15th ICCRTS

"The Evolution of C2"

Title: Investigating Tabletop Interfaces to Support Collaborative Decision-Making in Maritime Operations

Topics: (Topic 3) Information Sharing and Collaboration Processes and Behaviors

Authors: Stacey D. Scott, Antoine Allavena, Katherine Cerar, Glenn Franck, Mark Hazen, Ted Shuter, Chris Colliver

Contact: Stacey D. Scott, Systems Design Engineering, University of Waterloo

Address: Systems Design Engineering
University of Waterloo
200 University Ave W
Waterloo, ON N2L 3G1
Canada

Phone: 519-888-4567 ext 32236
Fax: 519-746-4791
E-mail: s9scott@uwaterloo.ca

INVESTIGATING TABLETOP INTERFACES TO SUPPORT COLLABORATIVE DECISION-MAKING IN MARITIME OPERATIONS

1.

2. Stacey D. Scott[1], Antoine Allavena, Katherine Cerar

3. [1]s9scott@uwaterloo.ca
Systems Design Engineering

4. University of Waterloo
200 University Avenue West
Waterloo, ON, N2L 3G1, Canada

5.

6. Glenn Franck[2], Mark Hazen

7. [2]glenn.franck@drdc-rddc.gc.ca
Maritime C2 Concept
Development Group

8. Defence R&D Canada - Atlantic

9. 9 Grove Street

10. Dartmouth, NS, B2Y 3Z7, Canada

11. Ted Shuter[3], Chris Colliver

12. [3]tshuter@gallium.com

13. Gallium Visual Systems

14. 400-411 Legget Drive

15. Ottawa, ON, K2K 3C9, Canada

Abstract

An interactive tabletop computer is a computing device that offers a large, horizontal digital display and enables one or more users to input commands to the device by interacting directly with the display surface, either via a pen-based device or directly with their hands. Tabletop computers provide a fundamentally different type of user interaction environment than traditional computing platforms, such as personal computers or laptops. The ability to interact directly with one's data on a large digital display provides opportunities for developing richer, more natural human-computer interaction metaphors. These possibilities, combined with a tabletop computer's ability to support multi-user interaction, further introduce opportunities to provide improved interaction metaphors for data sharing during collaboration. As modern

military personnel face increasing pressure to respond quickly to complex situations with limited resources, there is increasing demand for key decision makers to have access to up-to-date electronic data sources and to be able to share these data with other key personnel. To address this issue, we are investigating the potential for interactive tabletop computing platforms to support collaborative planning and decision-making in the military command and control domain. Inspired by the chart and plot tables historically used in the naval domain, our initial focus is on developing a tabletop interface that supports collaborative planning and decision-making in maritime operations. This paper reports on preliminary results from this ongoing project, including a description of the multi-user tabletop technology being used, a discussion of how individual and shared user interaction is supported by the system, and an overview of the initial graphical user interface that has been developed.

INTRODUCTION

One of the fundamental elements of military operations is planning. While planning is often thought of in terms of large formations like armies or fleets, traditionally the majority of naval operations have consisted of single unit or small squadron operations – for example surveillance, showing the flag, anti-piracy patrols or convoys, and economic blockades. Since oceans are large, sensor ranges were short, and the units were generally without long range communications, naval unit commanders were given general instructions and expected to take initiative. These factors meant that all naval units were expected to be able to conduct tactical and operational planning, often involving a large spatial component. Command and control is about positioning of units and maximizing their likely utility to accomplishing the mission, as well as the real-time conduct of warfare. Hence the primacy of charts and the need to annotate them with planned movements, as well as expected currents and weather.

Planning in naval units was traditionally conducted in the captain or squadron commander's quarters where valuable charts could be laid out and stored. These functions then migrated to the wheel-house as control of ships moved inside, and, as ships grew larger, into the ship operations centre.

