DESIGNING AND ASSESSING A MULTI-USER TABLETOP INTERFACE TO SUPPORT COLLABORATIVE DECISION-MAKING INVOLVING DYNAMIC GEOSPATIAL DATA

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ABSTRACT

Collaborative decision-making in maritime domain operations, such as port security and naval search and rescue, often requires access and sharing of rapidly changing geospatial information. This paper presents a novel digital tabletop application, called ASPECTS (Asset Planning Employing Collaborative Tabletop Systems), that enables a group of maritime domain personnel to interact with dynamic map data and related information in a rich face-to-face communications environment. The hardware platform, software architecture, and user interface of the ASPECTS system design are described, along with an initial usability study of the application. The results of the study revealed that the window management and interaction techniques provided by the ASPECTS system foster information sharing and workspace awareness during decision-making sessions. The study also revealed several limitations with the current application that are discussed, along with design issues warranting further study.

Keywords: co-located collaboration, interactive surfaces, pen-based interfaces, multi-user input, collaborative decision making, command and control

INTRODUCTION

Currently, there are two primary methods in which maps and other geospatial data are accessed and shared during collaborative decision-making tasks in land-based and ship-based maritime operations, such as port security, coastal and shipping lane patrol, or naval search and rescue. The traditional method is for personnel to gather around a paper-based map, potentially annotated with additional sensor data or intelligence information. The second method is for personnel to sit at individual workstations monitoring digital geospatial situation displays while commanders learn about the current situation status by walking around, talking over the shoulders of personnel or on a radio feed.

Each method has advantages and disadvantages. Gathering around a paper map provides decision-makers the benefit of physically shared communication references (the map, annotations on the map, etc.). This configuration facilitates the establishment and maintenance of common ground during discussions, and consequently, efficient communication [5]. Furthermore, the face-to-face arrangement of decision-makers around the map data provides an unobstructed view of the geospatial data as well as a rich non-verbal communication environment, both of which promote effective communication [26]. However, decision-makers must rely on static, potentially dated, information that may be incorrect or misleading and result in decision error.

When decision-makers are located at workstations displaying geospatial data that are dynamically updated in real-time, they can make more up-to-date, and ideally, more correct decisions. However, the physical configuration of decision-makers in this situation, where operators each look at different computer screens and sit with their backs to their commander, presents a more impoverished communications environment that can interfere with establishing common ground, and consequently lead to communication breakdowns [5]. In maritime operations, where life-critical decisions are often made under time pressure, such communication breakdowns can have dire consequences.

To explore the possibility of providing the benefits of both decision-making methods—that is, to provide a rich face-to-face communication environment that provides decision-makers access to dynamically updated geospatial and other important information—an application prototype was developed for an interactive, multi-user tabletop system in collaboration with a national defense research organization and an industrial partner (unnamed for blind review). The main objective of the project was to explore the use of a digital tabletop system to enable decision-makers to access and share geospatial and related data in the context of defense-based maritime operations. This domain context provided unique design requirements that influenced the choice of hardware platforms and user interface design, discussed in more detail below.

Before describing our application prototype, we first overview related work on tabletop systems that have been developed for maritime operations and other time-critical application domains. Next, we describe the system design, including the hardware platform, software architecture, and user interface. Finally, we present the results of a usability study conducted to evaluate the strengths and weaknesses of the application prototype design.

BACKGROUND

Horizontal display systems are not new to the maritime context. The Canadian Navy deployed the Automatic Data Link Plotting System (ADLIPS) on many of their ships from the late 1970’s to 1997 [8]. ADLIPS was a tactical display system consisting of a 20-inch horizontal cathode-ray tube (CRT) situation information display (SID), remote plasmas displays positioned elsewhere on the ship, and a hardcopy plotter [3, 8]. Around the horizontal SID were three operator stations that each had a separate trackball and keyboard for interacting with the geospatial maritime situation displayed on the SID. Though ADILPS provided a form of “tabletop” system, its separate input and output spaces were unable to provide the integrated or natural interaction environment that modern digital tables offer.

Research on modern tabletop systems in the context of military command and control and other time critical environments has thus far been limited. Through creation and testing of a digital sand table using Frustrated Total Internal Reflection (FTIR) technology [13], Szymanski et al. [27] showed that interactive tabletop computer systems could better support in-person collaboration in an Army environment, but that this support was hindered by the limitations of the specific technology used. Their tabletop platform was not able to uniquely identify users, nor was the orientation of the interfaces intuitive – two limitations addressed in our application prototype.

