Interaction with autonomous, mobile agents in a hazard monitoring context.

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Abstract
This paper discusses our ongoing research on user interaction with autonomous mobile agents. The overarching project, DIADEM, involves the development of a (semi-)autonomous system that detects potential environmental hazards in heavily populated urban-industrial areas by using input from both a distributed sensor network and humans through their mobile devices. User experiments in this project will focus on social and affective issues in interacting with autonomous mobile agents (such as positioning of mobile agents in relation to the user, empathic interaction and user trust). We describe the project and research context for our studies.

Keywords
Mobile interaction, adaptivity, context-awareness, autonomy, sensor networks, environmental safety

ACM Classification Keywords
H5.m. Information interfaces & presentation

Introduction
Autonomous mobile agents can provide access to users and can connect them to services wherever they go. The potential to respond to user state and surroundings offer an intriguing area for research. Various research projects have shown applicability of context-aware and user-adaptive applications for potentially high-risk and high-stress applications such as healthcare (Varshney, 2003) and disaster prediction and alerting (Kung et al.,

2008). The dialogue with such agents presents challenges beyond dealing with limited screen real estate and designing for a wide array of different mobile devices. These mobile applications are not simply passive tools; instead we are presented with settings in which users interact with remote autonomous agents that also appear to have their own goals and intentions.

The DIADEM project, discussed in this paper, revolves around such a setting. The project aims to develop a system that detects potentially hazardous situations in urban-industrial areas by using input from both distributed sensors and human users. It aims to prevent catastrophic chemical incidents and monitor air and water quality through quick detection of harmful gasses and identification of pollution sources. A distributed sensor network provides information about e.g., air quality and gas emissions by industrial plants. In case of unusual sensor readings, a Bayesian reasoning system reduces the number of possible events (e.g., which gas is detected and whether it poses a threat). If a potential hazard is detected or reported, the system will call upon human observation in and around the affected area to gather more information. With the information that people provide the system can reduce uncertainty further and determine the scope of the event and polluter. For this purpose, participating users will be asked by their mobile agent (e.g., application or service on phone/PDA) to self-report their observations, which are communicated to the central system. If necessary, the system provides location-based warnings and safety instructions. Two types of users are explicitly considered in the project: expert users who are employees of environmental monitoring services and monitor certain routes and specific locations, and members of the general public who live and work in the area.

Part of this project will be a series of user studies serving to both inform the design of the mobile agent's interface that will interact with members from the general public via their mobile phone, and gain insight in mobile interaction with semi-autonomous agents. These experiments will tackle research questions such as how to interrupt the user, which interaction modality to choose (e.g., text, voice, screen agent), how to respond to the users' affective state, as well as design of the user-system dialogue. Of interest are for example the effects on user perceptions, accuracy of the information provided by users, trust and behaviour. Potential dialogue style variations could, for instance, include manipulating the way the system presents information (empathetic or not, formal vs. informal, with specific lexical cues aiming to build and maintain a close personal relation vs. without, etc.).

The remainder of this paper discusses a methodological approach to investigate these issues in a series of experiments. The first study within DIADEM will be a controlled experiment investigating, both quantitatively and qualitatively, the effects of social system behavior and system positioning on user behavior and trust in interaction with semi-autonomous, context-aware mobile systems. It will specifically focus on the effects of empathy and proxemics.

Experimental background

User-adaptive and context-aware systems offer the potential to adapt to specific needs and preferences of individual users and the specificities of their current context. However, interaction with adaptive systems also introduces specific challenges for user trust. (Semi-)autonomous system decisions may lead to a potential loss of user understanding and control (Höök, 2000). Systems that display autonomous behaviour will not simply be treated as tools; instead, factors mimicking processes in human communication will also play a role (Reeves and Nass, 1996). Especially when systems interrupt and request information from the user, reason about users' circumstances and decide whether or not to warn people they are in danger, social and affective aspects of the interaction might be decisive in system acceptance. As illustrated by e.g. the research into mobile persuasion (Fogg and Eckles, 2007), such processes play a role when interacting with mobile agents. Mobile agents that represent distant services present new issues, such as perceptions of proximity and (lack of) shared context between agent and users (Takayama and Nass, 2008). Mobile agents on users' mobile devices can for example either act as intermediaries to remote services or as representations of them. The extent to which the system is perceived as sharing the same goals and concerns as the user will also affect interaction. Does a system for example appear more concerned with gathering information for itself, or with taking care of the individual user, or does it emphasise keeping an area safe? Aspects such as perceived system empathy with the user and his/her circumstances and (re)acting accordingly, could be key in achieving trust and managing affective reactions (Brave et al., 2005; Bickmore and Schulman, 2007). Effects of such design choices need further investigation; in this project a series of studies will explore their impact.

