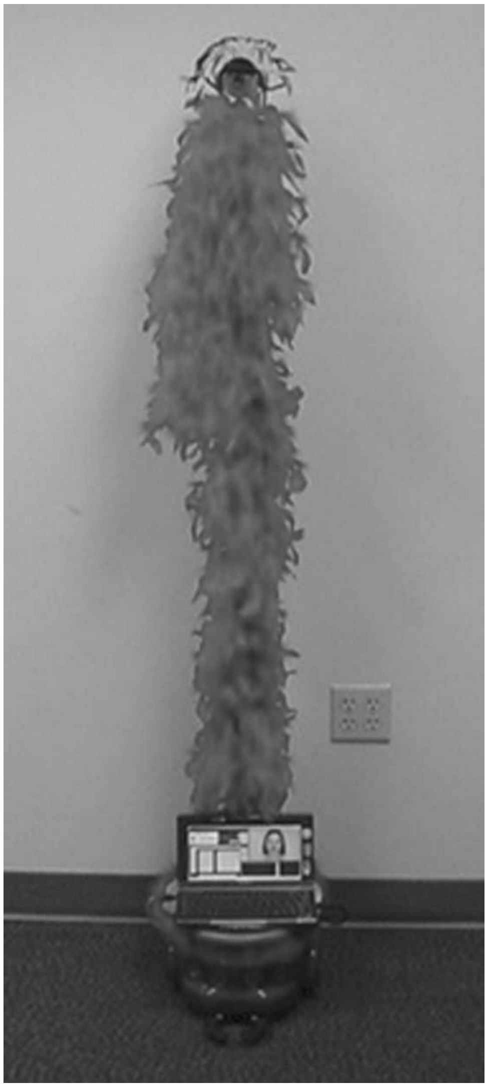

Fig. 6. Cherry equipped for social interaction.

Method: **Sample**: The sample included 25 students and staff members from the engineering and computer science departments. There were eight females and 17 males: one Hispanic, 16 Caucasians, six Asians, and two Native Americans. Their ages ranged from 18 to 55; however a mean age could not be calculated because the question asked the participants to specify their age range (i.e., 18–25 [$n = 19$], 26–35 [$n = 2$], 36–45 [$n = 2$], 46–55 [$n = 2$], and 56+ [$n = 0$]).

Procedure: The participants were given a demonstration of Cherry's features and social capabilities and were shown the avatar developed for Lola. The subjects then completed a questionnaire regarding their reactions to Lola's avatar and Cherry's features and appearance. In addition, the questionnaire also asked for their opinions of service and social robots.

Questionnaire: The questionnaire included 38 items: four demographic items (i.e., status, sex, age, ethnicity); 15 items assessing personality characteristics; four open-response items; and 15 items assessing their reactions to Lola's avatar, Cherry's appearance and features, their opinions of robots with personality and emotion capabilities, and their opinions of service robots in general. The personality items were not used in the analysis due to the sample size not being conducive for confirming the reliability and factor structure of the scale. In addition, the four open-response items were not used in the analysis, as a coding technique to enter the data into SPSS was not created. The purpose of these items was to determine why individuals liked or disliked Cherry's avatar and voice, Lola's avatar, and the idea of a robot with a personality.

The remaining 15 items included: two items regarding Cherry's avatar, three items referring to Cherry's voice, one item with regards to Lola's avatar, six items referring to opinions of robots with emotion and personality capabilities, and three items regarding opinions of service robot features. Two five-point response options (i.e., one = definitely/extremely, five= not at all) were used with all but one item. The item, *Which communication method would you prefer a robot use to inform you about the difficulties it is having while accomplishing tasks?*, had three response options: human-like facial expressions of frustration, text-based list of commands the robot could not execute, or both.