Dohse et al. [6] explored the use of a multi-touch table to enhance user interaction with defense-related data displays that integrated multiple information sources. Their work focused on the use of multi-touch tables within a virtual reality setting—not an ideal context for collaboration, as the goggles that are needed to view the virtual reality display limit eye contact, which is a critical factor in effective face-to-face communication [5, 26].

Tabletop systems have also been explored in other time-critical environments. Ashdown and Cummings [1] showed tabletop displays to be well-suited to task domains such as urban search and rescue, where large amounts of data need to be displayed and where any piece of the information may need to become the centre of the user's attention. While developing solutions to support flood disaster response operations, Nóbrega et al. [18] identified a need for large display systems to allow experts to work in a collaborative and co-located manner without the extensive programming skills currently required to view and understand flood data. They first developed an interactive whiteboard solution, and found the interaction possibilities significantly useful, but ultimately concluded that a tabletop system might provide better opportunities for improved interaction and collaboration among flood experts.

Tabletop computers have also been explored for less time-critical task domains involving geospatial data. Scotta et al. [24] compared three tabletop systems for geospatial data manipulation: a city planning table called Tangitable, a water management planning table called MapTable, and a map viewing table called TouchTable. Their study revealed that the user interface pertaining to the geospatial information had a significant impact on usability and is a key factor in the design of tabletop computer displays. Schoning et al. [21] have also shown that the user interface pertaining to geospatial information displays in tabletop systems can greatly affect the value of these information displays. Accordingly, a major focus of our work was to design an effective user interface for intuitive interaction with typical content and media used in maritime operations.

In summary, though there have been several initial explorations of tabletop computing technology in maritime and other time-critical domains, this research is still in its infancy. This project represents another step towards understanding the utility of tabletop computing technology for supporting collaborative maritime operations.

SYSTEM DESIGN

Our application prototype, called ASPECTS (Asset Planning Employing Collaborative Tabletop Systems), was designed to support modern naval mission scenarios involving cooperative decision making around maritime geospatial situation data. An operations team using the application interface could either be located at a land-based or ship-based operations centre equipped with a tabletop computer. The remainder of this section details the design of the hardware, software and user interface components of the ASPECTS application prototype.

Tabletop Hardware Platform

ASPECTS was designed to run on a custom-built, top-projected Anoto-based tabletop computer hardware platform [11, 12]. This tabletop hardware platform enables user interaction using the Anoto digital ink pen technology, which allows any flat surface to be turned into an interactive computer surface through the use of four main components:

- a sheet of paper printed with a fine grid containing Anoto's proprietary dot-pattern,
- a computer with a Bluetooth receiver,
- a projector connected to the computer, and
- an Anoto pen, which determines its precise position on the paper by reading the unique dot-pattern using a tiny on-board camera, and streams its position data to the computer in real-time via Bluetooth protocol.

The Anoto-based tabletop hardware platform was selected over more common multi-touch vision-based tabletop platforms, such as FTIR [13] or Diffuse Illumination [20], as it provides the following desired system capabilities for the task domain:

- supports multiple, co-located users interacting with the system simultaneously, achieved by tracking multiple Anoto pens simultaneously,
- supports operators located at any position around the table, achieved by the wireless tracking of the Anoto pens via Bluetooth,
- supports user interaction on a horizontal surface from all sides, by placing the Anoto paper on a table,
- allows distinct operator roles and corresponding security levels, achieved by correlating roles to the unique serial number extracted from the tracked data of each Anoto pen, and
- allows fine-grained input control, utilizing Anoto pens' stylus-tip accuracy (tracking resolution of 0.03mm[1]), together with a tiled, dual-projector system providing 1536x1024 pixel resolution.

In brief, the Anoto-based hardware platform provides the necessary features to enable the types of user interactions identified in naval mission scenarios. Moreover, building an Anoto-based tabletop system is relatively low-cost and low-effort, compared to many alternative tabletop hardware platforms; any tabletop surface can be easily turned into an interactive tabletop with a sheet of Anoto paper, a top projection set-up, and an optional sheet of plexiglass for protecting the paper from damage due to repeated use.

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[1] http://mi-lab.org/products/interactive-surface-kit/

Software Architecture

ASPECTS was developed using the Windows Presentation Foundation software development framework and the C# object-oriented programming language. Our industry partner’s geospatial visualization engine (name removed for blind review) was used for visualizing map data in the user interface. The prototype runs on the Windows XP operating system.

Figure 1 shows a high level system overview of the ASPECTS software architecture. This diagram illustrates the dependencies of the ASPECTS software with other technologies, including:

- a simulation engine (Data Simulator) provided by our defense collaborator that supplies the vessel location data visualized in the user interface,
- the InterMAPhics library that provides support for map visualization and vessel information management,
- the Windows XP operating system that provides basic input/output events, and
- the Anoto-based digital pen technology that provides positional and identity data for the Anoto pens.

