



Table 1. RCTA HRI communication modalities

Modality	Delivery	Explicit	Implicit
<b>Auditory</b>	Speech, Sounds	Language	Tone, Rate, Pitch
<b>Visual</b>	Posture, Facial Expression, Gesture, Gait, Social Distance	Intentional Pointing, Hand Signals	Unintentional Body Language, Intensity, Eye Contact, Talking with Hands, Emotions
<b>Tactile</b>	Belt, Vest	Intentional Touching, Patterns	Pressure, Patterns, Shakiness

Humans naturally communicate with one another using redundant and simultaneous communication modalities that are flexibly switched to meet diverse needs (Oviatt, 2002; Oviatt, Coulston & Lunsford, 2004) and convey meaning and context at multiple levels of complexity (Bischoff & Graefe, 2002). Further, MMC positively impacts effectiveness and efficiency (Parr, 2004; Oviatt, 2000). These features represent critical and significant advancements in SR interaction and team performance. Therefore, the following operational definition is proposed.

*Multi-modal communication* is the exchange of information through a flexible selection of explicit and implicit modalities that enables interactions and influences behavior, thoughts, and emotions.

*Explicit communication.* With teleoperation being the contemporary standard for explicit communication from humans to robots, a goal for the December 2010 workshop was to develop a definition of explicit communication for use within the RCTA to support mixed-initiative operational teams. Within this new paradigm, explicit communication must support the purposeful communication of information through auditory, visual, or tactile modalities to influence the behavior, thoughts, and emotions of others. Through an examination of the literature, different methods of communication across modalities were investigated with a focus on bi-directional capabilities. For example, voice commands have shown reduced operation time in discrete robotic tasks, but perform poorly for continuous tasks (Redden, Carstens, Pettitt, 2010). Additionally, auditory cues were shown to increase performance within robotic tasks when used alone and in conjunction with tactile cues (Gunn, Warm, Nelson, Bolia, Schumsky, Corcoran, 2005; Haas, 2007). Arm and hand gestures are a natural and intuitive method of communication between humans (Wexelblat, 1995) and can be quicker and feel more intuitive than manual controls (Guo & Sharlin 2008). Tactile communication from robot to Soldier via skin stimulation is a method under investigation because it is hands-free, stealthy, and shown to increase situational awareness, decrease sensory overload, reduced response time, and even motor task training and reduced response time due to its egocentric directional cueing (White, 2010; Elliott, Coovet, Prewett, Walvord, Saboe, & Johnson, 2009; Hutchins, Cosenzo, McDermott, Feng, Barnes, & Gacy, 2009; Bloomfield & Badler, 2008). Based on this review and operational requirements, the following

operational definition for HRI research in explicit communication is proposed.

*Explicit Communication* is the purposeful conveyance of information through multiple modalities (i.e., audio, visual, tactile) that has a defined meaning.

*Implicit Communication.* Implicit communication is arguably the most difficult phenomenon to define in the context of HRI. Various definitions exist with differing components of what makes up implicit communication (Bauer, Wollherr, & Buss, 2007; Lin, Le, Becker, & Makedon, 2010; Rani, Sarkar, Smith, & Adams, 2008). The closest synonym for implicit communication is nonverbal communication. Examples of nonverbal communication are body posture, eye contact, touching, and social distance. However, as Richmond, McCroskey, & Hickson (2008) stated, "A difficult issue facing scholars of nonverbal communication has been the drawing of meaningful and clear distinctions between verbal and nonverbal messages." Aside from this challenge, many nonverbal communication taxonomies exist and no two are the same. Not to mention that while nonverbal communication seems to be the closest description of implicit communication, implicit communication sometimes includes verbal communication such as paralinguistics (e.g., grunts, sighs, tone, rate of speech). Mehrabian (1981) addressed some of these issues with his theory of implicit communication. That theory focuses on implicit communication as conveying emotions and attitudes through five major categories: Emblem, Illustrator, Affect Display, Regulator, and Adaptor. Considering the available literature, the following operational definition for HRI research is proposed.

*Implicit Communication* is the inadvertent conveyance of information about emotional and contextual state that will affect interpretation, thoughts, and behaviors.

### Conceptual Illustration: "Follow That Guy"

In order to convey how MMC is used within an operational context and to help differentiate between explicit and implicit communication, a vignette composed of "mission primitives" is used. A vignette is a short impressionistic scene that focuses on one moment or gives an idea about a character, setting, or object. Mission primitives describe specific action/interaction within a vignette and can be combined and reused. Through the identification of mission primitives it is possible to develop MMC solutions to support multiple vignettes and the larger scenarios they support.