Central to the planning process was the chart table which provided the space to lay charts out flat. So important was this horizontal flat surface that many operations centres had multiple chart tables, so that one could be used to plot/monitor the current situation while others were used to plan ahead. In the evolution of operations centres, as sensor networks became viable, and then common, the current situation monitoring moved from charts to grease pencil-annotated situation boards and then to computer monitors – today's common operational picture (COP). However, due to the practical size of video displays, operations centres moved from a common display (chart table or situation board) to individual workstations. While this meant that more people could see the same "picture", it had two other effects: first, the picture concentrated on the situation monitoring function, and second, collaboration between team members became more difficult because they were physically separated. This was not seen as a significant problem since naval operations at the time were concentrated on "cold war" operations that emphasized the coordination of larger fleets and operations groups. Of more importance than local operational planning was the integration of tactical data-links to allow widely dispersed forces to operate in unison. In many of the naval operations centres built during the last two decades, space for operational planning is extremely scarce, as is the capacity within combat control systems (CCS) for annotation of the COP for planning purposes.

Of particular interest to this paper was the Canadian Forces (CF) development in the 1970's of an inexpensive commercial off-the-shelf (COTS) data link system for its older destroyers called the Automatic Data Link Plotting System (ADLIPS) (Carruthers, 1979). Unlike most systems of the time, it was built around a horizontally mounted video monitor (table) and provided user input from multiple keyboards. The system replaced the starboard operations centre chart table, and since it provided the larger operational picture, it could be used by the command staff in a similar fashion. The system was installed in all non-data-link enabled CF naval units in order to provide the data-links required for anti-submarine warfare. What is interesting is that the developers decided to stay with a horizontal flat surface rather than a vertical one.

The nascent research program reported in this paper is motivated by the nostalgic memories of senior naval staff for the ADLIPS system and especially in the light of the confluence of surface computing technology, large flat display systems, electronic charts, and the return over the past decade to traditional small task-group operations. So the question at hand is, what was it about the use of the ADLIPS system that commanders found lacking in more recent CCS systems?

Since the basic information content of today's systems is much greater, and the display capability much more advanced than those of ADLIPS, these are not the qualities that have been missed. Instead, it is the conjecture of this research that it is the collaborative nature of the whole command team working on a common display and in a common space that is important. This conjecture is supported by human-factors studies conducted to support the next generation of operations centres (Edwards, 2003) that have shown improved operations when team-members can easily see and communicate with one another. These results have caused a shift from rows of workstations facing in the same direction to "T" and "chevron" configurations. However, these configurations are still aimed more at the tactical response to current situations and the maintenance of the COP than at the other traditional function of operational planning.

The research program discussed in this paper is looking at the use of collaborative displays to facilitate the operational planning functionality. In particular, the research focuses on the utility of tabletop computing to support command team collaborative planning for small naval formations.

Before detailing this research project, a brief overview of the state of tabletop computing technology is first provided, followed by a discussion of related research and commercial efforts to exploit tabletop computers in military and related contexts. The project objectives are then discussed along with the initial design requirements that were developed to guide the development of a collaborative tabletop system to support naval operations. The current state of the system prototype is then outlined, along with how the hardware and application software designs address the design requirements. Finally, ongoing and future project directions are discussed.

BACKGROUND

Tabletop computers have been in existence in one form or another since the early 1990's when Pierre Wellner (1991) proposed the *DigitalDesk* system. The *DigitalDesk* provided a crude direct-touch computer display using a low-resolution projector that displayed digital content onto a desk and an overhead video camera that captured user interaction with the projected display. Wellner's basic design solution of combining a projected display and video cameras to create a large display surface on which users can directly manipulate their data is still in use today for most available tabletop computing platforms. However, current interactive tabletop computers are markedly more sophisticated, now providing significantly higher resolution digital output and more accurate and collaborative input capabilities. The remainder of this section outlines the state of the art in tabletop hardware and software interfaces, and discusses existing research and commercial products related to tabletop use in military and other time-critical contexts.

TABLETOP HARDWARE

A significant breakthrough in tabletop computing technology was the ability to detect simultaneous user interaction. This ability was first enabled by systems using capacitive input technology that relies on a user's fingertip completing a circuit at a particular location on an array of antennas embedded into the display surface. For example, the DiamondTouch (Deitz & Leigh, 2001) and SmartSkin (Rekimoto, 2002) systems both used capacitive input to enable multiple users to work together on a shared surface. This same technology is now what enables multi-touch interaction on the commercially popular Apple iPhone system. Thus far, however, this technology has proven to have scalability issues and is not feasible for large-format surfaces.