User Interface

The ASPECTS user interface was designed to provide multi-user access to mission information during typical naval mission operations. The concept behind the ASPECTS interface is to have a basic map display system, enabling the display and editing of naval vessel information, and supporting data input from an arbitrary data source, such as a data simulator. Relevant maritime data, such as historical ship trajectory information and intelligence reports are also provided in the interface.

Figure 2 shows the user interface of the application prototype. Windows responding to touch and drag actions are used to display system data.

The ASPECTS interface provides a number of interaction and interface components optimized for collaborative use on a tabletop workspace. Specifically, the user interface enables simultaneous use by multiple people, each of whom may have different roles or security levels in the context of the mission operations supported by the system. The interface also enables 360-degree use, in which multiple users can interact from any side of the tabletop workspace. Finally, data access in the interface is simplified through spatial organization of data access points. The following sections describe the interface components and functionality that enable these capabilities.

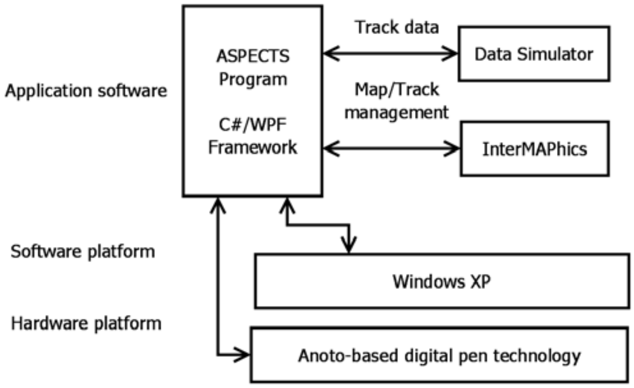

Figure 1. A high-level overview of the ASPECTS software architecture.

Multi-user Support

In order to accommodate multiple users who may interact with the system from different sides of the table, the interface content is provided in individual windows which can be easily repositioned to accommodate a number of users at different locations around the table. The map windows can also be resized to accommodate personal or shared use of the geospatial data. Also, the interface enables simultaneous user interaction, thus allowing users to work in parallel. When combined, these features allow individual and shared use of the system by multiple users.

Per User Interface Tailoring based on Security Level

In addition to supporting multiple users, the unique pen tracking provided by the Anoto technology enables the system to tailor the interface’s response to each user’s pen, based on an associated user profile. In the ASPECTS interface, this distinct user information is used to associate a particular security level to each pen, thus regulating access to certain system capabilities. For example, Figure 3 shows two different menu configurations provided to two users with different security levels: one user has access to more system features than the other, such as the ability to add a new “track”, or ship, to the maritime situation. Though security level is used in this application, this information could easily be mapped to other distinct user characteristics, such as task role or preference [19].

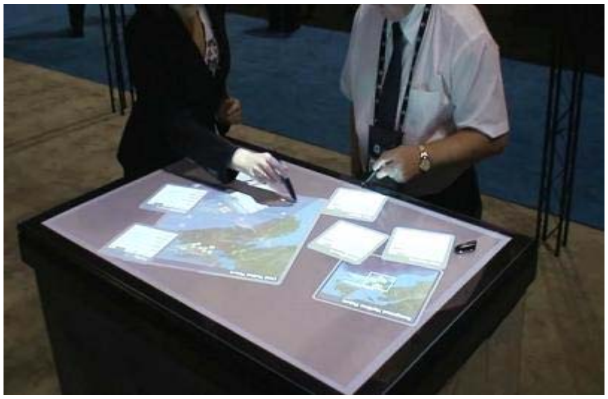

Figure 2. The ASPECTS application prototype running on a pen-based tabletop system.

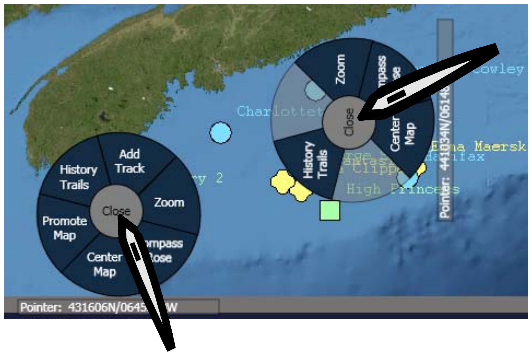

Figure 3. Interface tailoring for users with different security levels (left pen has higher security level than right pen, thus having more capabilities). Pop-up menus are automatically oriented toward the table edge associated with the activating pen.

