Task Performance Metrics in Human-Robot Interaction: Taking a Systems Approach

Jennifer L. Burke, Robin R. Murphy, Dawn R. Riddle & Thomas Fincannon
Center for Robot-Assisted Search and Rescue
University of South Florida
Tampa, FL 33620

ABSTRACT

Performance metrics for human-robot interaction in urban search and rescue (USAR) are just beginning to appear in the literature as researchers try to establish a way of describing and evaluating human-robot task performance in this high-risk, time-critical domain. In this paper we propose that human-robot interaction metrics should focus on the work system as a whole, examining the robot's effects on human task performance within the overarching context of human work. Moreover, these effects should be examined within the context of real-time human performance in field settings, rather than in simulation or experimental environments. This position stems from a basic assumption that we are interested in measuring human-robot interaction in USAR because we want to see how it affects and aids human performance in this time and safety-critical environment. We present a methodology for collecting data in the field and subsequent analysis using the Robot-Assisted Search and Rescue Coding System (RASAR-CS), specifically developed for this domain. The RASAR-CS allows us to capture 1)basic verbal and non verbal communications describing the task and how it is accomplished (what is being said, by who to whom); 2)situation awareness information requirements (from the robot and other sources) - for developing and maintaining situation awareness, including the ability to capture changing requirements over time; 3)team processes enabling coordinated activities, efficient communication and strategy planning; and 4) human-robot interaction in terms of: robot-operator initiated robot activities, and physical interaction with robot.

KEYWORDS: *human-robot interaction, performance metrics, field methodologies*

1. INTRODUCTION

Human-robot interaction in the Urban Search and Rescue (USAR) domain is a field of study that has drawn increasing interest in light of the use of robots at the World Trade Center [5] and its designation as a benchmark domain in the seminal DARPA-NSF study on Human-Robot Interaction conducted in 2001 [2]. Performance metrics for human-robot interaction in USAR are just beginning to appear in the literature as researchers try to establish a way of describing and evaluating human-robot task performance in this high-risk, time-critical domain. In the afore-mentioned DARPA-NSF study, simple base measures were proposed: the ratio of persons to robots (h-r ratio), spatial relationships (commander, peer, teleoperator, developer) and authority relationships (supervisor, operator, peer and bystander). Some of the metrics proposed subsequently focus on aspects of the robot system exclusively, (e.g., the interface) or on aspects of human performance solely in relation to working with the robot [8, 9, 14]. In this paper we take a more human-centric position: human-robot interaction metrics should focus on the work system as a whole, examining the robot's effects on human task performance within the overarching context of human work. This position stems from a basic assumption that we are interested in measuring human-robot interaction in USAR because we want to see how it affects and aids human performance (ultimately, that is the goal for measuring human-robot interaction in any work-related field or application).

1.1 *Field Studies in USAR*

Field studies conducted with rescue workers offer the most valid setting in which to study human-robot interaction. USAR is an established work environment offering opportunities to study the effects of introducing robotic technology into a workplace and occupation with existing goals, tasks and processes. It is arguably one of the first workplace applications where robots work in the same spaces with people whose jobs do not normally involve robotics to perform a task (Industrial robots are usually separated from humans, and are not mobile). Moreover, robots have been used in real disaster responses, and are gradually becoming incorporated into USAR training both nationally and internationally. Real-time high fidelity training exercises are conducted regularly in order for USAR task force members to attain or maintain certification; these exercises offer a double advantage for studying HRI in that the targeted end-users may be observed performing in realistic work environments. USAR task forces can be characterized as extreme teams [11] who function in dynamic, high risk, time critical environments. Team members must function in conditions which are often physically, mentally and emotionally taxing. Field studies with participants who are truly representative of this user group for whom the technology is being optimized offer the most power in terms of generalizability.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2004**	2. REPORT TYPE	3. DATES COVERED **00-00-2004 to 00-00-2004**

4. TITLE AND SUBTITLE **Task Performance Metrics in Human-Robot Interaction: Taking a Systems Approach**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of South Florida,Center for Robot-Assisted Search and Rescue,Tampa,FL,33620**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Proceedings of the 2004 Performance Metrics for Intelligent Systems Workshop (PerMIS ?04), Gaithersburg, MD on August 24-26 2004

