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Methodology for Study of Human-Robot Social Interaction in Dangerous Situations

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ABSTRACT
Applications of robotics in dangerous domains such as search and rescue require new methodology for study of human-robot interaction. Perceived danger evokes unique human psycho-physiological factors that influence perception, cognition and behavior. Human first responders are trained for victim psychology. Apart from real-life instances of disasters, studies of robots in this environment are difficult to perform safely and systematically with sufficient controls, fidelity, and in a manner that permits exact replication. Consequently, the trend to deploy rescue robots, for example, is proceeding largely without benefit of knowing whether human victims will readily cooperate with robot rescuers. The capability to deal with unique victim psychology has not been a testable requirement. We report on the methodology of an on-going study that uses virtual reality to provide a feature-rich immersive environment that is sufficient to evoke fear-related psychological response, provides simulation capability for robots, and enables systematic study trials with automated data collection via an embedded scripting language. The methodology presented provides an effective way to study human interaction with intelligent agents embodied as robots in application domains that would otherwise be impossible in the real world.

Author Keywords
Affective Computing, Artificial Intelligence, Autonomous Agents, Behavioral Science, Cognition, Disaster, Experimental Methods, Human-Robot Interaction, Intelligent Robots, Methodology, Second Life, Social Robots, Trust, Rescue Robotics, Virtual Environments

ACM Classification Keywords
H.1.2, H.5.1, H.5.2, I.2.9, I.2.11, I.6.3

INTRODUCTION
There is a demand for applications of intelligent robotics in domains and situations that may be dangerous for humans, i.e., where there exist manifestly real or perceived threats to life or limb. Such threats may be due to environmental factors one might find in broad-area natural disasters (e.g., earthquakes) or local crises (e.g., urban structure fires). Threats may also be a result of adversarial factors due to crime or armed conflict. A prominent application for intelligent robots in dangerous situations is search and rescue, as evidenced by government programs (e.g., DARPA Robotics Challenge) and observed market growth for rescue robots.

Many of these danger-related applications demand interaction between humans and robots, including active cooperation. Real or perceived danger presents stimuli that evoke human physiological and psychological factors that influence human perception, cognition and interaction. Yet very little can be said with scientific certainty about the impact of these unique psychological factors of danger on human-robot interaction owing to the difficulty of performing systematic, controlled studies in realistically high-risk situations. Apart from physical threat, researchers are compelled to minimize the psychological risk of causing trauma, or evoking a memory of trauma in participants. About 60% of men and 50% of women experience at least one trauma event in their lifetimes such as disaster, war, life-threatening assault or accident. Approximately 3.6% of Americans will experience a Post Traumatic Stress Disorder (PTSD) episode in any given year [13].

The challenge for researchers is to find methods for investigating human-robot interaction in dangerous situations safely, with sufficient controls, with situational and psychological fidelity, and with technical means that afford the opportunity for precise measurement. Experimental trials ideally are conducted in a manner that permits exact replication.

Immersive, virtual environments offer such capabilities by simulating physical robot features and behavior of interest, interfacing with external intelligent robot cognitive systems, and, most importantly, by simulating a dynamic, feature-rich environment in ways that *safely* increase a study participant's perception of risk and thus evoke the unique psychology present in dangerous situations.

Our research project is exploring how different factors are considered in a decision to trust and rely upon an intelligent, autonomous agent. We follow up on results reported by Robinette [22], who investigated the role of appearance and certain robot behaviors for gaining trust of people in an evacuation scenario. However, that study used a fairly primitive virtual environment that could not evoke unique victim psychology.

Our study examines how perceived autonomous agent characteristics impact the attribution of benevolence on the part of the human toward the agent in a disaster scenario. Specifically, we are investigating how the human participants' perception of intelligent, autonomous system agency (i.e., ability to choose among many alternative actions) and autonomous system competence (specifically, role-based capability) affects their choice to rely (or not) upon an autonomous agent in a high-risk disaster scenario. Will they cooperate and comply with directions intended to help them? There is insufficient information to give a sure answer, and this is what we hope to contribute.

METHODOLOGY CHALLENGE

Intelligent robot capability has been studied in the context of actual dangerous crises as well as in isolated laboratory settings. These are useful methods, although insufficient for systematic study of human-robot interaction.

Real-life instances of dangerous situations afford an excellent opportunity to both evaluate engineered robot capability and the possibility to provide needed aid to rescuers and victims. Murphy provided a thorough review of activities of rescue robots at the World Trade Center during the 11 September 2001 crisis [15]. However, such instances are thankfully rare. They are also uncontrolled, thus rendering studies performed in real-life disaster conditions nearly impossible to replicate and therefore of limited utility.

