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Spatial augmented reality as a method for a mobile robot to communicate intended movement

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ABSTRACT

Our work evaluates a mobile robot's ability to communicate intended movements to humans via projection of visual arrows and a simplified map. Humans utilize a variety of techniques to signal intended movement in a co-occupied space. We evaluated an augmented reality projection provided by the robot. The projection is on the floor and consists of arrows and a simplified map. Two pilots and one quasi-experiment were conducted to examine the effectiveness of visual projection of arrows by a robot for signaling intended movement. The pilot work demonstrates the effectiveness of utilizing arrows as a communication medium. The experiment examined the effectiveness of a simplified map and arrows for signaling the short-, mid-range, and long-term intended movement. Two pilot experiments confirm that arrows are an effective symbol for a robot to use to signal intent. A field experiment demonstrates that a robot can use a projected arrow and simplified map to signal its intended movement and people understand the projection for upcoming short-, medium-, and long-term movement. Augmented reality, such as projected arrows and simplified map, are an effective tool for robots to use when signaling their upcoming movement to humans. Telepresence robots in organizations, museum docents, information kiosks, hospital assistants, factories, and as members of search and rescue teams are typical applications where mobile robots reside and interact with people.

1. Introduction

Robots in the workplace have evolved from the past where they were assembly line machines performing heavy lifting, to the present working alongside humans engaged in a variety of tasks. These new robots include professional and personal service robots and a recent generation of embodied intelligent agents that operate in proximity and collaboration with humans (Asada et al., 2009; Hinds, Roberts, & Jones, 2004; Thrun, 2004). Service robots work alongside both trained and novice users in military, medical, entertainment, and education settings; functioning as receptionists, museum tour guides, and as members of search and rescue teams (Burke, Coovert, Murphy, Riley, & Rogers, 2006; Hinds et al., 2004; Thrun, 2004). More exotic applications find robots designed for virtual workers to enable an embodied physical presence (Tusi, Desai, Yanco, & Uhlik, 2011), to those that assist astronauts in space (Morring, 2012) and doctors performing intricate surgical procedures.

Service robots are projected to become pervasive in the workplace over the coming years and eventually as ubiquitous as today's computer (Asada et al., 2009; Burke et al., 2006; Hinds et al., 2004; Thrun, 2004). Researchers describe robots working as a trained assistant in the patient's home and providing the appropriate care, such as: supplemental physical therapy, continuing long-term care, and monitoring the patient in lieu of the primary doctor. Some predict robots co-existing in homes, offices, and the outdoors by the early 2020s (Asada et al., 2009). To this end, robots must be designed to engage in safe interactions with humans; and research should focus on developing and evaluating effective modes of human-robot communication (Burke et al., 2006; National Science Foundation, 2010). Both trained specialists and lay users need to have confidence in robotic technology in order for its use and acceptance, which also necessitate affordability and simplicity (Asada et al., 2009).

Experts believe that integrating robots into our work life will benefit companies by both increasing productive capacity and reducing workers' medical problems (such as carpal tunnel, back injuries, and burns; Asada et al., 2009; Burke et al., 2006). It is likely that organizations will have teams of both humans and robots that will leverage each other's strengths. To illustrate a typical application, envision managing a retail supercenter with a robot on your work team. One delegates tasks to the robot through a variety of communication modalities, including verbal and gestural

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instructions. After receiving these directions the robot autonomously and adaptively navigates the workday, performing routine work tasks such as: helping human coworkers lift heavy inventory and restocking shelves, assisting shoppers with directions; and, when appropriate, alerting humans to spills and cleaning those up.

If robots are joining the workplace as teammates, it seems reasonable to use knowledge, skills, abilities, and other characteristics (KSAOs) to specify worker attributes for the robots (Coovert & Elliott, 2009). One required KSAO is the ability to effectively communicate (Burke et al., 2006; Coovert & Elliott, 2009). Communication is essential for routine interactions and is especially important for mobile robots. It is critical for mobile robots to explicitly signal unambiguous information regarding their intended movements, as robots lack intuitive understanding about the movement of others in shared spaces. In humans this experience is gained over the years as one grows, and our responses to subtle cues from others regarding their intended directional movement becomes automatic (Shiffrin & Schneider, 1977). While moving in the same shared physical space people trust others to avoid collisions; however, individuals may not be as confident about the robot's abilities to do so because we simply do not have experience co-existing with robots on a daily basis. Our work focuses on mobile robots and examines the effectiveness of the robots ability to communicate movement intention to humans who are in close proximity – as is typically found in organizations and other public spaces.