Results: The average responses to the items regarding the two avatars were investigated first. The results revealed that, overall, the participants liked Cherry's avatar ($M = 1.96$, $SD = 0.73$) and did not like Lola's avatar ($M = 3.43$, $SD = 1.16$). In addition, overall, the participants enjoyed interacting with a robot having a human face ($M = 2.38$, $SD = 1.01$). The three items regarding Cherry's voice were summed and averaged. The average response to her voice ($M = 2.53$, $SD = 0.99$) indicated that the participants were pleased with the robot's voice and did not feel that her avatar mismatched her voice.

Overall, the participants felt that a robot with personality and emotion capabilities was a good idea ($M = 2.10$, $SD = .99$). In addition, they felt that a robot displaying positive emotions was acceptable ($M = 1.56$, $SD = .92$), however, they did not particularly like or dislike the idea of a robot displaying negative emotions ($M = 3.00$, $SD = 1.44$) or displaying frustration with people ($M = 3.20$, $SD = 1.47$) and objects ($M = 2.96$, $SD = 1.49$) interfering with its tasks.

With regards to service robots, the participants indicated that they liked the idea of a robot serving as a tour guide ($M = 1.91$, $SD = 1.31$) and a gopher ($M = 1.48$, $SD = 0.81$). Finally, on average, the participants preferred that a robot communicate its difficulties completing a task with both a human-like expression of frustration and a text-based list of commands it could not execute ($M = 2.44$, $SD = 0.87$).

B. Study Two: In-Depth Investigation

Once determining that Cherry's avatar and that service and social robots were acceptable to people, a second, more extensive study was planned. The questionnaire items were revised to include more items regarding Cherry's overall appearance and specific features. In addition, more items regarding attitudes toward social and service robots were developed. Of particular interest was whether a person's demographic characteristics determined their responses. Therefore, the item regarding the age of the participants was changed to gain their actual ages and items asking for their major and department were added. Although it was not possible to determine if educational interests were related to responses in this study, we added these items for future investigations. The degree of experience individuals have interacting with or working on robots may also influence their reactions to robots; therefore two items regarding experience with robots were also added. Finally, in order to determine whether an online demonstration of reactions to Cherry would be feasible (potentially useful for future telemedicine patient assistance and monitoring), items regarding how comfortable individuals would be with a robot broadcasting images to the Web were created.

The objectives of this study were to determine whether

1) survey we created meets psychometric standards;
2) perceptions of and reactions to service robots, social robots, and Cherry differ by age, sex, ethnicity, or personality;
3) exposure to Cherry changed perceptions of service robots and/or social robots;
4) features and appearance of Cherry were acceptable;
5) individuals would be comfortable with a robot taking their picture and broadcasting images to the Web.

The personality questionnaire developed for the current study is based on the Big Five theory of personality described in the "Related Research" Section.

Sample. The sample included 56 undergraduate students enrolled in a psychology course. There were 42 females and 14 males: five African Americans, seven Hispanics, 34 Caucasians, four Asians, five individuals indicating mixed ethnicity, and one subject who did not report their ethnicity. Their ages ranged from 19 to 33 with a mean of 23.04 years ($SD = 3.11$).

Procedure. The participants completed a pre-questionnaire, which included items regarding their demographics, their opinions about service robots, and their opinion of robots with personality and emotion capabilities. After completing the pre-questionnaire, Cherry's features were described and a demonstration of her capabilities was presented. The subjects then completed a post-questionnaire regarding their reactions to Cherry's features and appearance. In addition, in order to determine whether exposure to Cherry changed their opinions regarding robots, the post-questionnaire also asked for their opinions of service robots and robots with social capabilities.

Pre-Questionnaire. The pre-questionnaire included 21 items. Six demographic items (i.e., sex, age, ethnicity, major, department) and 15 items regarding their experience with robots, their opinions of service robots, and their opinions of robots with a personality and emotion capabilities. A five-point Likert-type scale was used for 14 of the 15 items. The remaining item, *Which communication method would you prefer a robot use to inform you about the difficulties it is having while accomplishing tasks?*, had three responses to choose from: human-like expressions, text-based list of commands it could not execute, or both. Two items determined the participants' experience with robots. *How often do you interact with robots*: 1 = daily, 5 = none? and *What level of experience do you have working with or on robots:* 1 = high, 5 = none?

