A Social Environmental Monitoring Robot that Interacts with People to Collect Information and Instruct

Vanessa Evers, Andi Winterboer, Frans Groen
Institute of Informatics, University of Amsterdam, Sciencepark 107, 1098XG, the Netherlands.
{evers, winterboer, cramer, pavlin, groen}@uva.nl

Abstract. This paper reports ongoing research into social robots in public environments as agents to monitor levels of pollutive gasses in the air. Next to licensed environmental agents and immobile chemical sensors, mobile technologies such as robotic agents are needed to collect complaints and smell descriptions from humans in urban industrial areas. These robots will need to interact with members of the public and ensure responsiveness and accuracy of responses. Highly developed social skills will be important to achieve this as well as compliance to the environmental robot's instructions in the case of a calamity. In this paper we will describe the intelligent environment the environmental robot is part of and discuss preliminary work on the effects of robot empathic and touch behaviors on human responses to robots. These and future findings will inform the design of social monitoring robot behaviors in public settings.

Keywords: Human Robot Interaction, Social robots, Environmental Monitoring, Robot Social Behaviors.

1 Introduction

In the future, virtual, mobile and physically embodied agents will function as part of distributed intelligent networks. In this paper we focus on a distributed intelligent network for environmental monitoring and the social robot that functions as the system's public interface. In urban-industrial areas, detection of chemicals (gasses) is important to monitor and control levels of environmental pollution. The environmental monitoring system DIADEM detects anomalies in air quality through dedicated electronic sensors and through complaints from the public. As anomalies are detected, an (semi-) autonomous system that in case of unusual sensor readings deploys a Bayesian reasoning system to reduce the number of possible events (e.g., which gas has been detected and whether it poses a threat). From that it will return a set of hypotheses (possible sources of pollution, for instance a factory or shipment in the harbor). If a potential hazard is detected, the system will call upon human observation in and around the affected area to gather more information. For this purpose, participating users will be requested by a mobile agent (through a remote mobile phone service or by autonomously mobile social robots) to self-report their observations, which are then communicated to the central system. Exploiting smell perceptions from humans is promising [1], but also challenging, because although hand humans are very good at odor detection and discrimination, they are not good at odor identification and naming [2]. For developers of mobile applications designed for long-term environmental monitoring, it is crucial to establish and sustain a human-agent relationship. The aim is to motivate as many volunteer users as possible to quickly provide accurate and detailed information concerning observations about the environment over a long period of time.

If necessary, the system provides location-based warnings and safety instructions. The pollution detection context makes the relationship between humans and agent delicate. On the one hand, the system requires information from users to determine the likelihood and location of an incident. On the other hand, users would like to express concerns, complain about unfavorable smells, or receive instructions in the (unlikely) event of a hazardous incident. To inform the design of the agent that will interact with members of the general public, a series of controlled experiments were carried out to assess the impact of several agent social behaviors on human responsiveness and accuracy of responses. In the following, we first present related work we consider relevant for studying human-robot interaction in field settings. Second, we present results of two studies that inform the design of the agent's social behaviors.

2 Related work

Various research projects have highlighted the potential of context-aware and user adaptive applications for potentially high-risk and high-stress applications (e.g., disaster prediction and alerting [3]). Frequently, user-adaptive systems make decisions on behalf of the user, thus potentially leading to situations where users' perceive they are not in control of the system [4]. An overview of user-adaptivity issues, such as controllability, privacy, and transparency is provided by [5]. Trust is considered to be one of the important affective elements that play a role in human interaction with technology (e.g., [6]), and is crucially important in the crisis response domain tackled by this project. In addition, systems that display autonomous behavior will not simply be treated as tools; instead, users will interact with such systems as if they were social actors following social conventions, comparable to human-human interactions [7]. As illustrated by research into mobile persuasion [8], social and affective processes also play a role when interacting agents. Aspects such as perceived empathy with the user, actively acknowledging the user's (affective) experience, and acting accordingly could be key in achieving trust [9]. In a research project concerned with human-robot interaction in contexts where the information communicated is potentially of vital importance establishing and maintaining a close social relationship between agent and user is crucial.