Attitudes toward robot are also important to understand as ones attitude influences acceptance of technology in the workplace (Coovert, 1995; Coovert, Ducey, Grichanik, Coovert, & Nelson, 2012; Coovert & Foster Thompson, 2014; Coovert & Goldstein, 1980). For example, Dauntenhahn (2005) reports a majority of individuals feel uncomfortable when a robot approached closer than three meters, or when a robot is moving behind them and out of sight. Individuals want a robot to be predictable and rate effective communication as more important than physical appearance.

According to Goodrich and Schultz (2007), when developing interactive robots the accepted standard is to "create real systems and then evaluate them using experiments with human subjects." To date, there is no research focused on examining a robot's ability to communicate its upcoming direction of movement – a critical aspect for successful human-robot interactions in shared spaces. The present study is a step in that direction.

2. Communicating upcoming movement

Effective communication between humans and robots is one of the keys to building a synergetic human-robot relationship. Humans collaborate effectively with each other using both overt verbal and nonverbal forms of communication. We rely on our ability to interpret what others are saying and how they act in order to understand and to predict their upcoming moves. Utilizing this same strategy, one approach for robots to use in order to work effectively with humans is to make the robot capable of interpreting intentions through recognizing and understanding human body language expressions, including: explicit auditory, facial, and gestural movements. Then, based on the robots perceived intention of the human, the robot could plan its next movement in order to act collaboratively with humans sharing a common goal. Interpreting human intentions has been the subject of much research in robotics and psychology (Ajzen, 1991; Fong & Nourbakhah, 2003; Ouellette & Wood, 1998; Willson, 2000; Fritsch & Kleinehagenbrock et al., 2005). Numerous research approaches employing pattern recognition techniques (Betkowska, Shinoda, & Furui, 2007; Li & Wrede, 2007; Sakaue & Kobayashi, 2006), have been designed and developed to recognize and understand human expression and extract intentions from speech, gestures, and facial expression.

One difficulty associated with creating robots capable of effective collaboration is that, from a robot's perspective, humans are highly uncertain. The onus is on the robot to perceive, understand, and appropriately react to rather unpredictable humans. Shifting the responsibility from the robot to the human will create safer interactions. It has been noted that the robot's ability to establish trust is a direct determinant of the user's willingness to engage and accept help from the robot (Asada et al., 2007). It follows that effective communication will lead to increased acceptance of the robot.

Enabling robots to interpret human intention is only one perspective of the problem. Another is to ensure humans can predict the robots intended movement. In order to interact safely and actively collaborate with robots, a human has to understand the current motion of the robot and predict its upcoming movements. One approach to accomplish this is to design a robot that can express itself as humans do; thereby allowing humans to identify the robot's current and intended movements (as humans do with other humans). Some researchers (Bates, 1994; Blumberg, 1996) have suggested that in order for effective social interaction with humans to occur, a software agent must have three characteristics: (1) it must have behavioral consistency, (2) it must have a means of expressing its internal states, (3) it must be believable and lifelike (human-like). We now consider each of these characteristics.

We agree with the first premise that it must behave in a reliable and behaviorally consistent fashion. A robot acting in a reliable fashion is an essential step in enabling humans to interact with it. Therefore any system that a robot employs to communicate its upcoming movements must be reliable. The second premise is that the robot must have a means of expressing its internal states. In our case, expressing its internal states means the robot must be able to communicate its upcoming movement (direction and speed) to those humans in close proximity. This communication act is the crux of our work.