Five items assessed their opinions of service robots in general. The five-point response options were of two types. For example, the item *Do you feel robots can be useful outside of an industrial setting (e.g., factories)?* included the following response options: 1 = definitely, 2 = pretty much, 3 = somewhat, 4 = a little, and 5 = not at all. The item, *How comfortable would you be with a robot serving as an assistant to help you remember appointments, grocery lists, etc.?* included the response options of: 1 = extremely, 2 = very, 3 = moderately, 4 = somewhat, and 5 = not at all.

An additional five items asked participants about their opinions of robots with personality and emotion capabilities. For example, *Do you think giving a robot a personality is a good feature?* and *Do you feel that interactive robots should display emotions, positive or negative*? (1 = definitely, 5 = not at all). The final three items of the survey asked participants how they would feel about a robot taking their picture and having the images broadcasted on the Web.

Post-Questionnaire. The post-questionnaire included 38 items: 15 items assessing personality characteristics based on the Big Five personality theory and 23 items assessing their reactions to Cherry's appearance and features, their opinions of robots with personality and emotion capabilities, and their opinions of service robots in general. Three items for each of the five personality characteristics were developed (i.e., *I am sometimes shy and inhibited; I easily get nervous; I usually cooperate with others; Most often, I do a thorough job;* and *I enjoy art, music, and/or literature*).

Eight items assessed the subjects' reactions to Cherry's appearance, features, and social capabilities. The same two five-point response options mentioned above were used. For example, *Did you enjoy interacting with a robot that has a human face?* had the 1 = *extremely* to 5 = *not at all* response options. The item, *Do you think the text box feature is helpful for understanding what Cherry says?* included the 1 = *definitely* to 5 = *not at all* scale. Six items assessed their opinions of service robots in general. The item *Which communication method would you prefer a robot use to inform you about the difficulties it is having while accomplishing tasks?*, was repeated in the post-questionnaire in order to determine if exposure to Cherry changed their preference for communication method. Other items included questions such as *Would you prefer a robot without a human face?* and *Would you like a robot to give you a tour of a building?* (1 = definitely, 5 = not at all).

An additional eight items asked participants about their opinions of robots with a personality and emotion capabilities. In order to determine whether exposure to Cherry changed their opinions regarding social robots, two items from the pre-questionnaire were repeated in the post-questionnaire: *Do you think a robot with a personality is a good feature?* and *Do you think that having a robot display emotions could make them more accepted into everyday roles in human life?* (1 = definitely, 5 = not at all). Two additional items from the pre-questionnaire were also repeated; however, they were assessed with two separate items each. For example, the item *Do you feel that interactive robots should display emotions, positive or negative?* was assessed with the items: *Do you feel that interactive robots should display positive emotions, such as happiness and surprise?* and *Do you feel that interactive robots should display negative emotions, such as discouragement, frustration, and anger?* (1 = definitely, 5 = not at all).

The pre-questionnaire item, *Do you feel it would be appropriate for a robot to get angry or upset with an obstacle or person that interferes with a robot's task?* was measured with the items *Do you think it would be appropriate for a robot to communicate frustration or anger toward a person that interferes with its task?* and *Do you think it would be appropriate for a robot to communicate frustration or anger toward obstacles (i.e., walls, boxes) that interfere with its task?* (1 = definitely, 5 = not at all). The final item of the post-survey asked participants how important a person's overall appearance is to them when interacting with him or her. This question was asked in order to determine whether Cherry's physical appearance might hinder interactions with her.