360-degree, Collaborative Interface

ASPECTS also provides a number of window management techniques to better support collaborative interactions at a large, horizontal tabletop computer. As shown in Figure 4, any interface window can be easily rotated to enable interface content to be viewed from any angle around the table using the simple touch and drag Rotate ‘N Translate (RNT) interaction technique [16].

The RNT interaction is accessible through touching and dragging the border of each window. Though providing RNT-type orientation support across the entire interface component is common [e.g., 22, 28], this interferes with the ability to interact with window contents such as the map or information tabs. The contents of the windows provide access to spatially organized data, as described below, and this access to data took precedence over RNT inside the window.

The ASPECTS interface also provides some automated orientation support in order to facilitate interaction from any position around the table:

- *System-level menus*, which allow users to bring up additional interface windows (e.g. the intelligence report window), are automatically oriented towards the nearest table edge, and positioned at the points where they are invoked (see Figure 5). This is a common approach for providing system-level access in collaborative tabletop applications [e.g., 25].
- *Contextual menus*, which provide users access to the system’s map-based capabilities, are automatically oriented towards the side of the table associated with the activating pen, and positioned at the points where they are invoked (see Figure 3).

Spatially Organized Data Access

To reduce visual clutter and maintain a simple interface, most data are not visible by default. ASPECTS initially displays a large map window that shows a geospatial visualization of the current maritime situation (i.e. the location and categorization of known ships in the region of interest) and serves as a “sandbox” for modifying the maritime situation. A smaller map window is also shown that represents the current “approved maritime situation”, and the two maps can be synchronized when users are satisfied with the larger map’s correctness. To delve further into the status of a displayed ship, or to learn more about its assets, users can touch their Anoto pen to the visual icon representing the ship. A ship information window will then appear. This method of data access provides a simple way for users to quickly bring up important data without searching through menus or lists.

Figure 4. The system provides adjustable windows to enable use from any side of the table.

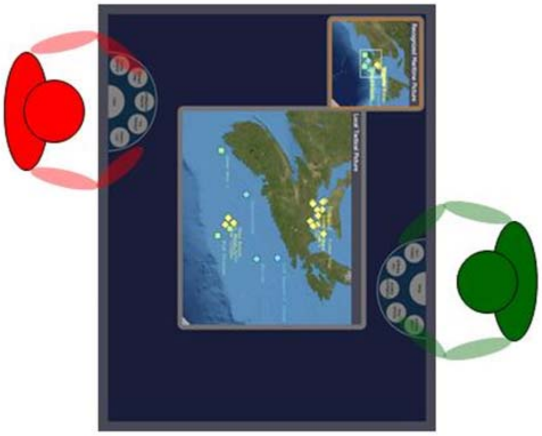

Figure 5. System-level menus are accessible from any side of the table.

USER STUDY

In order to investigate the strengths and weaknesses of the current user interface design, we conducted a usability study on the ASPECTS application prototype. As an intended future research direction is to expand the ASPECTS application to also support strategic planning in maritime operations, the study included both a real-time decision-making and a strategic planning task condition.

Participants

Forty-one participants (14 female, 27 male), from a local university's engineering and computer science undergraduate or graduate programs, participated in seventeen groups of two or three. Eight groups consisted of participants that knew each other and volunteered together, and nine groups consisted of two or three randomly-matched individual volunteers. Participants were paid $10/hour each for their participation in the study.

Setting

The study took place in a medium-sized university classroom setting, temporarily converted into a laboratory space for the purposes of the study. A custom-built Anoto-based interactive tabletop system was set-up in the room, with a 92x122cm (3x4 feet) tabletop surface (the actual interactive area was 76x92cm (2.5x3 feet) with 1536x1024 pixel resolution), see Figure 6. Participants performed the study while seated on bar stools at the table, which was 106cm (3.5 feet) high. Participants were arranged with one group member (randomly selected) at the "head" of the table and their partner(s) at one or both of the adjacent sides, for the 2-person and 3-person condition respectively.

Experimental Tasks

All groups performed two collaborative tasks during the study: a real-time decision-making task and a strategic planning task.

Real-time Decision-Making Task

In this task, groups were presented a representative naval mission scenario, known as a maritime interdiction operation. In this type of mission scenario, a group of naval and/or coast guard ships work together in a "task group" to patrol a maritime region of concern to guard against piracy, terrorism, or other criminal activity. If a suspicious vessel is discovered, the task group will typically send a boarding party to clarify the vessel's intent, taking further action if necessary. In the study, participants were first presented with a description of the scenario and mission instructions, of the task group ships, and of the mission goals (e.g. at least one task group ship must remain patrolling in the shipping lane of interest at all times).