We take exception, however, to the third premise. It is unrealistic and unnecessary to require robots coexisting with humans to have human-like appearance, kinematics, and dynamics. We provide two reasons for this dissention. First, in many cases a robot merely needs to communicate its upcoming movement direction and velocity; all the complexities and subtleties of human behavior are simply unnecessary for coexisting in a shared space, or to cooperate on a specific task. Second, a robot's motion, by its very nature, is far different from the routine behavior of humans. Certain motions we humans consider to be unnatural, are rooted in the very physical properties and configurations of a robot. A robot's material, actuators, and sensors are fundamentally different from ours, and these yield rather different patterns of acceleration, deceleration, and the like. A robot is designed to amplify its strength and to be efficient for certain tasks. These differences give it capabilities – such as superior speed and extreme precision – that humans simply do not have. Furthermore, even robotic manipulators that appear very human-like do not necessarily move as human arms move, since the manipulators have different kinematics and range of motion. For example, a typical robotic wrist has a large rolling motion – close to 360° – and the human wrist can roll only a little more than 90 and less than 180°. So forcing human-like abilities, such as limiting a robot's wrist motion to keep it in the range of humans, will significantly reduce its capability. This in turn will limit us in the goal of leveraging each other's strengths when robots cowork with humans.

Our perspective states that for a robot to employ an effective communication system with humans, it needs to have certain characteristics. First, to be reliable the system should signal the same information at the same time for similar tasks (e.g., alerts or warnings). Second, it needs to convey its upcoming goal states; in our case these correspond to short-, mid-, and long-term intended movements. Third, it should utilize characteristics that are most suited for task accomplishment; not necessarily ones that are the most similar to humans. Fourth, robots should employ a communication modality (e.g., visual, auditory, tactile) that will be optimal for human information processing, given the task environment. We now consider this fourth point in greater detail.

2.1. Communication modalities for HRI

It is well accepted that for humans, the visual sense/perceptual system is primary, followed by the auditory and, subsequently, the tactile (haptic) perception system (Wickens, 1984; Wickens, Lee, Liu, & Gordon Becker, 2004). These enable humans to sense and ultimately understand and interact with the world. There is little doubt that visual displays enable easy perception, awareness, and comprehension. At the same time, presentation of certain types of information using other modalities such as auditory (speech) and tactile (haptic) have been shown to effectively guide attention, reduce workload, support performance (Prewett, Elliott, Walvoord, & Coovert, 2012; Prewett, Johnson, Saboe, Coovert, & Elliott, 2010) and impact trust (Hancock et al., 2011).

It is not surprising that these modalities are most often used to signal and interpret intentions (de Ruiter et al., 2010). Yet, there is not always a "best" modality to handle communication of intention, as intention is often both task dependent (Barr & Keysar, 2002) and conditioned upon the exchange of those involved (Airenti, Bara, & Colombetti, 1993). As such, it is important for humans and co-robots to signal intended movement via the modalities (visual, auditory, tactile) typically utilized for communication.

Often used for alerts and warnings, auditory expression via sounds can be effective for communicating a simple intended action. There can be, however, limitations to using the auditory channel. For example, loud sound may be not acceptable in a quiet environment such as a hospital, museum, or office. Frequent auditory warnings/announcements are also annoying – consider the beeping that often accompanies a courtesy transportation cart in an airport terminal. Additionally, it is difficult to use auditory expression to effectively communicate more than one upcoming movement or change in direction.

Tactile displays have been utilized effectively for navigation and orientation (Van Erp, 2007; Van Erp & Werkhoven, 2006). These can take the form of a simple tap to direct and focus attention, or can be more elaborate as in the case of a tactile torso display used in aviation flight jackets (Jones, Nakamura, & Lockyer, 2004; Van Erp, 2006). Tactile direction and orientation cues have demonstrated faster reaction times, better situation awareness, and stable spatial orientation (Gilson, Redden & Elliott, 2007; van Erp, 2007). More complex tactile patterns (e.g., tactons, tactile melodies) have been shown to be effective for simple communications (Brewster & King, 2005; Brill & Gilson, 2006; van Veen & van Erp, 2003). All in all, simplicity and intuitiveness are linked to tactile cue success. Single alerts are ubiquitous and effective, such as the vibrate mode on a cell phone. Tactile cues that require more training and/or interpretation, however, can add to cognitive workload rather than ease it. Whether the purpose is attention management, visual search, navigation, spatial orientation, or communication; tactile arrays must provide signals that are easily and immediately recognizable.