One may reasonably ask whether some elements of human-robot interaction for dangerous situations may be studied in isolation – one at a time or in certain combinations. For many of the mechanisms of interest, such as methods of communication and others, the answer is yes. Specialized testbeds and competitions have been developed for this purpose [16, 17]. However, system level testing in fully evocative environments has remained elusive due to unique factors of the psycho-physiology of victims.

Unique Psychological Factors of Danger

Actual dangerous situations present unique stimuli that evoke reflexive physiological and psychological reactions in humans such as fear-potentiated startle [10], anxiety, and stress [18] that are not ordinarily present in day-to-day life. As a result, human social interaction is affected by the perception of danger, depending on both situational and individual personality factors [12]. The first responders who provide aid to victims must contend with the abnormal psychology that such high-risk situations evoke; indeed, they receive special training for exactly this purpose [9].

How will survivors respond to a rescue robot? Our recent exploratory survey of individual choice to rely on an autonomous, intelligent agent in hypothetical dangerous scenarios revealed a strong correlation with risk-related personality and situational factors [1, 2].

In high-risk situations, the symbolic meaning of situational cues interacts with social cues in ways that influence the interpretation of a physical and social situation, and thus behavioral response. These situations evoke an affective mental state with specific attributes and predictable psychological and behavioral results. These include fear, anxiety, panic, reduced compliance with social norms, hyper-vigilance and sensitivity to environmental cues, as well as avoidance behavior (references [10, 12, 18]).

Therefore, it seems likely that human-robot interaction in dangerous situations will be similarly influenced in ways that make it fundamentally different from interaction in other, non-threatening situations. To the extent that this influence is found to be significant, effective application of robots in dangerous situations where human interaction is a requirement (e.g., victim rescue, small team coordination) must account for the differences and adjust appropriately.

In a conventional laboratory setting, individual facets of threats can be studied in isolation (e.g., reaction to images) because potentially confounding cues can be controlled. However, the fear present in actual dangerous situations results from the perception of high risk [25]. To evoke the dynamics of human behavior and psychological factors that result in perception of high risk requires creating a laboratory environment with a large number of realistic cues. This is both difficult and likely to be judged unacceptable for human studies.

Use of Immersive, Virtual Reality

As an alternative to emulation of dangerous conditions in a physical testbed, our proposition is that immersive, virtual reality affords us the opportunity to study human-robot interaction in situations that are perceived as high risk, thus evoking unique psychology and behavior present in the kinds of dangerous situations we have in mind for robot applications, such as urban search and rescue.

The study of HRI in virtual environments is a relatively recent activity. There are a number of commercial and open-source virtual reality tools available to researchers, each with their own strengths and weaknesses. Our primary selection criteria were a) affordance and ease of creating customized, feature-rich environments; b) embedded programming language for robot cognitive emulation; c) ability to interface with external software and servers for data collection, and; d) ready availability "in-world" of potential study participants who would require minimal training.

In addition, the efficacy of our methodological approach entails several important requirements with respect to behavioral realism, psycho-physiological effects, robotics fidelity, and experimental control. We discuss each of these in the following sections.

Behavioral Realism in Virtual Environments

Our methodology requires that human social behavior carries over and is consistent with behavior in virtual environments. It is essential that human behavior in our immersive, virtual reality be sufficiently similar to behavior in the physical world. This requires sufficient fidelity in the simulated environment to enable the mental state of "immersion" by participants.

Behavioral realism requires social presence, that is, the immersive feeling of embodiment and identification of an individual with their in-world "avatar". Schultze [23] reviewed a number of studies and identified specific attributes that promote the sense of presence.

Our study has created a feature-rich virtual environment, a warehouse, that is designed to enhance the participants' sense of immersion. Seen from about, the warehouse layout is that of a typical psychological maze, with walls and stacks of boxes on pallets forming the structure of the maze. There is also the typical equipment found in warehouses, such as mechanical loaders, a crane, hand trucks, and other items that contribute to authenticity. Ambient sounds of machinery enhance the sense of immersion.

Figure 1. Warehouse Overhead View

As an aid to creating immersion, our study provides a period for acclimation to the task environment. This period limits the amount of distraction to participants that may occur when initially entering into the scenario. As discussed later, it also provides an opportunity for certain fear-potentiating cues to be noticed.

Blascovich [4] provided a survey of social psychological studies and their methods that support the mirroring of virtual and real human social behavior, even using technology that by today's standards would appear fairly primitive.

Yee [28] established the persistence of social norms of gender, interpersonal distance, and eye gaze in virtual environments. This study investigated online immersive games as a platform to study physical social interaction at the micro and macro level.