Analyses. Five statistical analyses were performed with the data. Reliability theory suggests that any measurement technique, particularly in the behavioral sciences, contains some degree of error. The more error a test contains, the less reliable the results. Therefore, estimates of reliability are important to calculate before any other analyses are performed. Reliability estimates range from zero to one: the larger the number, the more reliable the test. Estimates equal to or greater than $r = 0.80$ are recommended when the goal is to make comparisons between groups [67]. The reliability estimates for the items measuring attitudes toward service robots from the pre- and post-questionnaires were $r = 0.85$ and $r = 0.51$, respectively. For the items assessing attitudes toward social robots (e.g., with emotion and personality capabilities) in the pre- and post-questionnaire, the reliability estimates were $r = .079$ and $r = 0.92$, respectively. Finally, the reliability estimate for the three items in the pre-questionnaire regarding robots broadcasting images on the Web was $r = 0.80$. As can be seen, the reliability of the service robot questions in the post-questionnaire fails to meet Nunnally and Bernstein's recommendations. The implication is that finding a difference between pre- and post-attitudes toward service robots may be threatened. However, as will be seen in the results section, despite this threat, a significant difference was found. Had the reliability of these items been larger, the difference would more likely be larger [67].

The internal consistency estimate for the personality scale was $r = 0.74$. However, when a test, such as the personality measure used in the current study, measures multiple dimensions, lower reliability estimates are expected. Furthermore, Nunnally and Bernstein (1994) assert that estimates as modest as $r = 0.70$ are sufficient when estimating the relationships between variables. The purpose of the personality scale was to determine the relationship between personality and attitudes toward service robots, social robots, and reactions to Cherry. Pearson-product correlation coefficients were estimated in order to determine these relationships. The major implication is that the resulting relationships may be larger if the test were more reliable. When estimating correlation coefficients, r- and p-values are estimated. R-values indicate the degree of relationship between variables. For more information on correlation coefficients, see [68]. P-values will be discussed shortly. Before the correlation coefficients were estimated, principal component analysis (PCA, a data reduction technique that finds the underlying dimensions of a test) was conducted in order to confirm that the personality items indeed did assess five aspects of personality.

TABLE IV
MEAN SCORES AND STANDARD DEVIATIONS FOR ITEMS REGARDING CHERRY'S APPEARANCE AND FEATURES

Item	*M*	*SD*
Did you find Cherry's face to be pleasing?	2.91	1.06
Do you like Cherry's physical appearance?	2.84	1.07
Did you enjoy interacting with a robot that has a human face?	3.04	1.06
Do you like Cherry's overall appearance (e.g., physical and interface combined)?	2.89	1.07
Do you think the text box feature is helpful for understanding what Cherry says?	2.05	1.02
Do you like the video feature, which is the ability to see how your face is lining up with Cherry's camera?	2.77	1.25
Do you think it would be easy to use the point-and-click map to direct Cherry to someone's office?	2.23	.97
Do you like the search feature, which allows you to look up a person's name in order to find his/her office number?	2.05	.95

The final two statistical techniques used were analysis of variance (ANOVA) and t-tests. These procedures allow for comparisons of mean scores between groups and/or pre- and post-events in order to determine if they are statistically different. ANOVA results in F- and p-values. T-tests result in t- and p-values. In both cases, the p-value is the probability of obtaining a particular F- or t-value if there were *no* differences between groups and/or pre- and post-events. In the behavioral sciences, in order to conclude that there is a difference between mean scores, a p-value equal to or less than $p = 0.05$ is recommended [68]. In other words, a p-value of $p = 0.05$ suggests that there is a five percent chance that the mean scores are equal, indicating that the mean scores are probably different. The same logic can be applied to correlation coefficients: a p-value of $p = 0.05$ indicates that there is a five percent chance that the resulting coefficient would be obtained if there were *no* relationship between the variables, indicating that there is probably a relationship between the two variables.

