Proceedings of 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems
September 28 - October 2, 2004, Sendai, Japan

Evidence of the Need for Social Intelligence in Rescue Robots

Thomas Fincannon, Laura E. Barnes, Robin R. Murphy & Dawn L. Riddle
Center for Robot-Assisted Search and Rescue
University of South Florida
Tampa, FL

***Abstract*— This study investigates data collected from operating an Inuktun robot in an Urban Search and Rescue (USAR) confined space training exercise task at Virginia Beach Training Center. Data was collected from coding approximately one hour of video. The video had no sound so all analysis is based on the video feed. Indicators of communication, gestures, physical interactions with the robot, and robot movements were analyzed. The findings indicate that the robot emerges as a virtual presence for the support of the team outside of the confined space. The team members spontaneously responded socially to the robot despite the robot not being engineered to have a social intelligence. This confirms numerous studies in the cognitive science, psychology, and affective computing literature that robots will need a social interface regards of domain.**

I. Introduction

Extensive research is being conducted in the area of social robots [1], where robots are explicitly engineered to interact with humans in a naturalistic manner. Many of these robots are equipped with physical anthropomorphic fixtures (e.g., faces, ears, head and gaze tracking, etc.) to convey emotions or interest in the human [2]–[8] or are humanoid [9]. These research efforts assume that robots interacting with humans in social settings such as museum tour guides [10]–[14], education [15], or to mimic humans or animals [16], [17] will need to be socially intelligent in order to be effective. Indeed, there is some evidence to support this assumption for specific domains for even short term interactions [18].

An interesting question is whether all robots that interact with humans, even coincidentally, will need to be socially intelligent. Or put another way, do humans expect to interact with robots in a social way even if they don't look anthropomorphic and/or are not in a ”social setting”? The literature exploring social aspects of human-computer interaction presented in 2.2 suggests that the answer is ”yes,” humans will display and expect social interaction with robots they encounter. This paper presents a study of a search and rescue exercise where humans reacted socially to a rescue robot as a specific, unique entity. The robot was serving as a surrogate for the other members of the response team. The results of the study provides preliminary confirmation that robots working in proximity with humans will be treated with the same social rules as a human. This implies that humans will expect any robot they encounter to respond socially as well, i.e., have social intelligence.

Mobile rescue robots have been used in the field for two major activities in urban search and rescue: *search for victims* and *structural assessment* [19]. In each of these activities, the robot works in front of the rescuers, out of sight and with no side-by-side interaction with humans. This paper analyzes video data collected from a rescue robot where rescuers began carrying the robot with them on their tasks inside a collapsed structure, treating the robot as a virtual presence for the support team outside.

During a structural operations training exercise at the Virginia Beach Training Center, Virginia Beach, Virginia, in November, 2003, a teleoperated rescue robot was demonstrated by a researcher. It was operated in a confined space near a group of structural specialists working on breeching an obstruction. The intent of the demonstration was to show the mobility capabilities of the robot to the support team for the specialists. The support team has significant free time, since they typically wait for radio requests from the specialists inside the void and then send a person to crawl in with the needed tool or move to feed more cables or lines. Thus, a demonstration was expected not to be disruptive to the primary task. The specialists were operating deep within a tunnel of confined space so running the robot near the mouth would not impact the breeching operations.

During one of the demos, the specialists became aware of the robot when an operator decided to see what the specialists were doing and drove it side-by-side of the humans. The specialists immediately discovered that the two-way audio communications through the robot was superior in quality and convenience to radio communications. They began exploiting its two-way audio and one-way video capabilities to communicate with the robot operator and enlisted him in facilitating their task. Within half an hour, the researcher noted the use of the robot as a surrogate for team members and social interaction with the robot in that 1) the specialists were pointing and gesturing to the robot as if it were human, 2) the operator would move the robot and cameras to maintain a view of the workspace when occluded or a particular feature was of interest to the support team, and 3) the support team manager began to silently observe operations through the robot operator's console and using what he was seeing to assess the safety of the work and to anticipate what resources the specialists would need next and pre-stage them. When the time came to remove the robot, the specialists and support team strongly objected to removing the robot saying that their efficiency would go down.