These devices function by providing information to the human who wishes to navigate in (human) ego centered space as defined by Wickens and Prevett (1995); to overcome spatial disorientation (Rupert, 2000), or in situations of high workload when a visual field is saturated (Prewett et al., 2010). Thus, when operating in shared public spaces with humans, tactile or auditory cues may be useful for a robot to issue a simple alert or warning for short-term movement; but these cues are often not sufficient by themselves to communicate more complex motions, as when the robot needs to communicate an upcoming chain of movements that represent a mid- or long-term goal. Although intriguing and worthy of research, these tactile devices are beyond the scope of our current research in that our focus is on humans interacting with robots in a shared space where the robot is the center (described below); the human is under normal workload conditions, spatial disorientation is not a factor, and it is necessary to communicate more than one upcoming movement.

In many circumstances, making an intended action explicit through visualization is more intuitive since it is possible to easily communicate a multistep action or goal state with a visual display. A well-designed visual display can reduce cognitive load (Prewett et al., 2010, 2012; Sweller & Chandler, 1994; Fong et al., 2003) and seemingly amplify a human's cognitive ability (Cox, 1999; Ware, 2004). Adding animation to a visual display can be beneficial as well. When substituted for a written description, a graphical animation may allow human coworkers to avoid having to derive an upcoming action from a text-based communication. A robot using a visual means to communicate its upcoming action would allow human coworkers to rapidly discern its impending movement. The purpose of expressing movement intention with visualization is to structure and render an intended movement in such a way that it can be understood both easily and comprehensively. The challenge is to align the projected visualization accurately onto the real world so as to prevent distortion and not require further interpretation or mental computation on the part of the individuals to whom the communication is intended.

In related work there has been an interest in expressing a robot's "thinking of action" with animation to improve HRI. For example, Takayama, Dooley, and Ju (2011) utilized a Pixar animator to design and illustrate the robot's pre- and post- actions on a computer. Matsumaru (2011) employed a mobile robot equipped with a projector to display the robot's upcoming heading and speed as arrows on the floor. Fung, Hashimoto, Inami, and Igarashi (2011) modified a handheld device (similar to a smart phone) to teach a sequential task to a robot using a playbook of photographic instructions. Compared to a natural language interface, this approach enables users to visually recognize the available steps of the task. Our work differs from these prior efforts in that our robot derives short-, mid-, and long-term intentions from task state machines and superimposes the intention information on operated objects and environment with spatial augmented reality.

2.2. Spatial augmented reality

Our hypothesis is that the best way for a human to understand the upcoming moves and discern the future intended movements of a robot is to have the robot explicitly express its upcoming intended movements. Our work in this area centers on robots using visual projections of intended movements as a means to communicate with humans. We present an examination of a robot expressing its upcoming movements using spatial augmented reality techniques (SAR). The SAR approach has been successfully used in many different areas to render digital content on physical objects in order to generate an immersive display. A robot equipped with the SAR technique is called robot-centered spatial augmented reality (RCSAR). A RCSAR robot will be able to render interaction information on the operated objects and environment to illustrate a clear visualization of how the robot will act on the objects. It allows users around the robot to view the robot's intention and perform collaborative tasks without wearing head-mounted displays, tactile belts or arrays, or using handheld devices.

We exploit the fact that vision is our dominant sense and images or symbols are effective at conveying ideas (Rouse & Morris, 1986). In this study, the robot projected an image of an arrow (and map) on the floor ahead of it and that symbol communicated the robot's intent to move in a direction or to a particular location. The specific purpose of our work is to examine how individuals respond to a robot displaying visual projections of its intentions – namely where it is going in the short-, mid-, and long-term with the RCSAR technique. We hypothesized that when a robot displayed these projections, people are more accurate in identifying where the robot is going than when the robot does not display visual projections. We also examined whether projections would lead to increased confidence on the part of the observer regarding the path the robot would follow. Further, we investigated participants' attitude toward the robot and hypothesized that viewing projections provided by the robot will result in it being seen in a more positive fashion.