Results. Analysis of variance (ANOVA) was conducted in order to determine the item-by-item differences between the sexes, races, and ages of the participants. Two items resulted in statistically different average scores. For example, the mean scores for the item *What level of experience do you have with robots?* differed by ethnicity $F(4,50) = 2.818$, $p < 0.05$; however, overall, the participants did not have much experience with robots. Specifically, Asian participants ($M = 3.75$, $SD = 1.26$) had more experience with robots than any of the other ethnic groups (means and standard deviations ranged from 4.60–5.00 and .00–.68, respectively).

The results also indicated that the average scores for the item *Do you like Cherry's physical appearance?* differed significantly by sex $F(1,54) = 4.617$, $p < .05$. Females ($M = 2.67$, $SD = .95$) liked Cherry's physical appearance more than males ($M = 3.36$, $SD = 1.28$). Table IV lists the items, means, and standard deviations regarding Cherry's appearance and features. As can be seen, the subjects did not particularly like or dislike Cherry's appearance. However, the subjects did find her point-and-click map ($M = 2.23$, $SD = 0.97$), text box ($M = 2.05$, $SD = 1.02$), and search capabilities ($M = 2.05$, $SD = 0.95$) to be useful features. In addition, there was not a significant relationship between the importance of appearance when interacting with others and responses to Cherry's appearance ($r = -0.13$, $p = 0.40$).

TABLE V
MEAN SCORES AND STANDARD DEVIATIONS FOR REPEATED ITEMS

Item	Pre *M*	Pre *SD*	Post *M*	Post *SD*
Do you think giving a robot a personality is a good feature?	2.79	1.28	2.73	1.21
Which communication method would you prefer a robot use to inform you about difficulties it is having while accomplishing tasks?	2.48	.74	2.54	.74
Do you think that having a robot display emotions could make them more accepted into everyday roles in human life?	3.05	1.28	2.76*	1.20
Do you feel that interactive robots should display emotions, positive or negative?	3.07	1.22		
Post item referring to positive emotions			2.23tt	1.18
Post item referring to negative emotions			3.02	1.43
Do you feel it would be appropriate for a robot to get angry or upset with an obstacle or person that interferes with the robot's task?	4.14			
Post item referring to obstacles			3.41tt	1.37
Post item referring to persons			3.68t	1.32

*p < .05. tp < .01. ttp < .001.

TABLE VI
FACTOR LOADINGS OF PERSONALITY ITEMS

Item	Factors 1	2	3	4	5
E1	.695				
E2	-.689				
E3	.813				
N1		.772			
N2		-.663			
N3		-.833			
A1			.449		
A2			.747		
A3			-		
O1				-.376	
O2				.820	
O3				.802	
C1					.800
C2					.679
C3					-.515

Note. E = Extroversion. N = Neuroticism. A = Agreeableness. O = Openness to Experience. C = Conscientiousness.

The mean scores of the three items measuring comfort with a robot taking pictures and broadcasting those images on the Web indicated that the participants were either unsure or uncomfortable. In particular, the subjects were slightly uncomfortable with having a robot with a camera at eye level broadcasting images on the Web ($M = 2.32$, $SD = 1.19$). In addition, they were unsure about having a) the images viewed by the person(s) controlling the robot ($M = 2.96$, $SD = 1.28$) and b) a robot with a camera mounted close to the floor (showing feet and furniture) broadcasting images on the Web ($M = 3.02$, $SD = 1.34$).

Table V presents the means and standard deviations for the five items that were in both the pre- and post-questionnaires. After exposure to Cherry, the participants' responses were significantly more positive for three items. The participants indicated that it was more acceptable for robots to display emotions ($t = 2.131, p < 0.05$) after meeting Cherry than they did before meeting her. In addition, interactive robots displaying positive emotions was more acceptable after meeting Cherry ($t = 5.753$, $p < 0.001$) than before meeting her. Finally, a robot displaying frustration/anger with obstacles ($t = 5.203$, $p < 0.001$) and people ($t = 3.274$, $p < 0.01$) interfering with the robot's tasks was more acceptable after meeting Cherry.