To support this task, the ASPECTS interface was configured to display the maritime region of interest in the main map window and a basic simulated scenario was developed to populate the map window with relevant task group and non-task group ship traffic. Information was also generated to populate the task group ship information windows, which could be opened by touching the associated task group ship icon in the map window. These windows displayed information such as type of ship and available assets (e.g., helicopter or boarding party). A set of intelligence reports was also generated to provide additional information to participants through the scenario via the intelligence report window, which was accessible through the system's border menu. When a new intelligence report arrived, the border of the tabletop interface, or of the intelligence report window if open, would highlight in orange until the new report was read.

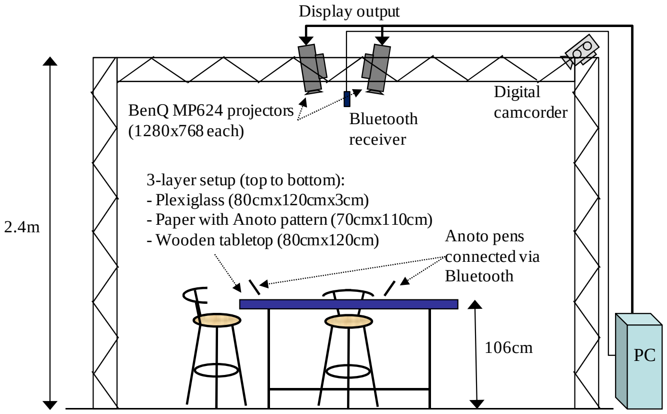

Figure 6. Anoto-based tabletop system set-up.

The participants' goal throughout the task was to monitor the situation by examining the available information and to make appropriate command decisions in response to incoming intelligence. The first decision participants faced was to task an aerial asset from one of the task group ships (e.g. a helicopter or unmanned aerial vehicle) to quickly confirm a report of a suspicious vessel. The second decision involved tasking one of the task group ships with a boarding party to rendezvous with the identified ship, after the first decision produced a visual report of the suspicious vessel. As there is currently no mechanism in ASPECTS to input command decisions into the system, the groups' decisions were provided to the experimenter on paper and the result was then provided verbally by the experimenter.

Strategic Planning Task

In this task, groups were presented a representative collaborative strategic planning scenario. In this scenario, a NATO joint task force has been formed to conduct maritime interdiction operations off the coast of Yemen to deter piracy in offshore shipping lanes. To accomplish this joint mandate, participants assumed the role of representatives from different NATO member nations to work together to form a one-year schedule of ships committed to the maritime interdiction task. At any time during the year-long period, the committed ships were to satisfy a minimum set of capabilities, e.g. a certain number of boarding parties, a supply ship, a certain amount of munitions, and so on.

As the current ASPECTS application prototype does not support this type of planning activity, the interface was used to provide map-based information only. In this task, participants could open up to two or three map windows, for the 2-person and 3-person groups respectively. Each map was populated with locations of relevant ports and travel distance information from those ports to the Yemen region to help groups determine travel distances from available ships in their respective nations' fleets. All other information was provided via paper media. The Anoto tabletop hardware allows these resources to be used directly on the interactive tabletop surface without interference.

As this strategic planning task is beyond the scope of this paper, it will not be described in detail, nor will its analysis be included in the study results section.

Procedure

Participants were first provided an overview of the study and then each completed an informed consent form. Next, the experimenter provided each participant with paper-based instructions and resources for one of the two experimental tasks; the order of presentation of the tasks was counter-balanced to account for learning effects. Once participants had finished reading the instructions and asking questions, the experimenter gave a brief tutorial of the ASPECTS interface that would be used for that task. After any additional questions from the group, the interface was then restarted with the experimental task scenario. Groups were then given 30 minutes to complete the task. Once the task was finished, participants each completed a post-trial questionnaire eliciting their opinions on the interface and its effectiveness for the given task.

The previous procedure was then repeated for the remaining task. A group interview was then conducted to discuss the participants' overall experience and opinions on the ASPECTS system and on the tasks they performed. Finally, participants were paid and thanked for their participation.

Data Collection

Participants' interactions with the ASPECTS interface were captured in computer logfiles. Their conversations and interactions in the physical workspace, including their use of paper on the table during their task activities, were recorded on digital video. Participants' subjective responses were collected via the individual post-condition questionnaires and the group post-experiment interviews.

Data Analysis

Data analysis of the real-time decision-making task included review of the video data to identify interaction patterns and interesting incidents. Participants' post-experiment interview comments from the video data and their free-form responses on the post-trial questionnaires were transcribed. The affinity diagramming qualitative data analysis technique [14] was then used to synthesize and identify common themes from these transcribed comments.