In the following example, illustrated by Fig. 1, a Soldier (A) and a robot teammate (B) are performing a reconnaissance and surveillance mission in an urban environment. At some time while traversing the city street, the robot teammate identifies a Point of Interest (POI) (e.g., enemy target) and alerts the Soldier. The Soldier then requests the robot teammate to follow the POI (C), while he/she moves to a Non-Line-of-Site (NLOS) location. As the robot teammate follows the POI, it keeps the Soldier informed of events.

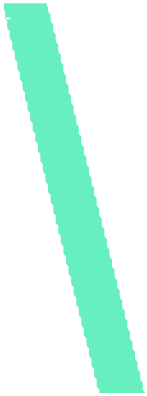


Figure 1 - Point of Interest (POI) vignette

From the start to the end of this vignette, there are several communication events that illustrate mission primitives. In Table 2, each mission primitive is described as a combination of explicit or implicit communication over a selected modality.

Table 2 – POI vignette communication events

Time	Events	Modality/Explicit	Modality/Implicit
T1	Soldier requests robot to follow him/her	Visual: Gesture	Visual: Urgency
T2	Robot acknowledges request	Tactile: Cue	Visual: Urgency
T2B	Robot Follows POI	None	Visual: Social Distance
T3	Robot notifies Soldier of POI	Tactile: Cue & Navigational Aide	Tactile: Context
T4	Soldier request robot to follow POI	Visual: Gesture	Visual: Urgency
T5	Robot acknowledges request	Tactile: Cue	Visual: Urgency
T6	Soldier moves to NLOS location. Robot follows POI.	None	Visual: Social Distance
T7	Robot notifies Soldier of change in direction (e.g. takes a right down street)	Tactile: Cue & Navigational Aide Audio: Cue or Voice	Tactile: Context and Urgency Audio: Context and Urgency

For example, at time T1, the Soldier uses an explicit visual gesture to signal the robot teammate to follow him/her. While performing this gesture the robot teammate looks for additional implicit information in the gesture to identify the urgency of the request. At times T2B and T6, the robot is following the POI, using social distance as a method of implicit communication with the POI. Finally, at time T7, the robot is communicating information to the Soldier via tactile and audio modalities to provide both explicit and implicit information about its change in direction while following the POI. Following mission primitives in this example, it is clearly shown how both modalities and explicit and implicit communications are used to support bi-directional communication within a mixed-initiative team. Moreover, this

brief vignette illustrates the importance of concurrent, diverse, and/or switchable communication modes to effectively convey meaning in the operational environment.

### Summary

The proliferation of unmanned assets (e.g., robots) within the military services indicates that the next-generation of SR operational protocols will undoubtedly incorporate novel SR team collaboration requirements; thus, necessitating equally innovative SRI communication methods. True integration of robotic assets within SR teams requires the scientific community to rapidly evolve the concept and implementation of human-robot communication for dismounted applications. Future systems will use traditional controllers and other device-based interfaces less, transitioning to natural bi-directional communications.

Given emerging trends in the fields of HRI and MMC, the research community is poised to significantly impact the imminent SRI communications revolution. A natural next step to enabling Soldiers to shift from controlling robots to collaborating with them is to enable Soldiers to communicate with robots in ways that are natural, efficient, and effective, is to reassess the current definitions of MMC, explicit communication, and implicit communication. This paper builds upon existing interdisciplinary research to advance these terms in support of basic and applied research conducted within ARL's RCTA. The definitions proposed for multi-modal, explicit, and implicit communication begin to bridge the gap between the current state-of-the-science and future mixed-initiative team applications. Further research and experimentation is required to test the proposed definitions, facilitate their refinement, and develop new technologies.

RCTA efforts planned for 2011 include basic and applied research in the area of MMC applied to the operational environment. Explicit communication research includes advancing the use of Parameterized Action Representation (PAR) to control simulated robots in an operationally relevant scenario (Pelechano, Allbeck, & Badler, 2008). Tactile encoding schemes for complex messages (e.g., cue and navigational aide) and bidirectional communication will be developed and assessed in live-virtual-constructive environments. Basic research in the area of implicit communication aims to develop foundational methods for detecting, classifying, and demonstrating implicit delivery mechanisms. The initial research conducted in 2011 will serve as a launching point for integration of innovative communication modalities within advanced robotic systems.

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