3. Method

Our goal is to assess how well a robot can convey its upcoming movements to humans using visual spatial augmented reality (e.g., arrows projected onto an existing environment). We are also interested in the degree of confidence individuals have in their understanding of the upcoming movements of the robot. Furthermore, we want to assess the veracity of the robots communicating three types of intentions: short-, mid-, and long-term. Prior to the main experiment we conduct two pilot studies. The first was to determine the efficacy of the stimulus arrows we would project. The second pilot was a preliminary test of the system with a mobile robot.

In the principal experiment participants were given instructions to observe the robot as it moved around the room and to answer questions when instructed by the experimenter. The response instrument consisted of several two-part questions; the first part soliciting a response about the robot's destination (effectiveness of the communication for short-, mid-, and long-term) and a second part of the question assessing the confidence in their rating of the robot's destination.

3.1. Pilot experiment 1

This study was conducted to examine human understanding of directional information from standard arrows. Visual presentation slides were developed following established principles from human factors signage and safety (Rasmussen, 1983; Woodson, Tillman, & Tillman, 1992). Each slide contained a picture of a robot and directional arrows (similar to Fig. 1). Our distal goal is to determine if humans will correctly interpret intended movement if a robot communicated information regarding its future direction by projecting an arrow on the ground in front of it (as shown in Fig. 2). So our first step is to validate the use of arrows to signal intended movement.

For each stimuli, participants were asked to indicate their confidence that the robot will move in a certain direction. Confidence was rated on a Likert scale of 1 (not at all confident) to 7 (completely confident). Two types of stimuli were developed: congruent and non-congruent items. Congruent items contained directional information in the picture that corresponded to the information provided in the item (e.g., arrow pointed forward and the item assessed confidence in the robot going forward). Answers to those

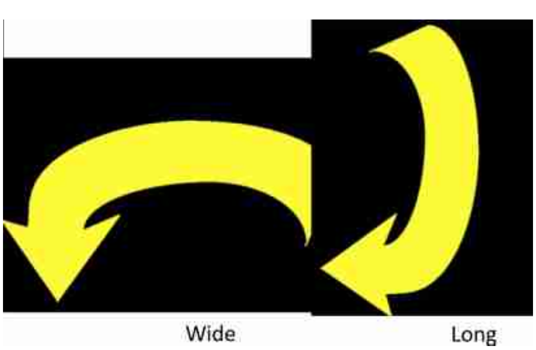

Fig. 1. Example wide versus long arrows.

Fig. 2. Robot projecting an arrow to communicate its intended path of movement. Red circle indicates position of projector. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

items should be high confidence. The non-congruent items presented mismatched information (e.g., arrow pointed forward and the item assessed confidence in the robot turning right). Answers to those items should be low confidence. Four directional arrows were used: forward, backward, right-, and left-turn (one for each possible direction the robot could move). Participants were presented with each slide one at a time and asked to mark their confidence rating on the answer sheet.

3.1.1. Pilot 1 results

Data were collected from 34 young adults at a large university in the southeast. Participants received extra credit points in a course for their participation. The means for all the congruent items were high, ranging from 4.59 to 6.26 (1 = no confidence, 7 = high confidence), while the means for all non-congruent items were low, ranging from 1.82 to 3.21. Together, these results suggest that the participants understood the arrows and expected the robot to maneuver in the direction the arrow was signaling. We also investigated the directional lead and orientation of the arrows, one where the body of the arrow was long in width and a second where it was long in length (left and right panel, respectively, of Fig. 1). This was done for both left and right turning arrows. A paired-samples *t*-test revealed significant differences in both the left- and right-turn arrows, $t(33) = -2.69$, $p < .05$ ($M_{wide} = 4.59$, $M_{long} = 5.62$) and $t(33) = -2.18$, $p < .05$ ($M_{wide} = 5.09$, $M_{long} = 5.85$), respectively, indicating that in both cases, the participants were more confident about the direction the robot was going to turn to when an arrow with a long body was presented.