The quantitative data from the post-trial questionnaire were summarized using histograms to visualize participants' opinions on the utility of the ASPECTS application prototype and its ability to support collaboration. Finally, the system logfiles were analyzed to determine common interaction patterns, including how often different interface components were used, and by whom. Activity plots were also generated from the system logfiles to illustrate the spatial interaction patterns of system use throughout each group's session (see Figure 7).

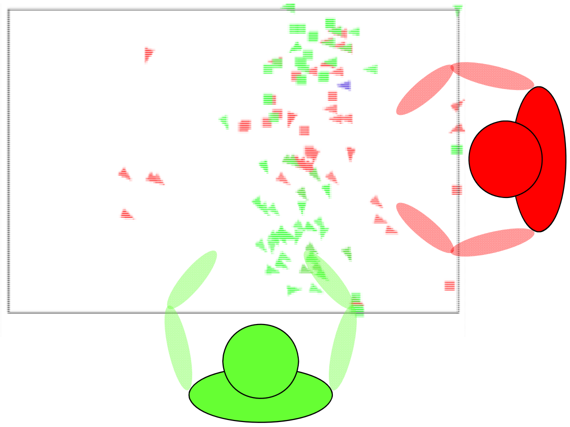

Figure 7. A sample activity plot generated from the system logfiles. Each colour maps to a different person's pen activity; square marks indicate menu invocation and triangular marks indicate window manipulations. The long tail of the triangle indicates the "down" direction of the window's orientation.

RESULTS AND DISCUSSION

Analyses of the video and logfile data show that participants became highly engaged in the maritime interdiction task and made extensive use of the ASPECTS interface to gather information and discuss possible command decisions in response to new information. The interview and questionnaire data revealed that participants found the interface highly effective for supporting information access and sharing throughout the task. These data also identified limitations of and possible improvements to the current interface design. Before presenting these findings in more detail, we first overview some observed work strategies to provide context to the reported interaction data and user opinions.

Observed Work Strategies

On average, groups took 12 minutes to complete the task (shortest session: 6 minutes; longest session: 24 minutes). Typically, the task consisted of three main phases. First, groups would spend the first minute or so trying to understand the current situation and to clarify their task goals. This phase was often characterized by parallel work, where participants independently reviewed their instructions and explored the interface. One minute into the scenario, a new intelligence would arrive that called into question the accuracy of the displayed maritime situation.

This event would typically lead into the next phase (the timing of which depended on when each group noticed that a new intelligence report had arrived, and how quickly they understood the information and its impact). In this phase, groups would carefully examine the maritime situation and the available ship information to determine how to respond to the conflicting information. The correct response was to task an appropriate aerial vehicle to visually confirm the report of a suspicious vessel. This phase was typically characterized by extensive discussion of information and decision options, sharing of information windows, and periods of individual group members breaking off (especially in the 3-person groups) to examine information more closely and report back to the other members. This phase ended once a correct command decision was submitted. Ten groups submitted the correct command decision on their first attempt, while seven groups needed one or two additional attempts.

After a correct decision was submitted, the experimenter verbally reported the results of that command (i.e. that the vessel is in fact suspicious and should be boarded). The final phase consisted of the group re-examining the situation to determine an appropriate task group ship to be re-tasked to rendezvous with the suspicious vessel. Behaviour in this phase was similar to the previous phase, with the exception of the groups also referring to information from the instruction sheets to obtain relevant shipping lane information. Four groups submitted the correct command decision on their first attempt, while 13 groups needed one or two additional attempts. A potential cause of this high level of decision error result is discussed further below.

Throughout these phases, four groups enlarged the map window to cover most of the table surface and then opened and examined other information windows on top of this window (the map window was designed to always stay below other information windows). More commonly, groups kept the map window at its original size (which covered 25% of the table surface), and opened other information windows around and/or over it. Groups used a variety of strategies for managing the information in the workspace, as discussed in more detail below.

Window Management and Interaction Techniques Fostering Collaboration

The data analyses revealed that the ASPECTS interface was intuitive to learn and use. They also revealed that the window management and interaction techniques provided in the interface facilitated information access and sharing throughout the collaborative decision-making task. These aspects of the interface are discussed below.

Effective Window Management for Information Access and Sharing

The ability to reposition and reorient windows by dragging on the window border was commonly reported to be one of the most beneficial aspects of the interface, as evidenced by comments such as, “The drag/swivel moving feature [was most useful] because it allowed me to position items in specific locations for easy viewing for myself and partners”, and “dragging/turning the windows to read them [was most useful] so that you don’t have to walk around the table.” This feature was reported to be especially useful for sharing information with others at the table, as illustrated by comments such as, “moving the display helped to show partner relevant information”, and “I find it most useful to be able to spin an image around because it was a great feature to let another see the picture from across the table.”