With respect to social behavior, Harris [11] tracked a small population of interacting individuals over time in SecondLife™, providing additional evidence for social influence on individual and group behavior.

Prattichizzo [16] investigated social interaction in heterogeneous communities of robots and humans in SecondLife™. Burden [7] deployed a mix of chatbots and avatar-robots ("robotars") in SecondLife™ to study verbal interaction between humans and embodied virtual robots versus un-embodied chatbots.

Non-verbal communication was studied by Bailenson et al., [3] who found that people exhibited similar personal spatial behavior towards virtual humans (agents controlled by a computer) as they would towards real humans.

Evoking Disaster-Related Victim Psychology

To study human-robot interaction in the context of a disaster, we must demonstrate that virtual environments actually evoke human perception of heightened risk in the absence of actual physical danger, and do so in a manner sufficient to create the unique psychological state in which we are interested.

It is well established in clinical psychology that immersive environments such as ours have the ability to evoke reflexive physiological and psychological reactions of this type. Wiederhold [26] reviews numerous clinical studies showing the effectiveness of virtual reality for treatment of phobias such as acrophobia and arachnophobia and anxiety disorders.

Immersion and visual features alone are enough to induce physiological arousal and strong negative affect [14]. The addition of other sensory modalities, such as audition, improves the sense of immersion and is a strong cue for eliciting fear and anxiety [24].

These studies have shown that specific situational cues elicit perception of high risk and fear-potentiated startle reflex. Based on those results, we have designed the warehouse task space to include many such cues.

As mentioned earlier, our study provides for an acclimation period to aid immersion. During the acclimation phase, prior to the onset of a simulated disaster, we potentiate the perception of high risk through a number of environmental cues, or "risk stimuli". The acclimation phase allows these stimuli to be processed.

Risk stimuli include a worn-out appearance to the warehouse, messy and untidy rows of boxes, and signs of incivility such as trash on the floor, graffiti, and broken windows. In addition, some of the containers contain warning symbols for hazardous chemical materials. Finally, there are prominent warning signs and fire alarms.

In addition, the lighting in the warehouse is carefully controlled to create dark, shadowed areas. Atmospheric diffusion limits clarity of vision at long distances. Visibility lines are also obstructed in many cases. These features combine to potentiate a fear of attack, evoking our evolutionary experience that predators may lurk in such places[6].

At a certain point in an experimental trial, we begin our most significant manipulation of participants with the purpose of swiftly ramping up their affective sense of risk. There is a sudden sound of a nearby explosion followed immediately by visible fire near the roof and smoke overhead (see Figure 2). Approximately every 30 seconds the smoke lowers and increases in density, further obscuring vision. What was a moment ago a spacious warehouse is now a confined space. A loud warning siren commences along with an announcement to evacuate the building. Concomitant with the increasing smoke, fire appears among the stacked pallets and debris falls from the ceiling, blocking the entrance to the door used previously by the participant to enter the warehouse.

Figure 2. Warehouse Fire, Participants' View

Our pilot tests during development suggest that at this point, a participant will feel a sense of entrapment, thereby eliciting the goal of escape. In addition to evoking physical fear, we add additional cues to raise the perception of other types of risk and overall stress. It becomes incumbent on the participant to locate an exit to escape the disaster.

Each element of the simulated warehouse and disaster is designed to cue fear and heightened perception of risk without presenting any actual physical threat. Psychological risk to participants in the study is mitigated by screening protocols that eliminate individuals from the participant pool who may have, or be at-risk for, Post Traumatic Stress Disorder (PTSD). For this purpose, we use the U.S. Government Veterans Administration PC-PTSD screen, modified in consultation with a PTSD expert to include questions from the SCID-PTSD module [19].

The sudden appearance of a bystander or presence of a companion is another cue that elicits perception of high risk. In our study, this is when participants first encounter one of several emulated robots.

Emulation of Robots in Virtual Environments

As a practical matter, immersive, virtual reality must provide appropriate affordances to implement emulated robots of sufficient behavioral complexity. Both cognitive abilities and kinematic behavior (including plausible physics) are important.

Our study takes advantage of the "bystander effect" (mentioned earlier) when participants encounter a robot shortly after the onset of the simulated disaster (i.e., a fire-fighting robot "FireBot" or a janitorial robot, "JanitorBot", see Figure 2). The specific appearance, simulated physical behaviors, and interactive behaviors of the robot in the study vary according to the specifications of the particular control or experimental trial.