Optical sensing techniques are more commonly used to enable simultaneous user interaction. Perhaps the most widely-known optical technique is frustrated total internal reflection (FTIR) (Han, 2005). When infrared (IR) light enters the side of a glass surface, it reflects internally and remains inside until a finger touches the surface, "frustrating" this reflection and scattering light away from it. IR-sensitive cameras located on the opposite side of the surface then capture this point of contact. Commercially available tabletop systems from Perceptive Pixel[1] and SMART Technologies[2] use this input approach. Microsoft Surface uses an alternative optical approach, called diffused illumination (DI), which provides enhanced touch sensitivity. In this approach, IR lights flood the back of the surface, and reflect off of fingers that are in contact with the surface. This reflected light is then captured by cameras located behind the surface. Refinements of these optical techniques that use embedded photosensors are emerging that enable similar multi-touch interaction within thinner form factors, such as multi-touch on an LCD display (Hodges, Izadi, Butler, Rrustemi, & Buxton, 2007).

A disadvantage of multi-touch optical sensing techniques, such as FTIR, is that only coarse-grained input, such as finger touch, is detected. This constraint limits the type of tasks that can be accomplished on these tabletops. For example, creating accurate annotations, drawing, or handwriting is not possible. To address these issues, pen-based techniques capable of supporting multi-user input are emerging. One approach is to use digital ink pens like Anoto[3] (Haller, 2007; Haller et al., 2006). This input approach relies on the pen's onboard camera detecting its position on a specialized grid pattern printed on a sheet of paper that is overlaid onto a surface such as a table. The pen's position is then streamed in real time to the computer driving the tabletop. Another approach, developed by Rosenberg and Perlin (2009), is the interpolating

[1] http:// www.perceptivepixel.com
[2] http:// smarttech.com
[3] http://anoto.com

force sensitive resistance (IFSR) technology that enables both coarse and fine-grained input, supporting both multi-touch and multiple pen input.

TABLETOP SOFTWARE INTERFACES

Over the last decade, the hardware innovations discussed above have been paralleled by similar innovations in software interfaces and user interaction techniques designed to address some of the challenges introduced by the fact that a tabletop computer presents users with a large, shared, and horizontal interface. These features quickly introduce interaction challenges related to reaching distant objects, and reading or interpreting content that is at an awkward viewing angle for the user's current position at the table. Significant strides have been made in redefining the basic interface fundamentals needed to interact effectively on this new computing platform. For example, tabletop software applications now typically include simple mechanisms for freely rotating and translating interface objects using a one-touch or two-finger rotation gesture (Hancock, Carpendale, Vernier, Wigdor, & Shen, 2006), enabling users to easily rotate interface objects to best suit their current position, while providing minimal interference to users working with other aspects of the interface (rather than rotating the entire display toward any particular side of the table).

Localized, context-based pop-up menus, similar to those that would typically appear on a right-click in a Windows system, are also commonly used in tabletop interfaces to enable users to access system functionality from any position at the table. Variations on standard pie-shaped and rectangular drop-down menus are also emerging that provide more complex functionality (Ahmed & Patrick, 2008; Guimbretiere & Winograd, 2000) or address such issues as hand or object occlusion of these context menus (Brandl et al., 2009; Leithinger & Haller, 2007). These interaction techniques and interface components provide basic building blocks for more complex applications, similar to the toolbars, buttons, and sliders in traditional windowing interfaces. The research and corporate communities are now just beginning to explore how these basic components can be integrated into more sophisticated interfaces to support real-world tasks where users need to access and share complex information sources. One example of this type of task is that of naval operational planning.