The concept of robots serving as surrogates is not new [20] for a recent examination of the concept, though we believe this is the first instance of the use of a robot as a surrogate for team members to spontaneously arise in the field. A mobile robot has significant advantages over a camera mounted on a rescuer's helmet. The robot can view the scene independently of what the rescuer is attending to [21]. This enables the support team to perform or continue other tasks, such as watching for hazards and anticipating needs. The robot can move to optimize its view without asking for assistance, facilitating the virtual presence, and the robot can serve as a physical placeholder for the support team.

In the paper, we present an interaction analysis conducted on the video gathered during the Virginia Beach event. The interaction analysis focuses on verbal and non-verbal communication and social and physical interaction emerging between the human and the robot. We explain the method used to analyze the video data and the results, discuss the findings relative to other work in human-robot interaction, and conclude that social interaction occurs in human-robot interaction settings even when no such interaction is expected.

II. Related Work

The data collected was examined in terms of whether it confirmed expectations generated by the cognitive science, psychology, and affective computing communities. In particular, the study allows for the opportunity to confirm observations in relation to three topics. The first relates to how people interact and communicate with machines and each other when they are physically distributed. The second asks when and how humans interact socially with computers and how they might extend to computers. The third examines how observations from the robotics community for non-rescue domains might contribute to understanding the data gathered.

A. Distributed Communication

An especially noteworthy aspect of this event was the way the specialists acted as they talked to the support team via the robot. The actions appear to explicitly establish common ground and implicitly express social communication. Common ground refers to the mutually shared knowledge [21], [22] which can exist from prior experience, but can also be developed through information exchange during interaction. As communication between the operator and teammates via the robot is distributed, it is important for participants to establish and maintain common ground.

One aspect that aids in the development of common ground is physical co-presence, which allows for the usage of environmental cues in grounding a conversation. [21] demonstrated that the incorporation of video in distributed work settings allows for the usage of environmental cues in the interaction, which help to create virtual co-presence. An instance of this includes the integration of deictic gestures, such as pointing to something in the environment during an explanation of something, by workers that are physically located at a site. As social presence refers to the degree of salience of people involved in an interaction and the subsequent quality of the interpersonal relationships [23], [24], questions should also arise regarding the nature of the interaction for workers that are physically removed from a site and the degree to which virtual co-presence affects them.

B. Human Social Interaction with Computers

There is generally a lack of literature addressing human-centric social interaction with robots. However, there is an abundance of literature examining social reactions of humans to computers.

One study by [25] examined the ability of people to developed team relationships with computers when performing team related tasks. When participants were informed that their individual performance rating was based on the performance of the human-robot team, thus denoting an interdependent work environment, ratings of the development of team relationships, including aspects of similarity, cooperation, and influence, were significantly higher that ratings of teams in non-interdependent work groups. Another paper by [26] reviewed studies examining how people generalize social human behavior to computers. Topics discussed in the article include how aspects of gender/ethnic stereotypes, social behavior of politeness and reciprocity, as well as cognitive commitment (in the form of specialized equipment providing better content than general equipment) manifest when humans interact with computers. Yet another study by [27] examined people's preference for consistency between verbal and non-verbal cues when communicating with computers. By comparing participants' reports of the nature of the interaction in groups where verbal and non-verbal cues of a 3D computer image were either matched or mismatched, findings demonstrated that people prefer the same consistency as when dealing with human beings.

The presence of social communication was unexpected, especially since the rescue robots are designed strictly for mobility with no thought of making them anthropomorphic or attractive. Though a significant portion of the social interaction is directed toward the operator, it is important to note that teammates inside the confined area are unable to directly observe the operator. Therefore, there is reason to believe that an equally significant portion of the social interaction is directed toward the robot itself.

C. Robot-Centric Social Interactions

The work in socially intelligent robots has largely been robot-centric, focused on creating robots capable of social expression with the topic of humans' social expressions to robots. The topic of how humans might differ in their social expressions to machines has been largely overlooked.