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1.2 *Focusing on Human Performance*

Measures of human-robot interaction in USAR must focus on human performance. The current state of the practice in robot-assisted search and rescue is teleoperation. Though autonomous and semi-autonomous robots may soon be entering the workplace, they will still be machines designed to perform tasks as determined by a person. Robots are not conscious, they have no projects of their own other than those assigned to them. Clancey [7] points this out to illustrate that it's too soon to talk about human-robot cooperation or collaboration: instead, robots serve as assistants to people working toward a project goal. Therefore the measure of a robot's usefulness, efficiency and functionality is based solely on whether it contributes to helping a person (or team) accomplish a goal by making that person's or team's task performance more efficient, effective, or easy in some way. This means measuring human performance (aided by robots) is the key. This is different from the position taken in Drury et al. [9] that usability requirements, which focus primarily on the robotic system, are the most appropriate way to measure human-robot interaction. We believe human-robot systems must be examined and measured in terms of their effect on human performance, since that is what they are designed to augment or improve.

What are the criteria for measures of robot-assisted human performance in USAR? In this domain there are established goals: search, rescue (extrication), structural evaluation, medical assessment & treatment, information transfer, command & control, and logistics. Blitch [1] pointed out the potential applications of robots in tunnel and confined space search: now, it is evident that there are many more tasks in which robots may play a part in USAR, e.g. medical reachback, shoring, communications & information transfer, and safety monitoring. Past experience shows that new technologies evolve when they reach the workplace, and many times end up performing tasks or serving purposes for which they were not originally intended. What we can do is identify tasks as they emerge, study the human-robot interaction processes and determine optimal task allocation and roles, understanding that this is an iterative process that will change as the technology advances. Based on these tasks, we can measure human-robot performance both individually (one person operating a robot) and in teams (more than one person operating a robot or robots).

Our field research has shown that situation awareness and team processes are two constructs which relate to human performance when working with robots [3, 5, 6]. Situation awareness (SA) as defined by Endsley [10] is "…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p. 97). Our studies have shown situation awareness to be related to performance and that most of the operators' time is spent gathering/maintaining situation awareness [3, 4]. Operators with high situation awareness ratings were better performers in our study of 28 robot operators [4]. Team processes are also related to operator performance; operators who talked more with their teammates about goal-directed aspects of the task had higher situation awareness ratings and found the victim more often. There is an interactive affect between situation awareness and team process—suggesting operators who talk more with their tether manager or teammate are better at building a mental model of the robot as it functions in the void space, and also are better at building a shared mental model of the search. Research on teams and mental models has suggested that having a shared mental model of the problem space can increase situation awareness and team performance [11, 16]. Effective planning and communication strategies were found to increase team shared mental models and correspondingly team performance. Therefore, human-robot interaction in USAR needs to be measured not only at the individual level, but also at the team level.

2. METHODOLOGY

In this section we present our methods of field data collection and data analysis, including a description of the Robot-Assisted Search and Rescue Coding System (RASAR-CS).

2.1 *Data Collection in the Field*

Data collection is an observational procedure, where the researcher is present during the user-robot interaction, though not an active participant. We tape the interaction using 2-4 cameras depending on the environment (Table 1). Minimally, one camera records the robot's eye view directly from the operator control unit (OCU), and a second camera records the operator (making sure to have a clear view of the face) as she works with the robot. When environmental conditions permit, we set up a third camera on a tripod to record the operator's hands manipulating the OCU, and a fourth camera to record an external view of the robot when available. Depending on the environment and the number of personnel available for the data collection process, some cameras may be fixed on tripods; however, in USAR conditions, most of the time views 2-4 must be handheld due to lack of level spots for setting up a fixed camera. Video recordings of the operators manipulating the robot, the robot's eye view, and the available external views are edited and synchronized to create tapes with 2 views side-by-side. These videotapes are then used to code statements and gestures made by both the operators and surrounding personnel, and robot movements. Trained raters code the videotapes using the Noldus Observer Video-Pro [13] observational coding software.