3.2. Pilot experiment 2

The goal of this experiment is twofold. First, to generalize our findings from the first study where participants viewed pictures of the robots and their signaling arrows to a situation where participants had a limited interaction with the robot and saw the projected arrow on the floor in real time. The second goal is to lay the foundation for signaling intended directional movements not only for the short-term, but also for mid-, and long-term movements.

3.2.1. Pilot 2 procedure and results

The robot moved toward the individuals in real time and projected one of four arrows (front, back, left, right) on the ground in front of it. The arrows were selected randomly and presented one at a time. After each stimulus presentation, the participants rated their confidence in the robot's upcoming movement using the same scale as in pilot experiment 1. Each participant made a total of 10 ratings (4 congruent and 6 non-congruent). Data were collected from five young adults at a large southeastern university. None of the participants in this experiment had participated in the first pilot. As in the first experiment, the means for the congruent items (range of the means: $M = 6.8–7$) greatly exceeded the means for non-congruent items (range: $M = 1–1.2$), $t(4) = 72.06$, $p < .001$, replicating the previous results and generalizing the findings to interactions with the robot.

The two pilot experiments demonstrated that individuals can reliably understand directional intentions in general (pilot experiment 1) and when visually projected into the environment by a robot (pilot experiment 2).

3.3. Primary study

3.3.1. Participants

Our interest is in developing a methodology that will be widely understood by a large cross section of individuals where interactions with service robots are found, such as: museums, fast food restaurants, and traditional organizations. As such, the participants chosen for this study were a convenience sample taken from a group visiting a large university in the southeastern U.S. as part of an exposure to STEM (Science, Technology, Engineering, and Mathematics) programs. The age of participants in this study ranged from elementary and middle school students to middle-aged adults. We employed a quasi-field experiment design where individuals were randomly assigned to one of two groups (a child and his/her parents, however, were not separated and were assigned to the same group). In the treatment group ($N = 31$), the robot projected its intended movement with the arrow and a map depicting a simplified rendering of the environment. A second group was a control ($N = 24$) and no information was provided by the robot relative to its upcoming movement.

3.3.2. Projection group

The robot and three marked cones were set up in the experimental room (see Figs. 3 and 4). The robot was programmed to travel along a path and approach cone 1, go around it, and ultimately reach either cone 2 or cone 3 as a final destination. Each question on the response instrument corresponded to a certain stage in the experiment and action of the robot (see Table 1 for stage descriptions). Question 1 focused on the stationary robot, displaying a map projection of its long-term intention (stage 1). The robot then began moving along a programmed path and the robot displayed an arrow projection of its short-term intention; subjects answered a second question. A third item inquired about the next phase where the robot displayed a curved arrow indicating its mid-term intention, i.e., to approach and move around an obstacle, cone 1. A fourth question assessed the utility of the robot again displaying the map projection; however, this time the robot was not stationary but en route to its final location, cone 3. Each question assessed both where the participant thought the robot was going and the degree of confidence in the rating. The robot paused for 30 s at each stage, projecting the image of its intention (e.g., arrow), as the participants recorded their responses.

3.3.3. Control group

For participants in the no projections condition, all actions of the robot were the same; the robot paused for 30 s at each stage without projecting any information. As in the treatment group, the pause allowed participants to record responses to the questions.

4. Results

We hypothesized the visual projection of a symbol(s) into the environment to be an effective modality for robots to signal

Fig. 3. Experimental environment with three marked cones and robot (front-most left).