User study example & challenges

The first experiment investigates the effects of empathy and proxemics on interaction and user trust. System empathy can be defined as actively acknowledging the user's (affective) experience and reacting accordingly. As such, system empathy combines social and affective aspects of interaction (McQuiggan and Lester, 2007). Proxemics is a concept that most commonly refers to the physical distance in human-human interaction, but can also affect human-computer interaction. In a car agent context for example, Takayama and Nass (2008) found that representing a service as an agent co-located with the user, instead of representing it as a distant, wireless service, increased feedback, decreased discontent and changed behaviours. Our experiment will investigate how social behaviours, such as empathy exhibited by a close or distant agent, affect interaction with mobile systems. One major research question is to what extent users will trust the instructions and recommendations offered by the system. In our study, agent empathy is manipulated by offering either non-empathic neutral, or more empathic requests and responses. Proxemics is manipulated by either positioning the system as an agent on the mobile phone itself, or as a distant agent that communicates with the user via the phone. Dependent variables include task performance, attitudes toward the agent, perceived stress, trust and compliance to the system's requests and warnings. Participants will perform tasks in a controlled setting.

Challenges & choices

Evaluating user interaction with 'intelligent', autonomous agents on mobile devices presents us with a number of research challenges. Evaluating mobile applications means having to deal with factors that can be difficult to control, ranging from failures of wireless connections and delivery of content, influence of the (social) environment surrounding users, to difficulties observing and recording user (re)actions (Kjeldskov et al., 2004; Kellar et al., 2005). Depending on the focus of a study, the weighting of these challenges can differ. When evaluating the user experience of a system in the last stages of development, evaluating in users' context is crucial (see for instance Riegelsberger and Nakhimovsky, 2007). When evaluating social and affective aspects of interacting with intelligent, autonomous, mobile agents for academic research purposes such as in this experiment, priorities shift from finding all problems in an interface to controlled comparison of different (simulated) conditions. For this first experiment we have chosen to conduct our study in a controlled setting in which participants can be individually observed and tasks are standardised to minimise external influences.

For studies within our project context, experimental settings need to be devised that emulate a potential high-risk situation in which users collaborate with a remote, autonomous system via mobile agents. Performing an experiment in a semi-crisis setting on an urban scale is not feasible; this experiment is designed as a smaller-scale 'exercise'. Since it is both implausible and unethical to convince participants that e.g. gas emissions are threatening an area, other tasks and settings have to be devised. In our case, participants will be instructed to participate in a training exercise to simulate hazardous situations that might arise in industrial buildings/chemical plants. Participants will interact with a mobile phone that both requests and supplies information about potentially dangerous situations in an indoor setting. The Wizard-of-Oz based setting for this 'exercise' consists of a number of rooms and cubicles representing an industrial building equipped with sensors detecting possible hazards. This setting facilitates video monitoring of the participants' behaviour.

Experiment settings such as these have to include tasks that are meaningful to participants to get useful data. Our current choice is a reward-based scavenger hunt-type task setting. Since mobile applications will be used in settings where users are engaged in other activities besides interacting with mobile applications, it is important to include multiple tasks in experiments. Both proactive and reactive system behaviour should be included for hazard monitoring systems that can autonomously ask users for input and warn them, but can also react to user requests and information. In this experiment we use an explicit task and a secondary task. The explicit task of participants is to locate a number of vessels containing chemicals. Participants need the system's help to identify the chemical. The system lets the user know whether the chemical (or combination of chemicals) is hazardous or not. Participants will be informed that the system will warn them in case a hazardous situation arises. This task simulates a situation in which both participants and system are dependent on each other to obtain information useful for their own purposes. As a secondary task, participants will be asked to supply additional information concerning their environment which they have not been instructed about beforehand. The mobile, touch screen-based application developed purposely for this experiment has a simplified interface in which both user and system can initiate an interaction.

The logistics of generating Wizard-of-Oz or mock-up responses and recording user actions when participants actually are on the move during experiments add additional challenges. In this context, (simulated) sensor data and system reasoning are necessary to generate experiment settings and events. A major challenge is how to incorporate such responses in prototypes. In this study, Wizard-of-Oz techniques will be used to simulate functionality of the autonomous system and sensor network. If actual reasoning about user supplied information or sensor data is necessary, the stochastic reasoning engine (Pavlin et al., 2007), developed for usage in the final hazard detection system, could be used to reason about the supplied data and generate queries for users at specific locations. Using mock-up mobile applications, as in the controlled Wizard-of-Oz experiment here, necessitates connecting to interfaces for observers. These observers have to, for instance, generate mock-up sensor readings and system reactions from a distance.

Even for these controlled lab settings, mobile devices add complexities in generating prototypes. Preferably, various interfaces and agents with different 'personalities' for different conditions can be generated by researchers with limited resources. Using web-based mock-ups, accessed using browsers on mobile devices can ease development. This however means functionality is limited and when e.g. evaluating effects of perceived proximity (such as in this particular experiment) or system 'personality', accessing an agent via a browser might increase perceptions of distance between user and agent. If web-based prototypes do not suffice for a particular experiment, mock-up or real applications will have to be devised. This requires additional efforts in creating (mock-up) agents on various mobile devices. The choice made for a specific platform and device might affect perceptions of experiment applications. A discussion how specific platform properties and e.g. access to other phone features or applications might interact with effects of intended manipulations could be beneficial.

At the workshop, we would like to further discuss research into interaction with autonomous mobile agents representing systems that gather information and make decisions about users' surroundings. A number of factors make this research unique and challenging: the need for human 'sensors' to inform an autonomous decision system with a distributed sensor network; the potentially hazardous and stressful interaction context; the need to interrupt users in their daily activities; the need to elicit information from and inform members of the general public and the use of meaningful representative tasks in controlled conditions. At the workshop we want to further discuss our experiences within this setting.

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