2.1 Trust in robots

Appropriate social expressiveness appears to have great potential to instill trust and build relationships with users. Social expressiveness can for example promote liking, trust and perceptions that a system cares about the user [10]. Autonomous robots could be present at any location and can provide (semi-) permanent connections to distant systems and services. They offer great potential for building long-term relationships where dialogues can be initiated by both users and systems at any time. Context-aware applications can provide users with services relevant to their current circumstances. Distant systems and services in turn can gather information from users and their devices about their surroundings (e.g. during a calamity). Such potential is accompanied by major challenges. These robots will make semi-autonomous decisions, request information and interrupt users' activities. We are not dealing with usage of robots as support tools anymore; instead we are presented with settings in which users collaborate with remote agents that also appear to have their own goals and intentions. These might differ from, or even conflict with, the current needs of the user. These systems will not simply be treated as tools; instead, users may interact with them following patterns from human social interaction [11]. Understanding what motivates people to collaborate with these systems is important.

2.2 Robot Empathy

Applying principles from social interaction has shown great potential, as illustrated by for example work on relational agents [10] and (mobile) persuasion [8]. Especially empathic system behavior has been suggested as a way to build relationships with users, increase trust and make interruptions more acceptable [9, 12]. Empathy has been gaining growing attention in the field as a very promising feature of user-system dialogues. Empathy combines social and affective aspects of interaction, it entails both the ability to accurately infer emotions the content of people's thoughts and feelings and providing a supportive and compassionate response. Expressing empathy has been shown to for example lower user frustration and comfort users [10], increase users' liking, trust and perceived caring and support [9]. There are also indications it might alleviate the negative effects of interruptions [12]. A full overview of effects of social, empathic expressiveness however is not yet available. Reactions to social system behaviors can be affected by factors including users' task and (social) surroundings, the artifact they are interacting with, whether users actively reflect on the interaction and the specific social phenomena in question [13]. For human robot interaction factors such as repeated (dis)engagement with the user system dialogue, proxemics and interacting with large autonomous technologies that have some antropomorph embodiment may also play a role. It is also unclear whether different effects exist for system requests and for example more urgent system advice.

2.3 Robot touch

The physical embodiment of robots makes it likely that humans will come into physical contact with them. Physical contact is an influential aspect of human encounters. Touch both influences and expresses interpersonal bonding; touch can communicate emotion, and can for example also decrease stress [14]. Physical contact can increase compliance with requests [15, 16], even when a person is not consciously aware physical contact has occurred [17]. Touch between humans and other living creatures can also have a profound effect on humans' affective state. Petting an animal for example can decrease stress [18]. Touch and tactile qualities are also an important aspect of product design. Additionally, tactile interaction can offer possibilities for intuitive interaction with interactive products and systems, as explored in e.g. tangible interfaces [19]. Users might even expect interaction using touch when they encounters physically embodied agents. The accompanying potential for interacting with robots via affective touch has lead to the development of robotic creatures that specifically aim to react to touch and/or offer haptic feedback. Haptic interaction with users is then implemented to achieve affective and social benefits especially in the context of therapeutic care, e.g. [20, 21]. However, humans will not only come into physical contact with robots specifically designed with affective touch capabilities. There are situations where physical contact might occur, 'by accident', or as part of social interaction, e.g. in human-robot collaborations (for instance consider a handshake, high five, pat on the shoulder, hug or elbow nudge).