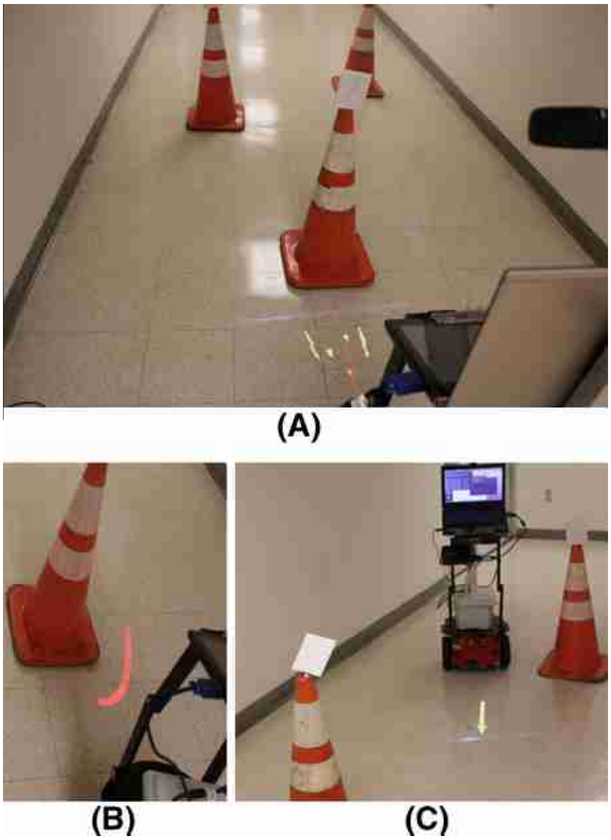

Fig. 4. (A) Long-term intention rendered as a map and an animated path that are aligned with the environment in orientation; (B) Mid-term intention superimposed in the environment with correct alignment; (C) Short-term intention that indicates the robot's moving direction relative to the environment.

upcoming movement. As such, participants who are provided visual projections will be more accurate in identifying where the robot intended to go than participants who are not provided this visual communication. Chi-square analyses reveal significant differences between the projection versus no projection groups for each of the four conditions: long-term movement intention when the robot is at the start of the path, $\chi^2(2) = 32.17$, $p < .001$; short-term movement intention, $\chi^2(4) = 24.59$, $p < .001$; mid-term movement intention, $\chi^2(1) = 8.15$, $p < .01$; and long-term movement intention at the end of the path (close to its final destination), $\chi^2(2) = 27.82$, $p < .001$.

In the group with projections, 74% of participants correctly identified the robot's long-term intention compared to 0% of participants in the group without projections. Eighty-seven percent of participants who saw projections correctly identified "forward" as the robot's short-term intention, while only 25% of participants did so in the group without projections. For mid-term intention, 94% of participants provided projections correctly answered "around the cone" compared to 63% of participants who were not provided projections. Lastly, for long term intention at the final stage, 87% of participants who saw projections correctly identified the intended final destination of the robot, while participants who were not provided projections answered correctly only 17% of the time. See Table 1 for a summary of the results.

These results support our hypothesis that individuals who see projections from the robot are able to correctly identify the robot's long-term, short-term, and mid-term movement intentions. Additionally, the majority of participants are able to correctly identify the robot's long-term intention at both stage 1 and stage 4. This indicates that individuals are able to interpret the map-like long-term intention projection when the robot is at varying distances from its intended destination, either proximal or distal.

We measured participant's confidence in their assessments of the robot's upcoming movement. Confidence ratings were obtained on a scale of 1 (not at all confident) to 7 (extremely confident). Results of independent samples t-tests show a significant difference between confidence ratings when projecting the robot's upcoming movement (long term at the start of its path, $t(52) = 3.425$, $p = .001$; short-term, $(53) = 4.796$, $p < .001$; mid-term, $t(53) = 4.541$, $p < .001$; and long term at the end of its path, $t(53) = 5.032$, $p < .001$). See Table 2 for a summary of these results. It is clear that participants who are provided projections are significantly more confident in their assessments of the robot's long term, short-term, and mid-term upcoming movements, compared

Table 1
Observed frequencies of responses for participants predicting a robot's upcoming movement.