One robot study is of special note in terms of how humans react to robots. One study by [28] considered what would make a person stop and interact with a robot. In this case, the robot could display a face and it could also turn its "head" in the direction of a passerby. The study found that movement had a

Fig. 1. External view of training space.

Fig. 2. Image from robot camera of teammate gesturing for the robot to come forward.

larger impact on people stopping than the face display, but that the impact of the movement plus the face was additive. This suggests that if the rescue robot looked at the worker, even if it had no face, the worker would respond to it. A second work, by [29] with a robot that mediated a round table by facing the intended speaker, supports this hypothesis. The findings in [28] are consistent with our study. However, our study goes further and observes that not only do humans interact with a robot that appears to be attending to them, but the humans use the same social rules on maintaining eye contact and personal distance with the robot as they would with a human.

In our study, it was noted that humans gestured to the robot to communicate directives (e.g., look here), state (e.g., thumbs up for ”ok”), and general information (e.g., relative distance of structural elements). We note that there is a large body of research too numerous to cite on multi-modal interfaces to robots, including gesturing. This study does not contribute to gestural interfaces per se, but rather notes that many of the gestures were social in nature (e.g., thumbs up) and exhibited social rules. As such, the study implies the value of gestural interfaces but we make no such claim at this time.

III. METHOD

This study examines 57 minutes and 10 seconds of video tape of USAR rescue personnel utilizing a teleoperated robot during a confined space training exercise. This is a continuous observation that has one gap, during which video tapes needed to be replaced. The video was collected in an opportunistic manner and is purely observational, with no experimental manipulations. The confined space task involves navigating through debris in a mock disaster scenario. Figures 1 and 2 give external and internal views of the training space respectively.

Seven trainees interacted with the robot during the exercise. Four were teammates directly working in the hole, two acted as operators outside of the confined space (switching places in the middle of the exercise), and one remained outside with the operators, observing from the robot's camera.

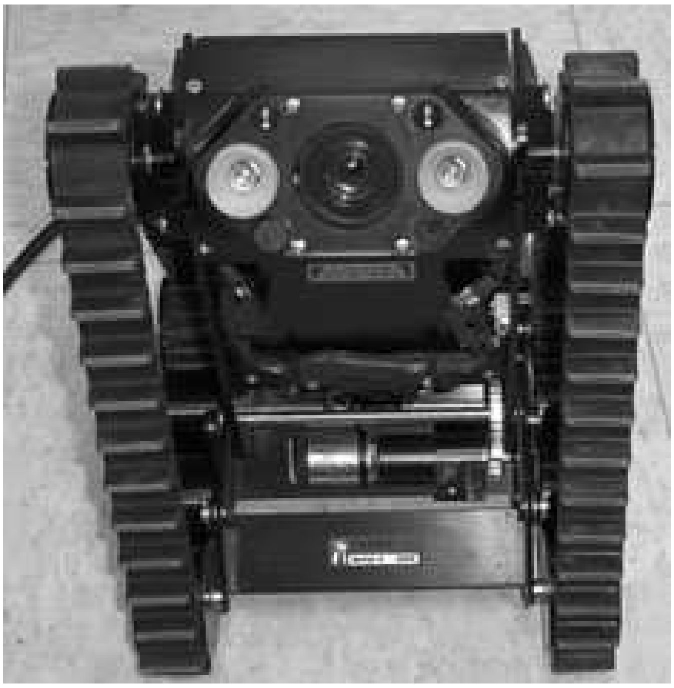

Fig. 3. Image of Robot

The Inuktun robot illustrated in Figure 3 used in this exercise is a shoebox sized, multitracked, tethered robot with a 53^o field of view color CCD camera on a tilt unit and two-way audio. The video feed from the robot camera was recorded remotely from a Sony recorder, but due to technical limitations, the two-way audio was not recorded. The image from the robot camera, as illustrated in Figure 1, allowed for observation of teammates and the surrounding environment. Operators could not be directly observed through video observation. The final tape from the observation was digitally transferred to MPEG

Fig. 4. Eye-to-Robot Communication.