Camera No.	View	Setup
1	Robot's eye view	Attached to OCU
2	Operator view	Tripod or handheld
3	Operator-OCU view	Tripod or handheld
4	Robot-external view	Tripod or handheld

Table 1. Camera views for human-robot interaction field research in USAR.

2.2 *Video-based Interaction Analysis*

What, then, are some appropriate measures and metrics for USAR human-robot interaction? Primary human performance outcome measures for search at the most basic level include: Was a victim found, how long did it take, were any victims missed, were important cues noticed (heat, color, objects, information synthesis with knowledge about the event & environment)? Other measures that are related to these primary outcomes specifically measure situation awareness and team processes. These measures are gathered via a video-based Interaction Analysis technique for investigating HRI in rescue robotics. Interaction Analysis (IA) is an interdisciplinary approach to studying the interaction of humans with each other and with objects in their environment. Jordan & Henderson [12] assert, "Video-based Interaction Analysis is a powerful tool in the investigation of human activity that is particularly effective in complex, multi-actor, technology-mediated work settings … It is currently undergoing a period of rapid development, driven, in part, by researchers' dissatisfaction with conventional methods, and in part by the ubiquity of video equipment." (p.44)

The goal of Interaction Analysis is to identify regularities in the ways in which participants utilize the resources of the complex social and material world of actors and objects within which they operate. To do this we must examine two components of IA, which are intertwined, but distinct as well: human-human interaction, and human-object interaction. Interaction Analysis assumes that knowledge and action are fundamentally social in origin, organization, and use. Knowledge is seen as located in the interactions between people engaged with the material objects in their surroundings; therefore communication analysis plays an important role in Interaction Analysis as a means of analyzing human-human interactions.

Although variety of approaches to examining communication, we chose the FAA's Controller-to-Controller Communication and Coordination Taxonomy (C^4T) [15] framework as the starting point for the development of our communication analysis system designed to assess HRI in rescue robotics. The C^4T uses verbal information to assess team member interaction from communication exchanges in an air traffic control environment. We used the C^4T model because it captures the "how" and "what" of team communication by coding form, content and mode of communication. Our goal, however, is two-fold, not only to capture the "how" and "what" of USAR robot operator teams, but also the "who", and to capture observable indicators of robot operator situation awareness. In addition, in order to adhere to the tenets of IA, the framework must be extended to include examination of physical interactions with the robot system(s) in the environment.

2.3 *Robot-Assisted Search and Rescue Coding System (RASAR-CS)*

A methodology to capture and assess robot assisted task performance in rescue robotics must consider both human team member interactions (robot operator and other team members), and human – robot interactions. To meet the goals of a methodology capable of defining robot assisted tasks, and examining SA and teamwork defined earlier, we developed the Robot-Assisted Search and Rescue Coding System (RASAR-CS). The RASAR-CS captures *Basic verbal and non verbal communications* describing the task and how it is accomplished (what is being said, by who to whom); *Situation Awareness Information requirements* (from the robot and other sources) - for developing and maintaining situation awareness, including the ability to capture changing requirements over time; *Team processes* enabling coordinated activities, efficient communication and strategy planning; and Human-Robot interaction in terms of: *Robot-operator initiated robot activities, and Physical interaction with robot.*

Following the Interaction Analysis approach, the RASAR-CS consists of four main coding components enabling analysis of SA and team factors through human-human interaction and human robot interaction. These components include verbal communication, communication medium, nonverbal interaction and robot movements.

2.3.1 Human-Human Verbal Communication

The verbal communication analysis codes team member statements across four categories: 1) Speaker-recipient dyad - who is speaking to whom, 2) Content or topic of the communication 3) Statement form or grammatical structure of the communication, 4) Function or intent of the communication (Table 2). By examining dyad, content, and form, we can examine task procedures and team coordination. Similarly, content and function provide indicators of operator situation awareness.

Speaker-recipient dyad. Based on review of the search task videotapes, potential conversants included the operator, tether manager, team member, the group, and the robot specialist/researcher. Dyad codes indicate the speaker, followed by the recipient. For example, "operator-tether manager" indicates a statement was made by the operator

Category	Subcategories	Definitions
Human-Human Verbal Communication		
Sender/Recipient Dyad	Operator-tether manager	Operator: individual teleoperating the robot
	Tether manager-operator	Tether manager: individual manipulating the tether and assisting operator with robot
	Team member-operator	Team member: one other than the tether manager who is assisting the operator (usually interpreting)
	Operator- team member	
	Researcher-operator	Researcher: individual acting as scientist or robot specialist
	Operator-researcher	
	Other-operator	Other: individual (not tether manager, team member, or researcher) interacting with the operator
	Operator-other	
	Operator-group	Group -set of individuals interacting with the operator
Content	Robot state	Robot functions, parts, errors, capabilities, etc.
	Environment	Characteristics, conditions or events in the search environment
	Information synthesis	Connections between current observation and prior observations or knowledge
	Robot situatedness	Robot's location and spatial orientation in the environment; position
	Victim	Pertaining to a victim or possible victim
	Navigation	Direction of movement or route
	Search strategy	Search task plans, procedures or decisions
	Off task	Unrelated or extraneous subject
Statement Form	Question	Request for information
	Instruction	Direction for task performance
	Comment	General statement, initiated or responsive, that is not a question, instruction or answer
	Answer	Response to a question or an instruction
Function	Non-operator	Default for statements made by individuals other than the operator
	Seek information	Asking for information from someone
	Report	Sharing observations about the robot, environment, or victim
	Clarify	Making a previous statement or observation more precise
	Confirm	Affirming a previous statement or observation
	Convey uncertainty	Expressing doubt, disorientation, or loss of confidence in a state or observation
	Plan	Projecting future goals or steps to goals
	Provide information	Sharing information (other than *report*) in response to a question or offering unsolicited information
Team Communication	Coordination	Team members coordinate actions to synchronize specific proximal task activities
	Planning	Planned strategies for future goal accomplishment
Source of Information used in discussion	Audio	Verbal information or information from previous dialog
	Visual image	Robot image or information from image provides the basis for statement
	Sensor	Sensor or information from sensor provides the basis for statement
Human-Robot Interaction (Nonverbal interaction via the robot)		
Physical orientation	Ear to robot	Ear is directed toward the robot
	Eye to robot	Turning so that the human looks at the robot
	No verbal communication	No verbal communication with the operator
Gestures	Come forward	Motioning toward the robot to move forward
	Thumbs up	Closing the fist with the thumb extended upward
	Stop	Holding up a hand with the palm toward the r
	Pointing	Using fingers to point in a particular direction or at a specific object
	"OK" sign	Closing the thumb and forefinger in a circle indicating the "OK" sign
	Other	Other gestures (usually conversational with no intended message)
Interaction with Robot	Clean lens	Cleaning the robot camera lens
	Move/shift	Altering the position of the robot
	Pick up	Lifting the robot off the surface upon which it is moving
	Other	Other physical contact with the robot
Robot Movement	Moving	Forward or backward locomotion
	Stationary	No movement at all
	Panning	Rotating side to side without forward movement, or manipulating the camera lens up/down

Table 2. RASAR-CS (for USAR search task)

and directed toward the tether manager (Note: the code "tether manager – operator" indicates the tether manager initiated the communication with the operator).

Content. Seven elements representing the content were generated: 1- Statements related to robot functions, parts, errors, or capabilities (Robot state), 2- Statements describing characteristics, conditions or events in the search environment (Environment), 3- Statements reflecting associations between current observations and prior observations or knowledge (Information synthesis), 4- Statements surrounding the robot's location, spatial orientation in the environment, or position (Robot situatedness), 5- Indicators of direction of movement or route, (Navigation), 6- Statements reflecting search task plans, procedures or decisions (Search Strategy), and finally 7- Statements unrelated to the task (Off Task). The first four content elements are relevant to building and maintaining SA in search operations, while the elements of navigation and search strategy require SA.

Form. Similar to the C^4T taxonomy, the form category contains the elements: 1- Question (request for information), 2- Instruction (direction for task performance), 3- Comment (general statement, initiated or responsive, that is not a question, instruction or answer) and 4- Answer (response to a question or an instruction).

Function. Function refers to the intent of the communication - elements include: 1- Seek information (asking for information from someone), 2- Report (sharing observations about the robot or environment), 3- Clarify (making a previous statement or observation more precise), 4- Confirm (affirming a previous statement or observation) 5- Convey uncertainty (expressing doubt, disorientation, or loss of confidence in a state or observation), 6- Plan (projecting future goals or steps to goals), 7- Provide information (sharing information other than that described in report, either in response to a question, or offering unsolicited information).

The function elements of reporting and providing information merit explanation, as they appear very similar. Reporting involves perception and comprehension of the robot's state or situatedness, the environment or information synthesis. Any other information shared by an operator, in answer to a question or on his own, is classified as providing information (for example search strategy or navigation). Indicators of SA are captured in the function category primarily through the elements reporting and planning. When operator shares information (reports) based on the robot's eye view, we can infer the first two levels of SA, perception and comprehension, have taken place. The third SA level, planning and projection, is captured in the function category as the element "plan."

2.3.2 Team

Communication. Team communication offers insights into how goals are accomplished. Categories include: 1- Coordinating activities (to synchronize specific proximal task activities) and 2- Planning (for future goal accomplishment).

Medium. Team communication is also coded according the medium used to in conveying information: 1- Visual (visual image provided the foundation for the communication), 2- Auditory (verbal information provided the foundation for the communication), and 3- Sensor (sensor provided the foundation for the communication).

2.3.3 Human – Robot Interaction

Nonverbal interaction with robot. Nonverbal HRI includes nonverbal communication between humans via the robot camera, and physical interaction of humans with the robot. When robots are co-located with humans, humans physically orient to the robot and use gestures when communicating with the operator in control of the robot. Additionally, humans have the ability to physically touch or interact with the robot to cooperatively accomplish goals. The three main nonverbal categories include: physical orientation, gestures, and physical interaction with co-located robot.

Physical orientation. Physical orientation includes positioning the body during communication with the robot operator so that the 1- Ear is directed toward the robot (ear to robot), and 2- Turning so that the human looks at the robot (eye to robot).

Gestures. Again, while communicating with the robot operator, gesture can be used to convey meaning to the operator via the robot camera. Gestures include: 1- Come forward (motioning toward the robot to move forward), 2- Pointing (using fingers to point in a particular direction or at a specific object), 3- Thumbs up (closing the fist with the thumb extended upward), 4- Stop (holding up a hand with the palm toward the robot), and 5- OK (closing the thumb and forefinger in a circle indicating the "OK" sign).

Physical Interaction with Robot. Physical interaction codes include: 1- Clean lens (cleaning the robot camera lens), 2- Move/shift (altering the position of the robot), and 3- Pick up (lifting the robot off the surface upon which it is moving).

Robot Movement. The three major robot movement coding categories of the RASAR-CS include: 1- Moving (traveling forward or back), 2- Stationary (no movement at all) and 3- Panning (turning from side to side without forward or backward movement).

3. CONCLUSIONS

We have presented a field methodology for examining human-robot interaction in USAR which focuses on robot-assisted human performance. Using a video-based Interaction Analysis technique, we examine both human-

human interaction and human-robot interaction with measures designed to capture performance of human-robot systems. The Robot-Assisted Search and Rescue Coding Scheme enables us to

- *Examine archival videotaped data*. Video data involving users provides a richness of information that we previously had no established means of harvesting.
- *Decompose novel robot assisted tasks.* Understanding how USAR personnel use robots to accomplish tasks provides the foundation for developing a model of robot assisted task performance, which can be used for defining best practices and generating field training.
- *Identify task specific SA requirements* and effective *modalities for information transfer* among team members for use in system design (e.g., operator control unit interfaces, and web pages for remote team members).
- *Evaluate requirements for team performance* such as shared mental models, coordination of activities, and patterns of cooperative behavior.
- Obtain *quantifiable SA and team data* for evaluating effective performance.
- *Adapt and respond to changing task and technology requirements*. The RASAR-CS can be reconfigured to meet needs of various tasks and to be responsive to changes in technology as advances in robotics occur.

The RASAR-CS allows researchers to decompose both human-robot and human-human interaction in a meaningful way to define robot assisted task performance including task procedures, situation awareness requirements, and team process and coordination. The system can be applied across tasks and domains by utilizing the procedures outlined for modifying the relevant codes. In assessing complex environments it is important to use multiple methods of assessment. The RASAR-CS is an effective methodology to add to researchers' HRI toolkit for analysis of archival videotapes of field data, or used as a complement to other techniques, e.g. onsite expert ratings of situation awareness and team process, self ratings of situation awareness and team process, and user ratings of traditional evaluative components (usefulness, ease of use, effectiveness, satisfaction) for using the robot.

4. References

[1] Blitch, J. G. (2002). Robot intelligence for tunneling and confined space search and rescue. In *Performance Metrics for Intelligent Systems Workshop*, 2002.

[2] Burke, J., Murphy, R.R., Rogers, E., Scholtz, J., and Lumelsky, V. (2004). Final report for the DARPA/NSF interdisciplinary study on human-robot interaction. *IEEE Systems, Man and Cybernetics Part C, 34*(2), 103-112.

[3] Burke, J., Murphy, R.R., Coovert, M., Riddle, D. (2004). Moonlight in Miami: An ethno-graphic study of human-robot interaction in USAR. *Human-Computer Interaction, special issue on Human-Robot Interaction, Volume 19, Nos. 1-2*, 85-116.

[4] Burke, J. & Murphy, R.R. (2004). Report on the 2002 Connecticut Field Exercise. Center for Robot-Assisted Search and Rescue Technical Report.

[5] Casper, J. & Murphy, R. (2002). Workflow study on human-robot interaction in USAR. *Proceedings of the 2002 International Conference on Robotics and Automation* (pp. 1997-2003). Piscataway, NJ: IEEE Press.

[6] Casper, J. & Murphy, R. (2003). Human-robot interactions during the robot-assisted search and rescue response at the World Trade Center. *IEEE Transactions on Systems, Man and Cybernetics, Part B, 33*(3), 367 -385.

[7] Clancey, W.J. (2004). Roles for agent assistants in field science: Understanding personal projects and collaboration. *IEEE Systems, Man and Cybernetics Part C, 34*(2), 125-137.

[8] Drury, J., Riek, L., Christiansen, A., Eyler-Walker, Z., Maggi, A., Smith, D., (2003). Evaluating human-robot interaction in a search-and-rescue context. In *Performance Metrics for Intelligent Systems Workshop*, 2003.

[9] Drury, J.L., Scholtz, J. & Yanco, H.A. (2003). Beyond usability evaluation: Analysis of human-robot interaction at a major robotics competition. *Human-Computer Interaction, special issue on Human-Robot Interaction, Volume 19, Nos. 1-2*.

[10] Endsley, M. (1988). Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors Society 32nd Annual Meeting, 1*, (pp. 97-101). Santa Monica, CA: Human Factors Society.

[11] Jones, H. & Hinds, P. (2002). Extreme work groups: Using SWAT teams as a model for coordinating distributed robots. *Proceedings of the CSCW 2002 Conference on Computer Supported Cooperative Work* (pp.372-381). New York: ACM.

[12] Jordan, B. & Henderson, A. (1995). Interaction analysis: Foundations and practice. Journal of the Learning Sciences, 4(1), 39-103.

[13] Noldus, L., Trienes, R., Hendriksen, A., Jansen, H. & Jansen, R. (2000). The Observer Video-Pro: new software for the collection, management, and presentation of time-structured data from videotapes and digital media files. *Behavior Research Methods, Instruments & Computers, 32*, 197-206.

[14] Olsen, D.R. & Goodrich, M.A. (2003). Metrics for evaluating human-robot interactions. In *Performance Metrics for Intelligent Systems Workshop*, 2003.

[15] Peterson, L., Bailey, L., & Willems, B. (2001). *Controller-to-controller communication and coordination taxonomy (C^4T).* (DOT/FAA/AM-01/19). Department of Transportation, Federal Aviation Administration, Office of Aerospace Medicine, Washington, D.C.

[16] Prince, C. & Salas. E. (2000). Team situation awareness, errors, and crew resource management: Research integration for training guidance. In M. Endsley & D. Garland (Eds.), *Situation Awareness Analysis and Measurement*, (pp. 325-347). Mahwah, NJ: Erlbaum.