	Group			
	Treatment (with projections)	Control (without projections)	χ^2	*V*
Stage 1: Long-term intention (far)				
Cone 1	2 (7%)	13 (54%)	32.17***	.765
Cone 2	6 (19%)	11 (46%)		
Cone 3[a]	23 (74%)	0 (0%)		
Stage 2: Short-term intention				
Left	0 (0%)	6 (25%)	24.59***	.669
Right	3 (19%)	4 (17%)		
Forward[a]	27 (87%)	6 (25%)		
Backward	0 (0%)	2 (8%)		
Circle	1 (3%)	6 (25%)		
Stage 3: Mid-term intention				
Straight into the cone	2 (7%)	9 (38%)	8.15**	.385[b]
Around the cone[a]	29 (94%)	15 (63%)		
Stage 4: Long-term intention (close)				
Cone 1	0 (0%)	4 (17%)	27.82***	.711
Cone 2	4 (13%)	16 (67%)		
Cone 3[a]	27 (87%)	4 (17%)		

[a] Correct answer for robot's movement intention.
[b] Φ.
** $p \leqslant .01$.
*** $p \leqslant .001$.

Table 2
Mean confidence ratings for group with projections and group without projections.

	Group			
	With projections	Without projections	*t*	*df*
Confidence in assessment of long term intention (far)	5.17 (1.80)	3.50 (1.75)	3.425***	52
Confidence in assessment of short-term intention	5.55 (1.36)	3.63 (1.61)	4.796***	53
Confidence in assessment of mid-term intention	6.35 (1.33)	4.46 (1.77)	4.541***	53
Confidence in assessment of long term intention (close)	5.52 (1.84)	3.08 (1.69)	5.032***	53

Standard deviations in parentheses.
*** $p \leqslant .001$.

to participants who are not provided visual projections by the robot.

We also examined the extent to which increased predictability in upcoming movement leads to increased favorability ratings of the robot. A Pearson correlation was computed between participants' total confidence rating and rating of the robot's likeability. The two variables are significantly correlated, $r(53) = .446$, $p < .001$, suggesting increased confidence in assessing the robot's movement is associated with a more favorable attitude toward the robot. Furthermore, a *t*-test was conducted to compare mean ratings of robot likeability between the treatment and control groups. Results show a significant difference, $t(53) = 2.674$, $p < .01$ (mean for group with projections $M = 5.84$, mean for group without projections $M = 4.58$), such that participants who are provided upcoming movement information view the robot in a more positive light than participants who are not provided this information by the robot.

4.1. Summary

Our results indicate that individuals can correctly interpret projections onto an existing environment of a simplified map and arrows in order to determine the upcoming movement of the robot providing the projection. Individuals have confidence in their interpretation of the upcoming movement and this confidence leads to a more favorable rating of the robot.

5. Discussion

Our research contributes to the field of HRI, especially relative to robots intended for environments where they must coexist with humans. From our work, we provide evidence that people are able to understand several types of visual projections (straight arrow, curved arrows, and a simplified map) projected by a moving robot and interpret those projections as the robot's upcoming movement direction. Furthermore, individuals are able to do this quickly and without prior training. Our results provide support that designing robots with the ability to communicate via projections helps individuals identify and feel confident about a robot's short- mid-, and long-term movements. Additionally, people's confidence is positively linked with liking the robot – a necessary component for a wide range application of robots in work and service roles throughout society.

Future studies should continue evaluating users' experience with robots by examining participant attitudes and trust. Confidence, trust, and safety will lead to an increased acceptance and use of robotic technology. It would also be beneficial to compare modalities (Coovert, Walvoord, Elliott, & Redden, 2008; Fritsch et al., 2003) and combinations of modalities for communication, such as the robot displaying both visual and auditory intentions of movement, in order to identify those preferred by users and those most effective in various work and social contexts. Finally, scientists from various disciplines will need to re-examine team performance as a function of processes involving interaction with robots, and perhaps refine selection tools that assess aptitude (c.f. Coovert & Elliott, 2009) for working collaboratively with robots.

The fact that our primary study (not the pilot work) occurred in the field adds to the generalizability of our findings. The background noises during the field experiment were similar to the daily distractions experienced in real life, akin to the actual settings for which robots of this type are intended, thus adding to the external validity of our results. Another strength is that we utilized a real robot (not a computer simulated robot) with a wide cross-section of human subjects, again adding to the generalizability of our findings. Finally, our work contributes to the discipline of HRI as our findings provide support to the fact that robots can use uncomplicated technology – visual projections that are intuitively understood by humans - as a means for effective communication, paving the way for the development and testing of robots to become contributing members of organizational teams.

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