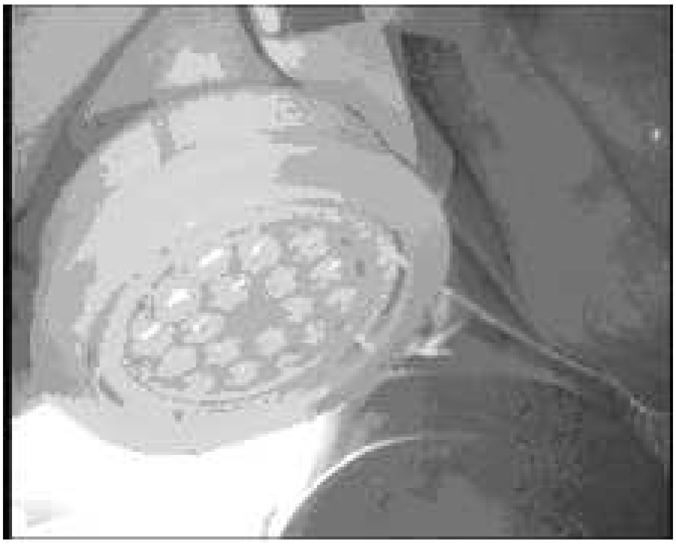

Fig. 5. Ear-to-Robot Communication.

Behaviors	Time (mm:ss)	Percent of Total Time
No Verbal Communication	43:26	76
Verbal Communication	13:44	24

TABLE I

TOTAL TIME OF VERBAL COMMUNICATION DURING OBSERVATION

format for coding.

A team of four subject matter experts generated codings to capture these categories. First were indicators of verbal communication. These included turing to face the camera as eye-to-robot (Figure 4) communication and leaning into the robot as in ear-to-robot communication (Figure 5), each of which being coupled with movement of the respirator that was covering the rescue worker's face and mouth. Second were gestures as instances of non-verbal communication, which included come forward, stop, thumbs up, ok, pointing and other. Third were instances when a teammate came into physical contact and touched the robot, which include cleaning the lens, moving and shifting the robot, and other. Fourth were the state of robot movement, which included points during which the robot was stationary or active. An active robot state included points during which the robot was moving forward or backward, panning from side to side, zooming in or out, and changing its physical configuration.

Two of the original subject matter experts acted as raters, observed the interaction, and came to a consensus regarding the coding scheme. The video was coded with the Noldus Observer software allowing a systematic analysis of behaviors [30].

In addition to the coding, the researcher that was on sight at time of the video data collection observed the interaction and provided a play back commentary identifying points of communication, specific topics during instances of conversation, and who was talking to the operator behind the camera.

IV. RESULTS

The results from the coding and analysis of the Virginia Beach confined space training exercise fall into 4 categories: verbal communication, gesturing, physical contact with the robot and active robot operation. The rescuers used the robot for communication 24% of the total task time, replacing 2-way radio communications. The availability of video seems to have enabled the rescuers outside of the void to anticipate mission tasks and requests and then initiate communications to confirm needs or state of the mission, rather than solely respond to requests. Gesturing was divided between facilitating the operator's attention to the task and adding emphasis, thereby enriching communication.

A. Verbal Communication

Table I looks at the total time during which raters marked the amount of verbal communication with the operator via the robot. As illustrated, verbal communication was observed for a total of 13 minutes and 44 seconds, showing that the rescuers talked with other via the robot 24% of the total observation. Once the rescuers discovered that the robot provided a better 2-way audio quality than the radios, they used the robot exclusively for communication. The content of the communication was derived from interviews with the on-site researcher.