TABLETOP COMPUTERS IN MILITARY AND OTHER TIME-CRITICAL CONTEXTS

Horizontal display systems are not new to the Canadian Navy. The Automatic Data Link Plotting System (ADLIPS) was introduced during a fleet upgrade in the late 1970's and early 1980's, and remained in service until 1997 when the last of the ships on which ADLIPS was installed were retired (Friedman, 1997). ADLIPS was a tactical display system consisting of a 20-inch horizontal cathode-ray tube (CRT) situation information display (SID), remote plasmas displays positioned in the Electronic Warfare control room and the bridge, and a hardcopy plotter (Carruthers, 1979; Friedman, 1997). The horizontal situation display was surrounded by three operator stations that each contained a separate trackball and keyboard for performing target detection and identification tasks to maintain an up-to-date situation picture on the SID. Though ADILPS provided a form of "tabletop" system, its separated input and output spaces provided a considerably less integrated or natural interaction environment that modern digital tables offer.

As an emerging technology, the research on interactive tabletop systems in the context of military command and control (C2) and other time critical environments, has thus far been limited. Through the creation and testing of a digital sand table, Szymanski et al. (2008) showed that interactive tabletop computer systems could better support in-person collaboration in an Army environment, but that this support was affected by the specific technology used. Their tabletop system was not able to uniquely identify users, nor was the orientation of interfaces intuitive – two limitations addressed in the developed prototype. A team at the Virtual Reality Application Centre at Iowa State University has explored the use of a multi-touch table to enhance user interaction with defence-related data displays that integrate multiple information sources (Dohse, Still, & Parkhurst, 2008). Their project focused on exploring the use of multi-touch tables within a virtual reality setting; not an ideal context for collaboration as the goggles needed to view the virtual reality display limited eye contact, which is a critical factor in effective face-to-face communication (Clark & Brennan, 1991; Short, Williams, & Christie, 1993).

Tabletop systems have also been explored in other time-critical environments. While developing solutions to support flood disaster response operations, Nóbrega et al. (2008) 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. Using urban search and rescue as an example, Ashdown and Cummings (2007) showed that large displays such as tabletop computers are most useful for those situations where a large amount of data needs to be displayed, and where any piece of the information may become the centre of the user's attention.

A key aspect of naval planning is the use of geospatial information. Scotta et al. (2006) 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 interfaces surrounding the geospatial information are more important than any other factor in the design of the tabletop computer display. Schoning et al. (2008) have also shown that the interface surrounding geospatial information displays in tabletop systems can greatly affect the value of these information displays. Thus, our project focuses on this aspect of tabletop systems: designing an effective tabletop interface for intuitive interaction with typical content and media used in naval operations.

Within the commercial space, there are several companies currently offering customized tabletop solutions for command and control and other time critical contexts, including TouchTable[4] and Perceptive Pixel[5]. These companies offer solutions for defence and intelligence, homeland security, and public safety applications, primarily focusing on data display and manipulation. A shortcoming of these commercial systems is that they typically treat the entire tabletop surface as one contiguous workspace, forcing users to work in concert during their entire collaborative session. This interface model is not well suited to common tabletop collaborative work practices, which often involve group members switching between periods of independent and cooperative work during a collaborative activity (Hinrichs, Carpendale, & Scott, 2006; Scott, Carpendale, & Habelski, 2005; Scott, Grant, & Mandryk, 2003).

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

DESIGNING A TABLETOP COMPUTER FOR COLLABORATIVE MARITIME OPERATIONS

As discussed above, the navy has a rich history of using working tables (chart tables, plot tables) in maritime environments. As computer technology has improved, the charting information has

[4] http://touchtable.com
[5] http://perceptivepixel.com

moved away from those tables and the traditional paper-based systems, and into the realm of individual workstations, with these data being available digitally and single operators controlling individual workstations.

In the last few years, however, C2 research has begun to shift back towards the concept of the collaborative team environments and the clustering of team members. This natural progression reflects the underlying need for collaborate team working areas, something which the military is very familiar with. With the makeup of command team groups and the need to share information with commanding officers, the extension of tabletop computing for use in a naval environment is a natural progression of technology, but one that has yet to be fully exploited.

The current research project, initiated by Defence Research and Development Canada (DRDC) