Graphical Narrative Interfaces: Representing Spatiotemporal Information for a Highly Autonomous Human-Robot Team

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***Abstract*— Having a well-developed Graphical User Interface (GUI) is often necessary for a human-robot team, especially when the human and the robot are not in close proximity to each other or when the human does not interact with the robot in real time. Most current GUIs process and display information in real time, but the time to interact with these systems does not scale well when the complexity of the displayed information increases or when information must be fused to support decision-making. We propose a new interface concept, a Graphical Narrative Interface (GNI), which presents story-based summaries driven by accumulated data. We hypothesize that the GNI allows users to search and analyze spatiotemporal information more easily and quickly than a typical GUI. This paper (a) uses literature and preliminary GNI designs to identify a set of design requirements and (b) develops a conceptual GNI implementation that satisfies these requirements.**

I. Background

Human-robot teams flourish in many different fields and are used for diverse purposes[5][10][31], but the methods of communication between humans and robots differ across applications[41]. Humans and robots may communicate through gestures, voice, sounds, or computer graphics. Since the best combination of these elements depends on the specific application, it is useful to introduce the application scenario that is the focus of this paper:

An automated rover is placed on another planet. Astronauts are supervising the rover from the planet's orbit. Information transmitted from the rover will arrive at the ground base on earth after passing through the orbiter occupied by the astronauts. The rover is used to surveil potential antenna sites and to prepare the ground for an eventual extra vehicle geology expedition by astronauts. While the rover is executing a mission plan, various problems may occur: malfunctioning equipment, obstacles in the rover's path, communication loss, and so forth. Human users, both astronauts and members of the ground crew on earth, need to be aware of these situations and make adjustments to the plan so that the mission will be accomplished.

In the space-based application area described above, the robot will operate in a remote area, so having a GUI is a natural way (a) to represent spatiotemporal information obtained by the vehicle and (b) to enable the user to interact with this information to make sense of the remote environment.

Naturally, the best form of interaction depends not only on the application but also the capabilities of the robot. Teleoperation occurs when the robot has very low autonomy, but this form of interaction is inappropriate for a space-based application because of the potentially high time delays in communication. Supervisory control, by contrast, occurs when the robot is given sufficient autonomy to perform a suite of tasks under human supervision and is more appropriate for applications where time delays can occur[35].

Importantly, if the robot is capable of operating for periods of time without direct human input, the human has what Olsen has called *spare capacity* in which it is possible for a human to oversee multiple tasks[4][28]. One way for a human to use this spare capacity is to supervise multiple robots, which was how Olsen used it. Another way for the human to use this spare capacity, which is the focus of this paper, is for the human to manage a single robot but use that robot to perform a complicated task that requires many different subtasks to be performed, some by the human and some by the robot; NASA's Mojave Volatiles project is a good example[34]. This paper focuses on a single human user and a single robot for a mission that consists of multiple sequential tasks.

Although the robot can be "neglected" during periods of autonomous operation, robot performance and behavior eventually deviates from what is desired; how far it drops depends on the level of autonomy and the conditions of the environment. *Neglect time* has been defined as the expected amount of time that a robot can be ignored before its performance drops below a threshold[4]. *Interaction time*, the complement to neglect time, has been defined as the expected amount of time that a human must interact with a robot to bring it to an acceptable level of performance. Prior work has indicated that supervisory control in human-robot teaming benefits when the system is designed to increase neglect time and to decrease interaction time[4].

This paper assumes that the robot's autonomy is such that neglect time is fixed and, consequently, the paper discusses ways in which interaction time can be minimized. Decreasing interaction time can be beneficial for many problems, but most current GUIs do not directly address the interaction time problem because they are focused on real-time processing and control. This means that those interfaces are designed to display information when they obtain it, assuming that users would see the information immediately. This is a poor assumption for a human-robot team designed for the

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scenario described previously because, by design, the ability to neglect a robot while performing other tasks means that attention must be shared between multiple tasks, making it likely that changes in information may not be perceived or understood by the human manager[12][37]. Importantly, emphasizing interaction time opens up the possibility of applying the GNI concept to post-mission evaluation and problems associated with human-data interactions.

II. Solution Motivation

Although GUIs are designed to facilitate easy acquisition of situation awareness[8], they often fail to explicitly represent the mission-based narrative that is necessary for understanding how current data relates to previous observations and future objectives. This is especially true when there is a time gap between the display of information on the interface and the observation of the displayed information by the user. Metaphorically, the information displayed by a traditional GUI acts like a list; the GUI displays different kinds of useful information but fails to "gather up and make sense" of the information as a whole. Alarms[13], decision support systems[16], ecological displays[27], maps[24], change summaries [39], and other technologies can be used to make GUIs more effective, but we propose a more holistic approach.

For example, if an installed video camera on an automated rover stops working, a typical GUI might (a) display an alert or an alarm to explicitly let users know about the problem or simply (b) display a blank screen on the interface. The incident may be recorded in a log as well. Suppose that the camera failed for only a short period of time and quickly resumed working properly. It is possible and maybe even likely that the human missed the alarm because the user's attention was away from the interface when the incident happened and may be completely unaware of the incident until the log is reviewed as part of the mission debriefing. During the debrief, the user will find a record of the incident that the camera went off for a while and needs to figure out both why the incident occurred and what possible effects the incident had on the mission (e.g., was critical information missed).

The key observation from this example is that, although the GUI may provide cues intended to guide the human's attention in real time, it is ultimately the user's responsibility to recognize the problem, put it in context, and appropriately respond to it. The consequence of this is that users are forced to closely monitor robots during a mission to grasp the entire narrative "as executed" and handle all problems for which "as executed" behavior fails to match "as planned". Consequently, interaction time can be high because the human must mentally represent the mission-based narrative in order to gain situation awareness.

This paper attempts to design a new scheme that unifies and abstracts the data displayed on the interface to help the user grasp the entire narrative of the mission given that human attention must be shared between multiple tasks and mission elements. This research is particularly relevant given the state of literature: interface design and development are in transition from targeting low-autonomy robots to targeting high-autonomy robots. Increasing a robot's autonomy causes a change in the human role in a human-robot team[23][29]. Some interfaces designed for supervisory control tasks are connected to a data storage system that can retrieve data for later use [44]. Interestingly, simple playback of the old information may not help much [26]. Similarly, presenting data faster than real-time[18] to support human supervisors[2][17] may overwhelm users as they try to extract needed information.

A missing element of playback is that key information, like when and how the accident happened, requires the human to review the entire stored record. After action reviews or change summaries could potentially help[6][38] but are often used only after the execution of a mission is complete rather than during mission operation. One reason for this is the assumption that communication between humans and robots is one-way, meaning that robots throw a bunch of perceptual data at humans and leave it up to the users to interpret and understand what those data mean in the mission context. It is better (a) to have two-way interaction between data from robot and humans (similar to the way humans use two-way communication when they interact with each other) and (b) to present, explicitly, summary information that provides trends in the narrative. The concept GNI proposed in this paper attempts to do this.

III. Solution Approach

We propose a new interface concept that we call a Graphical Narrative Interface (GNI). The key GNI concept is, as the name indicates, narratives. Narratives have the potential to express dense information in a way that is easier for readers to understand than other methods. To understand the potential for including storytelling in the GNI, it is useful to understand the effectiveness of storytelling as a communication method[22][36][46].

A. Concept of Narratives

Worth says that " ... narrative is not merely a list or series of events or states of affairs, but there must be some sort of sequence of events, where the sequence minimally implies a temporal ordering"[46]. This "temporal ordering" also includes the manifestation of the connections of the events[47]. This means a narrative is not just a sequenced list of events like "*A*, *B*, *C*", but rather "*A* happened first, then caused *B* to happen. *D* was expected but *C* ended up happening because ..." Notice that the temporal ordering can include causality.

Characters and their roles also have important meanings[40]. The reader may better perceive the meaning of a narrative if it is told from different perspectives. For example, a story of the race of a hare and a tortoise can be told as follows: "The tortoise won the race because it persistently tried its best regardless of its inferiority in the physical ability". However, the same story can be viewed from another perspective: "The hare lost the race because it slept too long in the middle of the race." In a Human-Robot-Team (HRT), there are at least two characters: a human user and a robot. If there are people who work with the robot in the field, then they are also characters who appear in the narrative. Additionally, there may be multiple roles for human users: mission planner, robot controller, mission supervisor, data analysis, etc..

Another critical element of narratives is the degree of abstraction. When someone is asked about the content of a movie, the person would not take two hours to tell the entire story from beginning to end. Rather, the story is summarized. The length and the content of the summaries varies depending on the purpose[20]. Storytelling is a useful metaphor for understanding how to summarize a narrative since it is easy for storytellers to organize and share information like when, where, and what happened. It also helps listeners to understand what is being told.

The principles of narratives discussed above are 1) temporal ordering, 2) characters and roles, and 3) abstraction. Are these principles of narratives useful and helpful in a real situation where a HRT would be used? In other words, how can we effectively generate narratives out of the work of a HRT?

GNI design principles can be distilled from the literature on storytelling, specifically by techniques introduced in [42][43]. This literature suggests three essential elements for creating an effective narrative of a HRT mission: 1) *selecting data boundaries*, 2) *incorporating grammatical semantics*, and 3) *presenting results in a context appropriate for the story*. Selecting data boundaries means separating the mission into smaller segments and treating them as individual events. In our project, we treat each task that a robot has to perform as a single event. Introducing grammatical semantics means generating text that includes both information about events as well as the temporal order and causal connections between the events. Presenting results in an appropriate context means generating and displaying narratives at various degrees of abstraction and from multiple perspectives.

B. Narratives and Situation Awareness

There are a lot of similarities between narrative-based understanding and Endsley's conceptualization of Situation Awareness (SA). Endsley proposed that SA, a human's sense of what is going on in the world, consists of three elements[7]:

> ... 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.

Hone *et al.* simplified Endsley's definition of SA into three general questions: who is where, what are they doing, and what will they do[14]. These are the questions that the human users of automated robots would like to answer to evaluate the level of success of their missions.

Narratives give answers to these questions. Each narrative clearly states who the characters are because that is a basic requirement of a narrative[47]. When the abstraction level is high, a narrative should focused on a few key mission events, and this gives the user a brief understanding for the entire mission. When the abstraction level is low, a narrative should give detailed information about many different parts of the mission. Through temporal ordering, the user can a) learn the relationships and connections between events and b) derive the reason why things went a certain way and c) predict what may happen next.

C. Application and Design of an Interface

Given this understanding, it is necessary to determine how to apply the concept of a narrative to an actual interface design. We present details, operational definitions, and implementations of components of a prototype GNI in section IV. Here, we list two assumptions about the project domain and mission.

The first assumption is that the GNI will be designed to support an Unmanned Ground Vehicle (UGV). The mission of this field operation is for the UGV to traverse through some location and perform various tasks in a specified order. This problem domain suggests that the GNI will require some kind of map that displays the geographical information as well as some kind of a time indicator to represent event timing and sequencing [3][21][45].

The second assumption is that the GNI will use only graphical information and interaction through keyboard and mouse[30][35]. This means that we do not include sounds, haptic signals, or any other means of communication on our interface. We adopt the standard model-view-controller architecture for a graphical display [19] and include the ability to abstract and display abstractions derived from the model in the GNI.

In contrast to existing GUIs, the GNI focuses on automated data analysis and abstraction of data. This means that users mainly analyze and understand the data collected by the robot and make plans for the future, instead of controlling the actions of the robots throughout a mission. Naturally, the GNI should be able to process and analyze narrative summaries in real-time, and present these summaries in a format that allows the human to make inferences and decisions faster and better than they could do with a traditional GUI.

We distilled the narrative concepts and our assumptions about environment and mission into five implementation requirements:

1) The GNI should have a chat-like text console to display auto-generated narrative summaries.
2) The GNI should have the capability to generate narratives at various granularities.
3) The GNI should have a map and a time indicator to handle spatiotemporal information.
4) The GNI should maintain cohesion between components described in requirements 1 and 2.
5) The GNI should process and display data in real-time.

Note that the GNI is not a direct extension of a certain kind of research or study but, rather, the GNI is based on a collection and collaboration of several different ideas. This means that the idea of using a timeline, map, and chat window need not be new or novel, but using them to display narrative-based information in a coherent view is relatively new. Thus, the requirements to use a timeline, map, and chat window are obtained not from first principles but rather because these are the commonly used GUI elements for human supervisory control of a UGV such as those found in Goodrich[11].

IV. Implementation Guidelines

The structure of this proof-of-concept implementation of the GNI concept is based on the followings: *anytime summarization*, *storytelling*, and *multi-perspective analysis*. Since it can be argued that the GNI is a specialized type of the more general class of Graphical User Interfaces (GUI), it is useful to relate the standard model-view-controller[19] architecture from GUIs to the GNI design. We explain each in the following sections. Figure 1 displays the basic layout of the components of GNI.

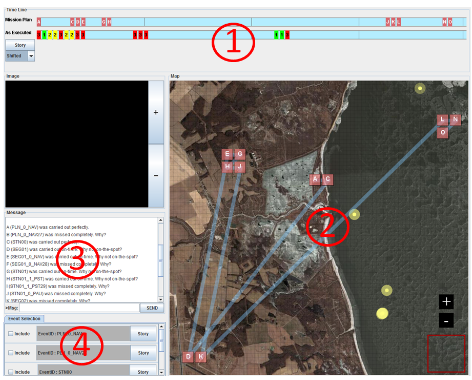

Fig. 1. Layout of components with example data

A. Anytime Sumamrization - Model

Anytime summarization is a concept proposed by Shreckenghost as a useful way to support a human operator who is interacting with remote robots, such as the mission described in Section I [33]. Anytime summarization provides users a provisional summary, perhaps in the form of mission-relevant metrics, of an in-progress mission[32]. Because of the provisional nature of the summary, it can be obtained at "any time." In terms of a narrative, an *anytime summarization embodies the metaphor of a plot summary*. The anytime summarization element of the GNI is designed to satisfy Requirement No. 5 from the list in the previous section.

We analyze the progress of a mission by comparing the mission plan and the actual data. This comparison may seem simple; however, there are many things to consider. There are various tasks to be performed in each mission, and for each task there are multiple categories of goals to be achieved. For example, if a task is to reach a certain point, the plan for the task should specify when the robot needs to be at the point and the specific information about the location. There may be additional requirements like places to avoid on the way to the designated location or a specific angle to reach the destination point. We compare each criterion like time, location, and other restrictions for the plan and the actual execution data to evaluation the degree of achievement of tasks. We need to have a scheme to select only the necessary information besides information abstraction.

From the model-view-controller perspective, the model for summarization requires algorithms that integrates data received by the GNI over time: a "block" structure and a graph structure. The fundamental representation of data used in this implementation of the GNI is an implementation of a "block," a formatted chunk of information, as described in [25]. A data table receives and sorts data blocks transmitted from the robot. The GNI creates narrative summaries out of the data stored in the table. We use a graph structure to create a set of narrative summaries on different criteria. A summary focused on the entire mission including all the types of information would be different from a summary that focused on a specific part of the mission with limited information types.

Note that the GNI concept is not without precedent; see Fiore's work on using narratives as the basis for coordinating among distributed teams [9][15]. These summaries are generated using automated data analysis algorithms at various granularities. This satisfies Requirement No. 2.

Processing time is an important factor in the concept of anytime summarization. The interface should be able to provide summarized data to the user whenever the user desires. Therefore, the difference in processing time for the GNI and a GUI which does not provide the narrative summaries should be minimized.

The GNI prototype was built from an existing interface called RESCHU[1]. We compared the interface execution times in two different ways: 1) the run time of the specific class that includes narrative summary generation algorithms, and 2) the time required for the whole interface to be ready.

We measure time for each interface described above ten times and calculated the average in seconds. There was a little difference in runtime of a class, but not significant (RESCHU: 0.1218 seconds, GNI: 0.1447 seconds). RESCHU runs faster since it does not generate a data table, analyze it, or produce narrative summaries. On the other hand, the total runtime for GNI was shorter than RESCHU, because some of the RESCHU functionalities were disabled in the GNI (RESCHU: 13.46 seconds, GNI: 12.53 seconds). From this result, we can conclude that the narrative generation does not take too long to process; this satisfies the requirement No. 5.

B. Storytelling - View

GUIs use various types of information-presentation methods to increase the user's SA. The problem of using lists, static images, and logical relations in a GUI is that these interface elements emphasize perception of elements but not comprehension or projection. These conventional GUI elements are forms of *one-way communication*; the system throws information at the user and it is the user's responsibility to give meaning and context to what is given. In order to increase the proficiency of the system, the user interface should allow not only more interactions between the data and the user, but also provide mission-based context for comprehending information and projecting information into the future. To achieve this, the GNI use storytelling.

The GNI prototype tells stories primarily using textual data implemented in a text box that satisfies Requirement No. 1 (component 3 in Figure 1). As we argued in sections III-A and III-B, well-constructed narratives include a temporal ordering and causality. This helps readers to understand and reason about the story line. Stories can be told through different types of information. Besides textual information, graphical aids can tell important important stories as well. These benefits might help human users to increase SA and help them understand what is happening and why it is happening.

The GNI prototype is also equipped with a map to display spatial information and a timeline to indicate temporal information; this satisfies Requirement No. 3 (components 1 and 2 in Figure 1). Each component is designed to tell narratives independently. They both have a capability to zoom in or out to achieve different degrees of abstraction. They both use icons with various shapes, colors, and symbols to indicate the results of analysis in such a way that the user can pick up the meaning of them at a glance.

C. Multi-Perspective Analysis - Controller

In the GNI model, a graph structure was used to associate different narrative summaries with different performance criteria. In this section, we discuss two features used to allow the human to control this portion of the model: *event selector* and *relation links*.

The event selector, component 4 in Figure1, lets the user to choose which events will be displayed or not. This feature allows a user to focus on a certain part of a mission or some specific types of events throughout a mission.

Relation links unify the icons and narratives on different components together. Each component of the GNI is designed to tell narratives on its own. Thus, users can obtain information-specific narratives just focusing on a single component. However, by referring to all the components and their narrative summaries, the user can obtain an understanding of the entire mission. When an icon or information about a task on timeline, map, or text box is selected, all the icons or information that represent the same task will be highlighted. This satisfies Requirement No. 4.

When the GNI displays information, the user can respond to it through various types of actions like selecting events, comparing icons on different components, or requesting more detailed information. For example, right-clicking on an icon on any component will pop up a new small window with detailed information about the event.This is achieves the two-way communication between the GNI and the user.

V. Conceptual Interaction

In this section, we present a conceptual interaction between the GNI and a user. Consider a GNI user who is both a mission manager and a scientist who wants to utilize the data obtained by the robot. The user uses the GNI to review a completed mission. Suppose that the objective of the mission is to explore a remote place by using an automated rover. The rover has a pre-programmed plan to traverse through way-points.

When the user requests an information about a mission, the GNI first presents a high-level summary of the entire mission on components 1 (timeline), 2 (map), and 3 (text box) in Figure 1. The user can request more detailed information on all or some selected components. The user also can select a certain amount of information using the component 4 (event selector) in Figure 1.

From a mission manager's perspective, the user may want to know the degree of mission completion. This includes how many way-points were successfully reached and how much time was spent on the entire mission. These kinds of general information are included in the narrative summaries so that the user may be able to grasp the overall achievement of a mission quickly. The user can request more detailed narratives to investigate if there were any minor problems such as short-term delays or unnecessary maneuvers.

From a scientist's perspective, it is beneficial to know whether planned experiments were performed as they should or the reason for failure, if any. To do this, the user can use the event selector. This component lets the user select only necessary events and eliminate others. Through this, the user can find the information of certain events quickly. Also, by clicking on an event icon, all other icons for the same event will be highlighted. Through this, the user can easily tell the planned and actual locations of the event on the map and the planned and actual execution time of the event on the timeline. By right-clicking on an event icon, more detailed information can be obtained.

VI. Conclusions

The prototype GNI satisfies the requirements given in Section III-C but much needs to be done. A conceptual interaction, derived from the MVP project [34], illustrated how the GNI could be used to provide meaningful information to the user. Future work includes a user study to explore how the GNI concept actually supports human users. Currently, the GNI is a proof of concept, meaning that future designs are likely to modify, delete, and add needed features.

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References

[1] Research enrivornment for supervisory control of heterogeneous unmanned vehicles (RESCHU). [Online]. Available: http://web.mit.edu/aeroastro/labs/halab/inventions.shtml

[2] J. Bruce and M. Veloso, "Real-time randomized path planning for robot navigation," in *Intelligent Robots and Systems, 2002. IEEE/RSJ International Conference on*, vol. 3. IEEE, 2002, pp. 2383–2388.

[3] J. W. Crandall and M. Cummings, "Developing performance metrics for the supervisory control of multiple robots," in *Proceedings of the ACM/IEEE international conference on Human-robot interaction*. ACM, 2007, pp. 33–40.

[4] J. W. Crandall, M. A. Goodrich, D. R. Olsen Jr, and C. W. Nielsen, "Validating human-robot interaction schemes in multitasking environments," *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, vol. 35, no. 4, pp. 438–449, 2005.

[5] T. Davies and A. Jnifene, "Multiple waypoint path planning for a mobile robot using genetic algorithms," in *Computational Intelligence for Measurement Systems and Applications, Proceedings of 2006 IEEE International Conference on*. IEEE, 2006, pp. 21–26.

[6] P. F. Drucker, *The practice of management*. Allied Publishers, 1975.

[7] M. Endsley, "Theoretical underpinnings of situation awareness: A critical review," *Situation awareness analysis and measurement*, pp. 3–32, 2000.

[8] M. R. Endsley, "Situation awareness global assessment technique (sagat)," in *Aerospace and Electronics Conference, 1988. NAECON 1988., Proceedings of the IEEE 1988 National*. IEEE, 1988, pp. 789–795.

[9] S. M. Fiore, R. McDaniel, and F. Jentsch, "Narrative-based collaboration systems for distributed teams: Nine research questions for information managers," *Information Systems Management*, vol. 26, no. 1, pp. 28–38, 2009.

[10] J. Gertler, "Us unmanned aerial systems." DTIC Document, 2012.

[11] M. A. Goodrich and A. C. Schultz, "Human-robot interaction: A survey," *Foundations and Trends in Human-Computer Interaction*, vol. 1, no. 3, pp. 203–275, 2007.

[12] J. G. Hollands and C. D. Wickens, *Engineering psychology and human performance*. Prentice Hall New Jersey, 1999.

[13] B. R. Hollifield and E. Habibi, *Alarm management: Seven effective methods for optimum performance*. ISA, 2007.

[14] G. Hone, L. Martin, and R. Ayres, "Awareness–does the acronym SA still have any value," in *Proceedings of the 11th International Command and Control Research and Technology Symposium: Coalition Command and Control in the Networked Era. held at Cambridge UK. Washington*, 2006.

[15] J. H. Johnston, S. M. Fiore, and R. McDaniel, "Applying the narrative form and xml metadata to debriefing simulation-based exercises," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 49, no. 25. SAGE Publications, 2005, pp. 2135–2139.

[16] P. G. Keen, "Decision support systems: the next decade," *Decision Support Systems*, vol. 3, no. 3, pp. 253–265, 1987.

[17] J. Kjeldskov, M. B. Skov, and J. Stage, "Instant data analysis: Conducting usability evaluations in a day," in *Proceedings of the third Nordic conference on Human-computer interaction*. ACM, 2004, pp. 233–240.

[18] G. Klein, R. M. Pliske, B. Crandall, and D. Woods, "Features of problem detection," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 43, no. 3. SAGE Publications, 1999, pp. 133–137.

[19] G. E. Krasner, S. T. Pope, *et al.*, "A description of the model-view-controller user interface paradigm in the Smalltalk-80 system," *Journal of object oriented programming*, vol. 1, no. 3, pp. 26–49, 1988.

[20] Y. Li, S.-H. Lee, C.-H. Yeh, and C.-C. Kuo, "Techniques for movie content analysis and skimming: Tutorial and overview on video abstraction techniques," *Signal Processing Magazine, IEEE*, vol. 23, no. 2, pp. 79–89, 2006.

[21] D. M. Mark, "Human spatial cognition," *Human factors in geographical information systems*, pp. 51–60, 1993.

[22] T. Matlock, "Fictive motion as cognitive simulation," *Memory & Cognition*, vol. 32, no. 8, pp. 1389–1400, 2004.

[23] J. McLurkin, J. Smith, J. Frankel, D. Sotkowitz, D. Blau, and B. Schmidt, "Speaking swarmish: Human-robot interface design for large swarms of autonomous mobile robots." in *AAAI Spring Symposium: To Boldly Go Where No Human-Robot Team Has Gone Before*, 2006, pp. 72–75.

[24] B. S. Morse, C. H. Engh, and M. A. Goodrich, "UAV video coverage quality maps and prioritized indexing for wilderness search and rescue," in *Proceedings of the 5th ACM/IEEE international conference on Human-robot interaction*, ser. HRI '10. Piscataway, NJ, USA: IEEE Press, 2010, pp. 227–234. [Online]. Available: http://dl.acm.org/citation.cfm?id=1734454.1734548

[25] T. Muramoto, "A proposal of a supporting method to implement an iterative multi-perspective story," Master's thesis, Tokyo University of Technology, Tokyo, Japan, 2008.

[26] C. W. Nielsen, "Using augmented virtuality to improve human-robot interactions," Ph.D. dissertation, Citeseer, 2006.

[27] C. Nielsen, M. Goodrich, and R. Ricks, "Ecological interfaces for improving mobile robot teleoperation," *Robotics, IEEE Transactions on*, vol. 23, no. 5, pp. 927–941, 2007.

[28] D. R. Olsen, Jr. and S. B. Wood, "Fan-out: Measuring human control of multiple robots," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '04. New York, NY, USA: ACM, 2004, pp. 231–238. [Online]. Available: http://doi.acm.org/10.1145/985692.985722

[29] R. Parasuraman, T. Sheridan, and C. D. Wickens, "A model for types and levels of human interaction with automation," *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on*, vol. 30, no. 3, pp. 286–297, May 2000.

[30] T. M. Rhyne, A. MacEachren, and T.-M. Rhyne, "Visualizing geospatial data," in *ACM SIGGRAPH 2004 Course Notes*. ACM, 2004, p. 31.

[31] J. Scholtz and S. Bahrami, "Human-robot interaction: Development of an evaluation methodology for the bystander role of interaction," in *Systems, Man and Cybernetics, 2003. IEEE International Conference on*, vol. 4. IEEE, 2003, pp. 3212–3217.

[32] D. Schreckenghost, T. Fong, T. Milam, E. Pacis, and H. Utz, "Real-time assessment of robot performance during remote exploration operations," in *Aerospace conference, 2009 IEEE*, 2009, pp. 1–13.

[33] D. Schreckenghost, T. Fong, H. Utz, and T. Milam, "Measuring robot performance in real-time for nasa robotic reconnaissance operations," in *Proceedings of the 9th Workshop on Performance Metrics for Intelligent Systems*, ser. PerMIS '09. New York, NY, USA: ACM, 2009, pp. 194–202. [Online]. Available: http://doi.acm.org/10.1145/1865909.1865950

[34] D. Schreckenghost, T. Milam, and T. Fong, "A perspective on human-robot interaction for nasa's human exploration missions," in *2014 AAAI Fall Symposium Series*, 2014.

[35] T. B. Sheridan, *Telerobotics, automation, and human supervisory control*. One Rogers Street Campbridge MA: MIT press, 1992.

[36] B. Shneiderman, "A taxonomy and rule base for the selection of interaction styles," *Human factors for informatics usability*, p. 325, 1991.

[37] D. J. Simons and R. A. Rensink, "Change blindness: Past, present, and future," *Trends in cognitive sciences*, vol. 9, no. 1, pp. 16–20, 2005.

[38] H. S. Smallman and M. John, "Naive realism: Limits of realism as a display principle," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 49, no. 17. SAGE Publications, 2005, pp. 1564–1568.

[39] H. S. Smallman and M. S. John, "Chex (change history explicit): New HCI concepts for change awareness," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 47, no. 3. SAGE Publications, 2003, pp. 528–532.

[40] M. G. Styles, S.-Y. Jung, C. Eto, and G. M. Draper, "An approach to hypertext fiction for mobile devices," in *Proceedings of the 2nd workshop on Narrative and hypertext*. ACM, 2012, pp. 1–6.

[41] S. S. Sundar, Q. Xu, and S. Bellur, "Designing interactivity in media interfaces: A communications perspective," in *Proceedings of the 28th international conference on Human factors in computing systems*. ACM, 2010, pp. 2247–2256.

[42] M. Theune, N. Slabbers, and F. Hielkema, "The narrator: NLG for digital storytelling," in *Proceedings of the Eleventh European Workshop on Natural Language Generation*. Association for Computational Linguistics, 2007, pp. 109–112.

[43] K. E. Thomas and S. Sripada, "Atlas.txt: Linking geo-referenced data to text for NLG," in *Proceedings of the Eleventh European Workshop on Natural Language Generation*. Association for Computational Linguistics, 2007, pp. 163–166.

[44] C. Wiecha, W. Bennett, S. Boies, J. Gould, and S. Greene, "ITS: A tool for rapidly developing interactive applications," *ACM Trans. Inf. Syst.*, vol. 8, no. 3, pp. 204–236, July 1990. [Online]. Available: http://doi.acm.org/10.1145/98188.98194

[45] M. F. Worboys, "A unified model for spatial and temporal information," *The Computer Journal*, vol. 37, no. 1, pp. 26–34, 1994.

[46] S. Worth, "Narrative knowledge: knowing through storytelling," *Furman University, Greenville, South Carolina*, 2006.

[47] S. E. Worth, "Storytelling and narrative knowing: An examination of the epistemic benefits of well-told stories," *The Journal of Aesthetic Education*, vol. 42, no. 3, pp. 42–56, 2008.