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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