Verbal communication with the robot was evidenced by a rescuer putting his ear to the robot and or looking directly at the robot while speaking. These methods varied during the interaction (18% and 6% of the total observation respectively). One of the marked differences between these two methods of communication was proximity to the robot, with team members maintaining a close distance during ear-to-robot communication compared to eye-on-robot communication. As noted through the interview, many of the instances of ear-to-robot communication occurred because of external noise, with closer proximity improving hearing. As proximity plays a role

Gesture	Verbal Communication	No Verbal Communication
Come Forward	1	4
Stop	0	2
Thumbs Up	2	1
Pointing	1	2
Other	4	0
Total	8	9
Total Time (mm:ss)	13:44	43:26

TABLE II

FREQUENCY OF GESTURES BY INSTANCE OF COMMUNICATION

Physical Contact	Verbal Communication	No Verbal Communication
Cleaning Lens	1	4
Movement	2	18
Other	1	2
Total	4	24
Total Time (mm:ss)	13:44	43:26

TABLE III

FREQUENCY OF PHYSICAL CONTACT BY INSTANCE OF COMMUNICATION

in face-to-face communication [31], it may also play a role in robot mediated communication.

Although audio was not recorded, our interview with the on-site researcher revealed that the conversations focused on topics related to structural integrity and state of the team members and there was little social conversation. The primary communication topic was how to facilitate task progress: a team leader outside of the void anticipated the needs and questions of personnel inside the hole and then directed the operator to ask the rescuers to confirm or answer. This is important because it suggests that the operator's mission role was relaying information between the two parties, and may not be a primary problem holder in the decision making process. If so, the operation of the robot could be largely replaced with a software agent to facilitate communication. It is not known if the robot encouraged the rescuers to talk more than they would have normally if restricted to radio.

B. Non-Verbal Communication

Table II displays the frequency of all observed gestures to the robot and whether they were coupled with verbal communication. Gestures are indicators of the role of 1-way video on communication. The frequency of gesturing was evenly distributed: they occurred without verbal communication 9 times, while gestures accompanying verbal communication occurred 8 times. While the total numbers are in a roughly 1:1 ratio, the ratio of no verbal communication to verbal communication was 3:1. The presence of 1-way video clearly enabled additional communication to occur that could not occur with only audio and enabled the operator to see gestures that would normally accompany verbal communication.

The purpose of the gesturing appeared to be either to *direct attention*, a task facilitation use, or for *emphasis*, a social use. Navigational directives such as a ”come forward” or a ”stop” dominated periods of no verbal communication. Periods of verbal communication were dominated by of the remaining gestures, such as waving one's hands (from the ”other” grouping) or giving a ”thumbs up” during conversation. Considering that gestures replace or compliment speech [32] and that the presence of useful visual information increases the usage of deictic gesturing [22], these nonverbal behaviors are most likely directed toward the operator. This suggests that the presence of 1-way video helped to facilitate communication.

The presence of gesturing for emphasis by the rescuer to the robot raises the question of whether the robot should gesture back, completing the social interaction associated with communication. Indeed, in one instance, the operator manipulated the robot in order to ”shake its head up and down”, acknowledging a communication. This type of movement is non-trivial to initiate and control in a robot, which may be one reason why it only occurred once.

C. Physical Contact

Table III displays the frequency of physical contact as it occurs by instance of communication. Physical contact with the robot, Table III, was coded into one of three different action categories: a teammate cleaning the lens of the camera, moving/shifting of the robot, or ”other” (manifesting as incidental contact). *Moving and shifting of the robot* occurred twenty times over the course of the observation. In most cases of moving the robot, it appeared that 1) the robot could not move over tool cables to get an appropriate view of the task or 2) the robot was not moving fast enough to keep up with rescuers as they moved forward in the confined space. The majority of moving and shifting took place during periods of no observed verbal communication; since audio was not recorded, it is not known whether communication took place. Picking up the robot and taking it with them was a totally unexpected mode of interaction. Here, the humans helped the robot, suggesting partnering and acceptance.

Shifting the robot appears to be related to facilitating the social dimension of communication. Just prior to or during indicators of verbal communication, the robot was shifted so that it (as seen through the camera) directly faced the teammate with whom the operator was talking. This indicates that teammates had preferences regarding directional attention during communication, which is consistent with literature dictating that people prefer verbal and non-verbal cues to match during interaction with computer systems [27].