Five mean scores for the participants' responses were calculated from the items measuring:

1) pre-attitudes toward service robots in general ($M = 2.83$, $SD = 0.94$);
2) post-attitudes toward service robots in general ($M = 2.54$, $SD = 0.68$;
3) pre-attitudes toward robots with personality and emotion features ($M = 3.11$, $SD = 0.82$);
4) post-attitudes toward robots with personality and emotion features ($M = 2.74$, $SD = 1.00$);
5) reactions to Cherry ($M = 2.63$, $SD = 0.77$).

After they were introduced to Cherry, there was a significant change in the participants' attitudes toward robots. For example, after meeting Cherry, the participants responded more positively to the idea of service robots ($t = 2.365$, $p < 0.05$) and to robots with social abilities ($t = 3.818$, $p < 0.001$).

Finally, the factor structure of the 15 personality items was assessed with principal components analysis (PCA) using SPSS. Prior to conducting the analysis, the suitability of the data for PCA was assessed. Working in accordance to the recommendations of Tabachnick and Fidell [69], the correlation matrix was inspected and revealed that several coefficients were equal to or greater than 0.30. The Kaiser-Meyer-Oklin measure of sampling adequacy value was 0.64, exceeding the recommended value of 0.60 [70], [71] and the Bartlett's test of sphericity [72] was significant ($p < .001$), supporting the factorability of the items. PCA was subsequently conducted and revealed five factors with eigenvalues greater than 1, which explained 66% of the variance. In order to interpret the pattern of item loadings, Varimax rotation was performed.

Table VI presents the resulting item loadings. As can be seen, with the exception of one Agreeableness item, the items corresponding to each of the personality dimensions loaded into their respective factors.

Once the factor structure of the personality items was confirmed, the three items for each personality dimension were summed and averaged. Pearson-product correlations were calculated in order to determine the relationships between the personality dimensions and five item clusters (i.e., pre- and post-attitudes toward service robots and social robots, and reactions to Cherry). One personality dimension, openness to experience, demonstrated a significant relationship. Specifically, openness to experience was negatively related to the subjects' opinions of Cherry ($r = -0.321$, $p < 0.05$). In other words, the subjects who were more open to experience responded more positively to Cherry than individuals who were less open to experience.

Discussion. The survey revealed significant results regarding sex, ethnicity, and personality with respect to Cherry and prior experience with robots. The most significant finding with respect to sex differences was that females found Cherry's physical appearance more pleasing than males; however, there were no sex differences with regards to Cherry's avatar. It is also interesting to note that, while participants had little experience with robots, the Asian participants had more experience than any of the other ethnic categories. Because those in this study, and even more generally most people, have little experience with robots, it is important to develop robots in such a way that people will be willing to use and interact with them, or at least be open to new ideas with robotics. In fact, the results suggest that individuals who are more open to experience indeed do react more positively to robots. The results from this study also showed that exposure to Cherry changed opinions concerning social robots. As a whole, people were more open to robots displaying emotions after interacting with Cherry than before, especially with respect to robots displaying positive emotions. Although there was a more positive reaction to robots exhibiting negative emotions toward obstacles and people after exposure to Cherry, the participants still did not find it suitable.

Because of the design of Cherry, broadcasting images is essential if the operator is to be able to safely control her. Therefore, this study also aimed to determine how comfortable people would be with the use of cameras. In general, the participants were not comfortable with the use of cameras at eye-level broadcasting to the Web for many to see and not sure about how they felt about an eye-level camera viewed by only the operator or about a floor-level camera broadcasting to the Web. However, these questions were asked in the pre-questionnaire and perhaps a better time to ask them would be in the post-questionnaire, after seeing what exactly the cameras project.