Participants also appreciated the multi-user support capabilities of the hardware and the software interfaces as they enabled people to work independently during the task, as illustrated by the comment, “having multiple access on the tabletop computer such that everyone could be working on various things simultaneously on the computer.” This capability enabled groups to delegate certain aspects of the task, such as assigning one member to examine task group information and another to examine the intelligence reports. The ease of repositioning/reorienting interface items also facilitated such delegation, as illustrated by the comment, “being able to open multiple windows and dragging them to your corner to view made it easy to delegate tasks.” The video and logfile analyses revealed that assignment of the intelligence reports to one group member was a common delegated task: the intelligence report was used exclusively by one group member in 9 of 17 groups, and by one group member 70% of the time in 12 of 17 groups.

Though task delegation can be an effective and efficient teamwork strategy [7], not all participants favoured this work strategy. Interview and questionnaire data revealed that several participants desired the ability to duplicate information windows to enable independent review of the information, as illustrated by the comments, “[it] would be nice to copy windows so that everyone can read them at the same time”, and “I couldn’t see the intelligence report as [my partner] was looking at it, we had to share.”

On the other hand, the physical sharing of information windows was recognized by many participants as an important feature for supporting collaboration and promoting workspace awareness. In the post-trial questionnaire, 76% of participants felt they had a high level of awareness of their partners’ actions during the session (rating 6 or 7 on a 7-point scale, where 7 indicated “high awareness”). Comments from the interviews and questionnaires were consistent with these ratings, as evidenced by the comments, “I think [the digital interface] helped more because we’re all looking at the same space”, “if we’re referring to something, we can just quickly point to it”, and “[the interface] allowed you to see everything, you had the same information that was right there and you could point to it.” These comments also illustrate that the shared map and information windows provided by the ASPECTS interface fostered the use of physical deixis (i.e., the pointing and gesturing that often accompanies verbal deictic references such as “this” or “that”), see, for example, Figure 8. Use of deixis during collaboration is an extremely effective way to minimize miscommunications, leading to more efficient and effective communication [5], and ultimately to more effective collaboration in a shared workspace [10].

Figure 8. A group using physical deixis (pointing) to group discuss a shared information window in the ASPECTS interface.

Figure 9. A group using the expansive workspace to create storage territories at the edge of the tabletop workspace.

Figure 10. A participant has arranged several ship information windows side-by-side to enable a visual comparison of the ships' available assets.

The contradicting participant opinions regarding sharing versus duplication of information reflects the classic tension between empowering individual users and facilitating awareness and overall group functioning that exists in the design of collaborative software applications [9]. Resolving this design tradeoff will require more investigation, and is likely to be task dependant. For example, if ASPECTS is to be further developed for supporting military naval operations, the task environment, including the organizational culture, must be considered [30]. The type of task delegation observed in the study, such as the delegation of intelligence information to one group member, is consistent with the role-based operations used in military naval operations [4]. Thus, further investigation is needed to determine which type of information, if any, would be appropriate to duplicate in this context, and the potential consequences (e.g. reduced task performance) of enabling duplication of some or all information windows.

Spatial and Conceptual Organization and Information Analysis

The window management interaction discussed above also enabled participants to easily organize their information windows in the workspace. As mentioned above, groups used various strategies to organize the information in the workspace. Some groups made extensive use of the available space on the table surface to keep many information windows open at once (see Figure 11 (right)). These groups often placed unused windows in "storage territories" [23] at the periphery of the tabletop workspace (see Figure 9), dragging windows back into the actively used workspace area when needed. The ease of opening and repositioning multiple (distinct) information windows was valued by participants, as illustrated by the comment, "[a useful feature was the] ability to compare ships status side-by-side." The video and logfile analyses confirmed that several participants took advantage of such spatial arrangements of information items. Figure 10 illustrates this behavior by one participant, who lined up three of the task group windows in front of him on the table to compare their available resources. Enabling such visual comparison fosters effective information analysis as participants do not have to rely on memory as they examine each new piece of information.

Other groups preferred to keep a less cluttered workspace in which only the windows currently being used were open (see Figure 11 (left)). For those groups, the interface also provided effective conceptual organization of the available information. To access the ship information windows, participants could simply touch the associated ship icon directly on the map. This information access method leverages both recognition and spatial memory, capitalizing on strengths of human cognition [17, 29]. This capability was reported to be a helpful interface feature in the interviews and questionnaires, as illustrated by the comments, "being able to pull up information from each of the individual [map icons], and see where they were with respect to each other, was definitely useful", and "I did find it intuitive to call up ship information, like just clicking on it…it just made sense to couple that spatially."