D. Robot Movements

Table IV shows how frequently the operator moved the robot. For the majority of the interaction (90%), the robot was stationary, which supports an emergent robot as an observer providing a virtual presence for the physically-removed team members.

What is more striking is the lack of activity during verbal communication. There is active robot operation about 13 times

Robot State	Verbal Communication (mm:ss)	No Verbal Communication (mm:ss)	Total Time (mm:ss)
Stationary	13:19	38:10	51:29
Active	00:25	05:16	05:41
Total Time	13:44	43:26	57:10

TABLE IV

TIME OF MOVEMENT BY TIME OF VERBAL COMMUNICATION

more during periods of no verbal communication, which seems reasonable that the operator is trying to move to get a better view. But during verbal communication, the robot is stationary. This provides evidence that the operator is making an effort not to perform any robot operation during communication. The majority of movement that did occur during communication involved the robot moving closer to the teammate or panning to keep the teammate in view of the camera. In human-robot interaction, people prefer to interact with a robot that tracks an individual to maintain attention [28], and this focus of attention on the rescuer may be interpreted by the rescuer as a social interaction- that the robot is politely listening to him.

V. DISCUSSION

During the observation, the robot was treated as a separate entity with interaction following social norms. Proximity [31], for example, defined as a socially appropriate distance during communication, was observed. Teammates maintained a particular distance during eye-to-robot communication. Additionally, eye contact [33], as a form of directional attention, appeared to be to manifest as a preference through moving/shifting the robot to face a teammate during or prior to communication.

As stated earlier, social presence refers to the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships [23], [24]. A central point of observation is that robot inactivity coupled with visually tracking teammates during communication, was also in accordance with social norms. As the operator was in control of robot movement and was not asked to operate the robot in this manner, it can be inferred that the human operator felt that this was socially appropriate behavior, which provides evidence for social presence in the interaction.

Nowak & Biocca (2003) explored the affects of anthropomorphic features on people's perceptions of social presence. While people reported higher social presence in the presence, as opposed to absence, of anthropomorphic features, the highest reports of social presence were found to accompany low levels of anthropomorphism, which consisted of eyes and mouth only as opposed to viewing an entire face. In this study, one of the most interesting robot movements reflective of social interaction occured when the camera appeared to be "bobbing" up and down during verbal communication; almost as someone might nod their head. In human-robot Interaction, people prefer to interact with expressive interfaces [28], and subsequent questions need to be asked regarding the application of anthropomorphic features in rescue robotics.

VI. CONCLUSIONS

This study documents the use of a rescue robot as a *virtual presence*, or surrogate, for physically removed team-members. Through proximity, preferred directional attention (by operator and teammates), and anthropomorphic movements, it illustrates the *spontaneous emergence of social interactions with a robot not designed for social interaction* in a realistic training exercise with rescue professionals. Essentially, the robot became a valued team member and was treated as such. While the social interaction might have emerged simply due to the robot being able to move independently, we believe the presence of 1-way video contributed to the interaction, as was evidenced by deictic gesturing. Specifically, the video allowed the rescuer to point things out and use social gestures for emphasis during communication with the operator and providing for a richer interaction.

Results from this study support literature addressing distributed communication between humans and social interaction with computer/robots. The presence of gestures, particularly deictic gesturing, indicate that the visual feed from the robot camera helps to ground the communication process [21]. Preferences for consistency between directional attention and verbal communication, as illustrated by teammates moving the robot to face them during or prior to communication, are also found in literature [27]. As there is a lack of literature addressing distributed communication, social rules in robotics, and any resulting interaction in scenarios of teleoperation, there is a need for more research in this area.