As far as usability of Cherry, the participants in the study were pleased with her complete interface. The results for the survey items that referred to the text box, point and click map, and the search feature reinforced the decision to include these elements. Even though there was a negative reaction in general to the use of cameras, the participants did find the video feature used for facial recognition to be useful.

Limitations. A limitation of the survey in particular was that the reliability of the post-questionnaire items referring to service robots was low and one of the personality items referring to Agreeableness did not fall into its respective factor. In addition, because the study will be an ongoing endeavor, improvements to the scale items will be made. Therefore, more substantial positive increases in attitudes toward service and social robots as well as reactions to Cherry might be found.

VI. Future Research Goals

A. Survey Research With Cherry

As noted previously, participants from study two were predominantly from the psychology department. Further studies will incorporate people from other disciplines in order to study how background, in addition to sex and ethnicity, might influence views and reactions to Cherry. Another area of interest is the effect of age, especially with respect to individuals over 40. Previous research in the field of training indicates that older individuals may be more apprehensive toward technology than younger individuals. For example, researchers have found that older individuals report more anxiety toward technology and less confidence in their ability to learn new technology than younger individuals [73]–[75]. In addition, in a training program for a new technical tool, the findings suggested that older individuals found the technology to be less useful than younger individuals [76]. By expanding our pool of participants to include older individuals, we will be able to better determine whether Cherry's design and features is acceptable to a wider variety of individuals.

B. Avatar Research

Another area of concern is the importance of the use of a face, or avatar, for service and social robots with respect to interaction, usability, and understanding from a human's point of view. In the study where Bruce and colleagues [23] monitored the time students interacted with their robot, they reported that students interacted longer with the robot when it displayed a face. The authors concluded that a robot with a face is important for social robotics. However, the responses to Cherry and Lola's face in study one, described previously, indicated that the *appearance* of that face may also influence the human–robot interaction. Therefore, future work with Cherry will build on the importance of a face for human–robot interaction, the importance of physical attractiveness of the avatar, and the usefulness of an avatar for communication.

C. More Sophisticated Personality for Cherry

Our plan is also to create a framework that enables designers to set an overall encompassing personality parameter that can predispose an agent to a specific personality type also linked with a specific set of emotions (e.g. agent with a meek personality might get discouraged more easily and give up in the face of adversity, whereas another one with an aggressive personality will get ANGRY and be inclined to fight back).

With robots collaborating with humans in a team, matching agent personality types to team members might bring about better overall group performance.

D. More Refined Emotions and Expressions of Emotions

We plan to enhance the emotion-based architecture to fully implement the AKR scheme described in [50] and to enable more sophisticated robot decision-making based on more complex emotion-like states.

In human-human communication, intuitiveness comes from the congruency of all the various communication signals together. One can get an uncomfortable sense from an interlocutor by perceiving (consciously or not) that his or her multimodal expressions are not in sync with each other (e.g., facial expressions are incongruent with vocal intonation and body posture). In robots, similar intuitive "body" languages such as camera tilt, navigation speed, etc. can be used to exteriorize internal states to the user in a manner in which the user will naturally understand.

E. Porting the Design to a New Hardware Platform

We are currently porting the interface and the collection of social behaviors from our original toy amigobot to our new ActivMedia Peoplebot—a much more versatile robot.

F. Realistic Test Beds and Applications

As mentioned before, many applications involving human–robot interaction may not benefit from including social intelligence in the robot portion of the interaction.

However, some applications intuitively lend themselves to it, such as personal care (e.g., home elderly care), service robots (e.g. office assistant), and entertainment robots (e.g. toys, pets, museum docents).

Indeed, "within a decade, robots that answer phones, open mail, deliver documents to different departments, make coffee, tidy up and run the vacuum could occupy every office" [77].

The question as to whether military robotic forces might also benefit from robots with social intelligence may not be as intuitive and might require more inquiry. These kinds of applications are very likely to depend on the type of numeric relationships and authority relationships [12].

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