Overall, the ASPECTS interface appeared to support the maritime interdiction task quite well, and was perceived to be intuitive and effective for accessing and sharing the necessary task information. The data analyses, however, did reveal some limitations in the current system prototype. These are discussed below.

System Limitations

As the current ASPECTS system is an exploratory system prototype, certain usability and design issues arose during the study. A few groups experienced input issues related to

Figure 11. Groups differed in their handling of windows – some groups kept a tidy workspace (left) while others kept many windows open (right).

the Anoto-based hardware setup. In particular, due to either the participants or the experimenter bumping the table during the session, the display-to-input calibration became misaligned, causing some frustration with system interaction until the problem was discovered and resolved. A fixed table set-up would prevent this issue in the future.

An interface issue that arose was the inconsistency in how the interface presented new windows in the display. While the system menus were automatically oriented toward the side of the table to which the user's pen was registered, the information windows were opened at a fixed location and were orientated towards the "bottom" of the interface instead of towards the instantiating user. This resulted in accessibility issues, issues in noticing that the window was opened, and sometimes "unexpected orientation," as reported by one participant. Applying similar orientation and positioning rules to the information windows as used in the contextual menus would address this issue.

Another interface design issue that arose was information clutter in the map window interfering with user interaction. In particular, in certain areas of the map, and at certain zoom levels, adjacent ships and their associated textual labels overlapped and made selection of specific ships difficult. This is a common issue in the design of complex information displays, and can be addressed by using intelligent decluttering algorithms to display ship labels [2].

Beyond these usability issues, the data analyses also uncovered several limitations of the basic interface design currently employed in ASPECTS for supporting this type of complex decision-making task. One issue identified by participants was the lack of visual or conceptual linking of related information items in the interface, as illustrated by the comments, "if an intelligence report comes from the Halifax [ship], I'd want to see the Halifax [map icon] blink", "status/intelligence reports should be linked to ships onscreen", and "[it would be useful] if the [intelligence] message had 'go to Emma Maersk' or something like that" (Emma Maersk was the suspicious vessel the groups had to investigate). Providing more visual links between related pieces of system information may improve information access and analysis by reducing information search time, especially across a large, collaborative workspace.

Another issue that arose was that not all task information was provided in the interface. For example, the shipping lane boundaries were provided on the paper instruction sheets instead of on the digital map. Enabling annotation in the map may have helped groups recall these boundaries and also recall the instructions to maintain a ship within the shipping lane, which may have reduced the level of error observed in the second required task decision. Likewise, participants expressed a desire for more visualization of spatial information, such as the flight range of the available aerial vehicles, as indicated by the comment, "a range circle for UAVs and helicopters would be useful to find out what was in range." In general, participants expressed a desire for the interface to visualize spatial relationships in the map window whenever possible.

Despite these interface and system issues, overall, the findings showed that ASPECTS provided a generally intuitive environment for the completion of a real-time decision-making task. The study data provided insight into typical work strategies employed by groups, as well as an understanding of window management, data access, and organization strategies. Together, these findings provide a significant first step in understanding the appropriateness of the ASPECTS system for maritime domain operations.

CONCLUSIONS AND FUTURE WORK

This paper presented a new digital tabletop application for supporting collaborative decision-making in maritime operations. The ASPECTS application provides decision-makers with a set of window management and interaction techniques that enable collaborative access to dynamically updated geospatial, and related information, in a face-to-face setting conducive to effective and efficient communication. The Anoto hardware platform used in the system prototype enables the ASPECTS application to provide user-specific interface tailoring such as automated orientation support and access control to system functionality based on a user's associated profile.

Though the ASPECTS application was designed to support the maritime application domain, the system design provides relevant capabilities to support a wide variety of application domains that involve collaborative interaction with dynamic geospatial or digital information. The map view, ship information, and intelligence reports could easily be replaced with other forms of geospatial, graphical, or textual information needed for other types of tasks. In applications that involve potentially large amounts of information sources, the system would likely need to provide additional assistance for workspace organization than is currently provided by the ASPECTS application, such as providing information containers [22, 28] or content alignment mechanisms [15].

Although workspace management was not identified by participants to be an issue during the ASPECTS study, we anticipate the need to provide further organizational support if the application were to be developed for operational use in the maritime task domain. Therefore, integrating additional workspace management techniques into the ASPECTS application warrants further exploration. We hope to engage maritime subject matter experts on this and other application issues, such as addressing the usability issues and limitations revealed by the ASPECTS study in a manner appropriate for the task domain.

Finally, as mentioned earlier in the paper, we intend to explore extensions of the ASPECTS application to support a broader range of collaborative activities in maritime operations, such as strategic planning. We also intend to explore extending ASPECTS to support other collaborative task domains, such as emergency response and gaming.

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