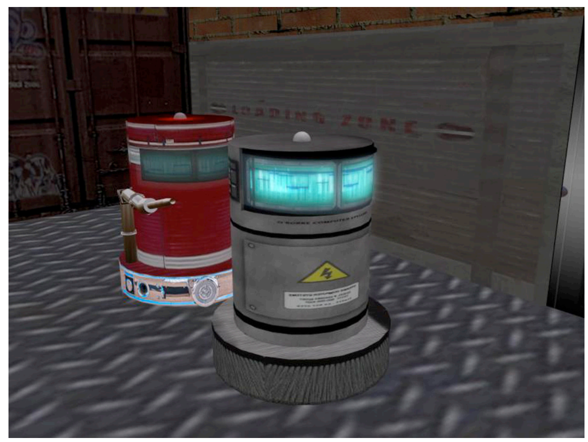

Figure 3. "FireBot" and "JanitorBot"

Programming the simulated robot requires software architecture choices between interfacing with the external "real world" for robot cognition or implementing these capabilities in a limited form within the virtual environment. Both approaches have met with success.

Our approach implements the robot's cognitive and control capability within the SecondLife™ script-oriented language [8] to avoid latency introduced by external communications. We use an augmented subsumption architecture [5] with sensing, perception and individual behaviors implemented as individual scripts that do not directly depend upon or interact with each other. Rather, they interact via executive control scripts that implement activation and suppression consistent with the subsumption architecture framework. Social interaction is implemented via behaviors that "overlay" robot kinematic behavior insofar as they are compatible [6]. Additional details on specific attributes of the robots in our study and their implementation of social interaction are left for later discussion.

Implementing robot cognition via external interface to the virtual world is also a viable option. Veksler [27] demonstrated that an external cognitive architecture, ACT-R, could be easily interfaced with SecondLife™ for studies of the differences in cognitive models with respect to performance, learning and decision-making in the presence of complex and dynamic environments full of distractive cues. Additionally, Ranathunga [21], who studied multi-agent interaction in virtual worlds using SecondLife™ as a platform, reported a key engineering result was the ease of interfacing external cognitive agent platforms such as Belief-Desire-Intention (BDI) programming frameworks with the virtual world.

With respect to robot kinematics and dynamics, Ranathunga also concluded that, unlike simpler simulation environments, SecondLife™ provided a dynamic world of sufficient high fidelity, complexity, constraints and physical laws consistent with object behavior and proportionally suitable sensory-motor capability. Similarly, Prattichizzo [20] concluded that the emulation (i.e., matching external behavior) of robotic control, sensing and perception mechanisms enabled reasonable reproduction of the kinematics of robot behavior.

Controlled Virtual Experiments and Data Collection

Our methodology also requires that we have the ability to capture useful data under controlled and repeatable experimental conditions.

Blascovich (cited earlier, see [4]) reviewed multiple studies that demonstrated how virtual environments enable social psychology studies to increase the level of "mundane realism" while maintaining experimental control.

We have fully automated execution of individual trials for this study, including participant consent, pre- and post-task questionnaires, instructions to participants, environmental dynamics during the participant's task, debriefing delivery, and data collection throughout. This will help ensure systematic, controlled execution of each trial and assist in future replication.

This automation is also implemented using scripts programmed in LSL. These scripts include time-based events as well as events triggered by specific human-robot interactions.

Data from each study trial is delivered automatically online from SecondLife™ in suitable format for storage in a MySQL database. In addition to the questionnaire data, we collect a variety of data during the participants' task. These include physical data of the robot and participant at specific intervals. We also collect a transcript of textual communication by the participant (if any, and only with permission). Our physical data collection is primarily oriented towards proxemics, including: the relative geometry of participant and the robot, their absolute position, orientation, and movement vectors, and the continuous gaze direction and focal point of the study participant and robot.

CONCLUSION

To enable our investigation of human trust and human-robot interaction in the context of a disaster, we have created a virtual environment whose features evoke the affective state of high risk in study participants. Simulated robots and automation of study trial execution and data collection provide us with the methodological tools to conduct controlled and replicable studies in this important area. The key points of this paper follow below.

It is desirable to apply intelligent robotics in danger-related applications, many of which (e.g., urban search and rescue, dismounted infantry, humanitarian operations) require human-robot interaction and cooperation.

There are unique psychological factors evoked by dangerous situations that influence human perception, cognition and social interaction such that we anticipate similar impact on human-robot interaction.

Appropriate stimuli in feature-rich virtual environments can evoke physiological and psychological responses that manifest as a sense of high risk, fear, anxiety and stress similar to those seen in dangerous real-world situations.

Interactive human social behavior, and the norms governing it, carries over into immersive, online worlds such as SecondLife™, thus providing the necessary psychological fidelity for human-robot interaction studies.

The challenge of studying human-robot interaction in truly dangerous situations, inside or outside the laboratory, can be addressed using immersive, virtual reality.

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