Since physical contact is a very powerful and complex aspect of human communication, we should also consider how touch might influence interaction with physically embodied agents. Physical contact is not always considered appropriate behavior in every situation [14]. Personal preferences, cultural norms, familiarity, gender and social status all influence which physical distance is preferred in human interaction, how touch is experienced, how physical contact influences interactions and which types of tactile contact are considered appropriate ([14, 22], also noted by [21] and [23]). Given the importance of physical aspects of interaction between humans and the effects of touch on interpersonal bonds and e.g. compliance with requests, it is likely that physical contact will also have an impact on interaction between humans and physically embodied agents. What the effects of physical contact are on users' perceptions and attitudes towards social agents is however unclear. The importance of determining the suitable physical distance, or 'personal space', that robots should keep from users during interaction has been highlighted by e.g. [24] and [23]. However, only limited attention has been given to the effects of physical contact. It is still unclear whether touch in interacting with robots will fully resemble effects in human interaction or interaction with other living creatures. Especially when systems behave in a more autonomous fashion it is likely that users will react to these systems in line with affective and social processes resembling human-human interaction [11]. However, Walters et al. [24] show that some users keep smaller physical distances from robots than from humans. Conversely, negative attitudes towards robots can also increase users' preferred distance from robots [25]. It is unclear whether and when physical interaction might add to user trust and might be helpful in fulfilling social expectations. Studies into the effects of physical contact in combination with other social aspects of interaction are scarce as well. This, while the effects of touch also depend on social factors such as pre-existing bonds and attitudes towards other exhibited behaviors [14]. Research into the effects of physical contact with embodied agents is thus necessary especially when agents autonomously exhibit touch behaviors.

2.4 Robot Autonomy

When systems behave in a more autonomous fashion, social processes can play increasingly important roles [11]. We expect that the level of autonomy displayed by embodied social agents will also influence how social and affective aspects of interaction, such as physical contact, are experienced. Perceiving others' needs and intentions and proactively acting on these perceptions are an important part of social interaction. Proactive agents that infer intentions from e.g. non-verbal, or contextual cues can potentially offer more intuitive collaboration with humans [26, 27]. System autonomy however has a tensive relationship with predictability and user control [28, 29]. Autonomous behavior and a loss of perceived user control can negatively influence attitudes and trust [30, 31]. Control is also crucial in maintaining combined human-system performance, e.g. in recovering from system mistakes [32]. The willingness to work with autonomous agents, or the willingness to delegate tasks to an agent depends on trust in the outcome of this collaboration [31]. In-depth studies on how combinations of social behaviors, such as touch and proactivity influence user perceptions and trust, are still relatively scarce. Kim and Hinds [33] have found that people attribute more responsibility to a robot for its behavior when the robot is more autonomous. This suggests that the effects of social behaviors such as touch and the perceptions of these behaviors as being (in)appropriate, could be amplified for more autonomous agents.

3 Evaluation of robot empathy, autonomy and touch

In order to gain more understanding in the responses that people have toward robot empathy, autonomy and touch, we have conducted two studies in the context of everyday usage rather than crisis response or environmental monitoring specifically [34, 35]. We hypothesized that robot's empathic behavior (understanding the situation of the user and responding accordingly) would lead to increased positive attitudes toward the robot. Apart from emotional empathy, the physicality of robots is important to take into account and we also felt that empathic touching behaviors by robots would lead to increased positive responses. However, it was unclear how robot autonomy would interact with such empathic robot behaviors. Highly autonomous robots may be seen as 'coming too close' once they start touching humans?

4.1 Study A: effects of empathy

A video-based, online survey experiment investigated participant' attitudes toward a four-minute interaction of a male user and a robot, playing an online collaborative game together (for a discussion of validity of video-based methods, see e.g. [36]). The 2x3, between-subject experiment varied situational valence (negative vs. positive situation) and empathic accuracy (an empathically accurate, neutral agent and an empathically in-accurate agent), resulting in six randomly assigned conditions. The robot used in the resulting six videos was the Philips iCat, with a synthetic female voice. Data of 133 participants were analyzed (mean age 30.5, 53% male). Situational valence was manipulated by having the team do well on the collaborative game and win, or not do well together and lose. Empathic accuracy was varied using the robot's verbal responses and facial expressions. The verbal and facial expressions in the empathically accurate condition were congruent to the situation (e.g. acknowledging a negative experience when losing). In the neutral condition the social robot made no statements about the person's affective state. Participants' (negative) attitude towards robots in general was measured using the NARS scale [10]. Likert-type and semantic differential scales were used to measure our dependent variables, including perceived empathic ability, trust (dependability, credibility) and closeness.

A significant interaction effect was found between empathic accuracy and emotional valence of the situation for the perceived empathic ability of the robot ($F(2,112)=4.326$, $p=.015$). Simple effects analysis showed a significant difference for empathy shown in a positive or negative context. In the 'winning' condition, participants rated the empathically accurate robot as having greater empathic ability compared with the empathically inaccurate robot, but this effect of accuracy was not significant ($F=1.18$, $p=.31$). However, when the team was losing (negative context), participants found the empathically inaccurate robot to have better empathic abilities compared with the empathically accurate robot ($F=3.24$, $p=.043$).

The results show that inaccurate empathic behavior can be detrimental to user attitudes toward a social robot. Inaccurate empathic robot behavior (e.g. responding negative to a positive situation) lowered trust in the robot. An interesting result was that in a negative (losing the game) context, participants found the robot that responded inaccurately to have more empathic abilities. In short: When they were loosing they found a positive robot more empathic even though its behavior was empathically inaccurate.

4.2 Study B: Effects of touch and autonomy

An online survey experiment was set up to explore how touch and autonomy influence perceptions of and attitudes toward robots. The experiment investigated participants' responses to a video of an interaction between a user and a robotic assistant (WowWee Robosapien V2). The 2x2 experiment varied physical contact (touch, no touch) and robot autonomy (proactive, reactive behavior), resulting in four between-subject conditions. Participants were randomly assigned to one of the four conditions. To manipulate touch, the video in the touch condition showed four physical contact moments between the robot and user: the robot touched the user three times and the human touched the robot once. In the non-touch conditions, the robot and user made no physical contact at all. The four touch behaviors were: the user tapping the robot at the beginning of the interaction, the robot tapping the shoulder of the user, the robot and the user sharing a hug, and a high-five between the user and robot at the end of the interaction. Proactiveness was manipulated by varying whether help was offered by the robot on its own initiative (proactive) or is offered on the user's request (reactive). In the proactive condition, the robot offered help without active prompting from the user, while in the reactive condition, the user asked for the robot’s help. In total, 119 participants completed the survey-based experiment. 19 participants were female (16%), 100 were male (84%). Their average age was 25 years (SD=6). The majority of participants (80%) were Dutch. No differences were found between conditions on participants’ gender, age, education level, computer and robot experience. Participants’ (negative) attitude towards robots in general was measured using Nomura’s 8-item NARS scale [25]. A dependent variable was trust in the robot. Items were measured on five or seven-point Likert-type scales ranging from strongly disagree to strongly agree.

Significant interaction effects were found for perceived trust ($F(1,118)=4.66$, $p=.033$). Analysis of the interaction effect on perceived trust showed that in the reactive condition touch influenced perceived trust ($F(1,116)=5.43$, $p=.022$), while in the proactive condition it did not ($F(1,116)=.24$, $p=.622$) In the reactive condition perceived trust was significantly higher for the non-touch version ($M=5.4$,$SD=.80$) than for the touch version ($M=4.6$, $SD=1.0$). In the proactive condition, the touch robot scored higher on perceived dependability ($M=4.90$, $SD=1.03$) than the non-touch robot ($M=4.8$, $SD=1.2$). However, this difference was not significant.

The results indicate that people trusted the proactive robot (higher autonomy) more when there was physical contact between the user and the robot. However, the reactive robot (lower autonomy) was trusted less when it engaged in physical interaction with the user. These findings show that robot touch behaviors do not necessarily lead to positive user responses, in this case it depended on the level of autonomy of the robot.

5 Discussion and Conclusion

The results from our preliminary studies show that people’s reaction to robot social behaviors such as empathy and touch are not unequivocal. Depending on the situational context or characteristics of the robot (e.g. level of autonomy), people’s responses will vary. In the case of the studies above, the robot that was empathically accurate was responded to positively. Except for a negative situation, than the inaccurate empathic behavior was favored. Perhaps people prefer blind optimism in the face of adversity or experienced it as humor. Future research should investigate this further but it is clear that complex social perceptions result from simple social robot behaviors. In the context of environmental monitoring, the emotional valence of the situation can be very dynamic, when merely monitoring normal levels of pollution and gathering smell descriptions from humans, robots will not encounter users in high stress situations. However, when pollution is detected and smell descriptions from humans are necessary to determine the source and substance of pollution, human users may experience emotions such as stress and fear. It will be imperative for environmental monitoring agent robots to respond to users in such a manner to achieve high responsiveness and high accuracy of responses. In the case of an emergency, it is important that people comply with the robot’s instructions. Accurate social behaviors to instill trust and credibility will be highly imperative. Our future research efforts will focus on this issue and will evaluate these robot behaviors in environmental monitoring contexts.

The physical embodiment of the robot demands that we investigate what happens when humans and robots come into physical contact. In application areas where they will be in close proximity, such as environmental monitoring and calamity response, physical interaction whether intended or not, will happen. Yet, this is currently an under evaluated part of HRI research. Future research should focus on the effects of robot touching behaviors on humans. Intentional (lifting, shaking hands) as well as unintentional (bumping into each other, rubbing pas incidentally).

5 Acknowledgements

This research is partly funded by the Interactive Collaborative Information Systems (ICIS), project nr: BSIK03024 and the EC FP7-ICT project DIADEM, ref. no: 224318.

6 References

1. Brewster, S.A., McGookin, D.K. and Miller, C.A. : *Olfoto: Designing a smell-based interaction.* In Proceedings of CHI, pp. 653-662 (2006)
2. Yeshurun, Y., Sobel, N.: An odor is not worth a thousand words: From multidimensional odors to unidimensional odor objects. A. R of Psy. Vol. 61, pp. 219-241 (2010)
3. Kung, H., Ku, H., Wu, C. and Lin, C.: Intelligent and situation-aware pervasive system to support debris-flowdisaster prediction and alerting in Taiwan. Network and Computer Applications, 31, pp. 1-18 (2008)
4. Partala, T., Surakka, V., and Lahti, J.: Affective Effects of Agent Proximity in Conversational Systems. In Proc. Of NordiCHI 2004, Tampere, Finland, ACM Press, 353-356 (2004)
5. Jameson, A.: Adaptive interfaces and agents. In: Jacko, J., Sears, A. (eds.) The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications, pp. 305–330. Erlbaum, Mahwah, NJ (2003)
6. Lee, J.D., See, K.A.: Trust in automation: designing for appropriate reliance. Human Factors, 42(1), pp. 50-80 (2004)
7. Nass, C., Steuer, J. and Tauber, E.R.: Computers are social actors. Proceedings of the SIGCHI conf. on Human factors in comput. systems, CHI'94. ACM Press, pp. 72-78 (1994)
8. Fogg, B.J. and Eckles, D.: Mobile Persuasion: 20 Perspectives on the Future of Influence. Stanford Captology Media (2007)
9. Brave, S. Nass, C., and Hutchinson, K.: Computers that care: investigating the effects of orientation of emotion exhibited by an embodied computer agent. International Journal of Human–Computer Studies. *62*, 161–178 (2005)
10. Bickmore, T. and Schulman, D.: Practical Approaches to Comforting Users with Relational Agents. In Proc CHI'07, pp. 2291-2296 (2007)
11. Reeves, B. and Nass, C.: The Media Equation. Cambridge University Press & CSLI Press (1996)

12. Picard, R. and Liu, K.: Relative subjective count and assessment of interruptive technologies applied to mobile monitoring of stress. Int. J. Hum-Comp. St. 65, pp. 4361-375 (2007)
13. Eckles, D. et al: Social responses in mobile messaging. In Proc. CHI’09, pp. 1651-1654 (2009)
14. Fisher, J.D., Rytting, M. and Heslin, R.: Hands touching hands. Sociometry, 39(4), pp. 416– 421 (1976)
15. Patterson, M.L., Powell, J.L. and Lenihan M.G.: Touch, compliance, and interpersonal affect. Journal of Nonverbal Behavior, 10(1), pp. 41–50 (1986)
16. Willis Jr. F.N. and Hamm H.K.: The use of interpersonal touch in securing compliance. Journal of Nonverbal Behavior, 5(1), pp. 49–55 (1980)
17. N. Gueguen. Touch, awareness of touch, and compliance with a request. Perceptual and Motor Skills, 95(2), pp. 355–360 (2002)
18. S. Shiloh, G. Sorek, and J. Terkel. Reduction of state-anxiety by petting animals in acontrolled laboratory experiment. Anxiety, Stress & Coping, 16(4), pp. 387–395 (2003)
19. H. Ishii and B. Ullmer. Tangible bits: Towards seamless interfaces between people, bits and atoms. In Proceedings CHI’97, pp. 234–241 (1997)
20. Stiehl, W.D., Lieberman, J., Breazeal, C., Basel, L., Cooper, R., Knight, H., Lalla, L., Maymin, A. and Purchase, S.: The huggable: a therapeutic robotic companion for relational, affective touch. In Proceedings CCNC’06 (2006)
21. Yohanan, S. and MacLean, K.E.: The haptic creature project: Social human-robot interaction through affective touch. In Proceedings AISB’08, pp. 7–11 (2008)
22. Major, B. and Heslin, R: Perceptions of cross-sex and same sex nonreciprocal touch: It is better to give than to receive. Journal of Nonverbal Behavior, 6(3), pp.148–162 (1982)
23. Tapus, A. and Mataric, M.: Socially assistive robots: The link between personality,empathy, physiological signals, and task performance. In AAAI Spring ’08, (2008).
24. Walters, M.L., Dautenhahn, K., te Boekhorst, R., Kheng Lee Koay Kaouri, C., Woods, S., Nehaniv, C., Lee, D. and Werry, I.: The influence of subjects’ personality traits on personal spatial zones in a human-robot interaction experiment. In Proceedings ROMAN’05, pp. 347–352 (2005)
25. Nomura, T., Kanda, T., Suzuki, T., and Kato, K.: Psychology in h-r communication. In Proceedings RO-MAN’04, Kurashiki, Okayama, Japan, pp. 35–40 (2004)
26. Schrempf, O. Schmid, A. Hanebeck, U. and Worn H.: A novel approach to proactivehuman-robot cooperation. In Proceedings RO-MAN’05 (2005)
27. Salovaara, A. and Oulasvirta, A.: Six modes of proactive resource management: a usercentric typology for proactive behaviors. In Proceedings NordiCHI’04 (2004)
28. Cheverst, K., Mitchell K., and Davies, N.: Investigating context-aware information push vs. information pull to tourists. In Mobile HCI’01 (2001)
29. Hook, K.: Evaluating the utility and usability of an adaptive hypermedia system. In Proceedings IUI’97, pp. 179–186 (1997)
30. Jameson, A. and Schwarzkopf, E.: Pros and cons of controllability: An empirical study. In Proceedings AH’02, pp. 193–202 (2002)
31. Castelfranchi, C. and Falcone, R.: Trust and control: a dialectic link. Applied Artificial Intelligence, 14(8), pp.799–823 (2000)
32. Desmond, P., Hancock, P.A. and Monette, J.: Fatigue and automation-induced impairments in simulated driving performance. Transportation Research Record, 1628, pp.8–14 (1998)
33. Kim T. and Hinds P.J.: Who should I blame? Effects of autonomy and transparency on attributions in HRI. In Proceedings RO-MAN’06, pp. 80–85 (2006)

34. Cramer, H., Goddijn, J., Evers, V., and Wielinga B.: Effects of (In)Accurate Empathy and Situational Valence on Attitudes towards Robots, Late breaking abstract, HRI'10, Osaka, Japan (2010)
35. Cramer, H., Kemper, N., Amin, A., Evers, V., Wielinga, B.: 'Give me a hug': the effects of touch and autonomy on people's responses to embodied social agents, Computer Animation and Virtual Worlds, 20, pp. 437-445 (2009)
36. Woods, S., Walters, M., Koay, K., and Dautenhahn, K.: Methodological issues in HRI: A comparison of live and video-based methods in robot to human approach direction trials." in Proceedings RO-MAN'06, Hatfield, UK, pp. 51–58 (2006)