The role of the robot as a virtual presence has implications for distributed teams and how members share information and develop common ground. How can the team members be sure they are all looking at the same scene or key feature? This research also raises new issues in human-robot interaction, particularly in how people will act socially around robots and expect robots to respond. In particular, are there social norms in teleoperated human-robot interaction? Teleoperation applications have traditionally been where the robot was acting in areas where there were no people; here, robots are operating side by side with humans, which could change the nature of the task and the demands on the teleoperator. The teleoperator may have to be skilled at expressing social interaction cues as well as executing the task (i.e., becomes a puppeteer). Another set of issues concern the specific differences in two-way versus one-way video. The impact of two-way video on teams has been studied, but literature comparing the one-way to two-video is limited. When is one superior to the other? Are anthropomorphic features or gesturing needed on a robot when acting as a substitute for a human interface? Can the correct gestures for a robot to make be inferred from the verbal and non-verbal communication (e.g., nodding the robot head while saying "yes")? Future research is needed to answer these questions.

VII. ACKNOWLEDGEMENTS

These efforts were supported in part by grants from the DARPA CSEE program ($N66001-03-8921$), NSF SGER

($CMS - 0229809$), and the NSF CISE-RR program ($E1A - 0224401$). The authors would like to thank Mike Brown of Virginia Task Force 2 for his help in arranging the robot demonstration at Virginia Beach.

REFERENCES

[1] T. Fong, I. Nourbakhsh, and K. Dautenhahn. A survey of socially interactive robots. *Robotics and Autonomous Systems*, 42(3-4):143–166, 2003.

[2] C. Breazeal and B. Scassellati. How to build robots that make friends and influence people. *International Conference on Intelligent Robots and Systems*, 1999.

[3] C. Breazeal, A. Edsinger, P. Fitzpatrick, and B. Scassellati. Active vision for sociable robots. *Systems, Man and Cybernetics, Part A, IEEE Transactions*, 31(5):443–453, 2001.

[4] C. Breazeal and B. Scassellati. Robots that imitate humans. *Trends in Cognitive Sciences*, 6(11):481–487, 2002.

[5] C. Breazeal. Regulation and entrainment in human-robot interaction. *International Journal of Robotics Research*, 21(10-11):883–902, 2002.

[6] C. Breazeal. *Designing sociable robots.* MIT Press, 2002.

[7] C. Breazeal. Toward sociable robots. *Robotics and Autonomous Systems*, 42(3-4):161–175, 2003.

[8] B. R. Duffy. Anthropomorphism and the social robot. *Robotics and Autonomous Systems*, 42(3-4):177–190, 2003.

[9] H. Okuno, H. Nakadai, and H. Kitano. Social interaction of humanoid robot based on audio-visual tracking. *International Conference on Industrial and Engineering Applications of Artificial Intelligence*, pages 725–735, 2002.

[10] S.Thrun, M. Beetz, M. Bennewitz, W. Burgard, A.B.Cremers, F. Dellaert, D. Fox, D. Hahnel, C. Rosenberg, N.Roy, J. Schulte, and D. Schulz. Probabilistic algorithms and the interactive museum tour-guide robot minerva. *International Journal of Robotics Research*, 19(11):972–999, 2000.

[11] W. Burgard, A. Cremers, D. Fox, D. Hahnel, G. Lakemeyer, D. Schulz, W. Steiner, and S. Thrun. Experiences with an interactive museum tour-guide robot. *Artificial Intelligence*, 14(1-2):3–55, 1999.

[12] Dominguez Brito, J. Cabrera Gamez, D. Hernandez Sosa, M .Castrillon Santana, J. Lorenzo Navarro, J. Isern Gonzalez, C. Guerra Artal, I. Perez, A. Falcon Martel, M. Hernandez Tejera, and J. Mendez Rodriguez. Eldi: An agent based museum robot. *Systems Science*, 27(4):119–128, 2001.

[13] J. Pineau, M. Montemerlo, M. Pollack, N. Roy, and S. Thrun. Towards robotic assistants in nursing homes: Challenges and results. *Robotics and Autonomous Systems*, 42(3-4):271–281, 2003.

[14] M.Hans, B. Graf, and R.D. Schraft. Robotic home assistant care-o-bot: past-present-future. In *11th IEEE International Workshop on Robot and Human Interactive Communication (ROMAN 2002)*, pages 380–385, 2002.

[15] I. Nourbakhsh, J. Bobenage, S. Grange, R. Lutz, R. Meyer, and A. Soto. An affective mobile robot educator with a full-time job. *Artificial Intelligence*, 114(1-2):95–124, 1999.

[16] R. Ambrose, H. Aldridge, R. Askew, R. Burridge, W. Bluethmann, M. Diftler, C. Lovchik, D. Magruder, and F. Rehnmark. Robonaut: Nasa's space humanoid. *IEEE Intelligent Systems.*, 15(4):57–63, 2000.

[17] T. Shibata, K. Wada, and K. Tanie. Tabulation and analysis of questionnaire results of subjective evaluation of seal robot in uk. In *IECON - 2002. 2002 28th Annual Conference of the IEEE Industrial Electronics Society*, volume 4, pages 3074–3079, 2002.

[18] J. Schulte, C. Rosenberg, and S. Thrun. Spontaneous, short term interaction with mobile robots. In *IEEE International Conference on Robotics and Automation*, 1999.

[19] J. Casper and R. R. Murphy. Human-robot interaction during the robot-assisted urban search and rescue response at the world trade center. *IEEE Transactions on Systems, Man and Cybernetics*, 33(3):367–385, 2003.

[20] Nicola Muscettola, Pandurang P. Nayak, Barney Pell, and Brian C. Williams. Remote agent: To boldly go where no ai system has gone before. *Artificial Intelligence*, 103(1):5–47, 1998.

[21] Robert E. Kraut, Susan R. Fussel, and Jane Siegel. Visual information as a conversational resource in collaborative physical tasks. *Human Computer Interaction*, 18:13–49, 2003.

[22] Robert E. Kraut, Susan R. Fussel, Susan E. Brennan, and Jane Siegel. Understanding effects of proximity on collaboration: Implications for technologies to support remote collaborative work. *Distributed Work*, 2002.

[23] J. Short, E. Williams, and B. Christie. *The Social Psychology of Telecommunications.* London: John Wiley and Sons, Ltd., 1976.

[24] Kristine L. Nowak and Frank Biocca. The effect of the agency and anthropomorphism on user sense of telepresence, copresence, and social presence in virtual environments. *Presence*, 12(5), 2003.

[25] Cliffod Nass, B. J. Fogg, and Youngme Moon. Can computers be teammates? *International Journal of Human Computer Studies.*, 45:669–678, 1996.

[26] Clifford Nass and Youngme Moon. Machines and mindlessness: Social responses to computers. *Journal of Social Issues*, 56(1):81–103, 2000.

[27] Katherine Isbister and Clifford Nass. Consistency of personality in interactive characters: Verbal cues, non-verbal cues, and user characteristics. *International Journal of Human Computer Studies.*, 53:251–267, 2000.

[28] Allison Bruce, Illah Nourbakhsh, and Reid Simmons. The role of expressiveness and attention in human-robot interaction. *Proceedings of the IEEE.*, pages 4138–4142, 2002.

[29] H. Okuno, H. Nakadai, and H. Kitano. Realizing personality in audio-visually triggered non-verbal behaviors. *IEEE International Conference on Robotics and Automation*, 2003.

[30] L. Noldus, R. Trienes, A. Hendrikson, H. Jansen, and R. Jansen. The observer video-pro: new software for the collection, management, and presentation of time-structured data from videotapes and digital media files. *Behavior Research Methods, Instruments and Computers*, 32:197–206, 2000.

[31] Sara Kiesler and Jonathan Cummings. What do we know about proximity and distance in work groups? a legacy of research. *Distributed Work*, 2002.

[32] Owen Hargie, Christine Saunders, and David Dickson. *Nonverbal Communication. Social Skills in Interpersonal Communication (2nd Ed.).* Brookline Books: Cambridge Massachusetts., 1987.

[33] Bonnie A. Nardi and Steve Whittaker. The place of face-to-face communication in distributed work. *Distributed Work*, 2002.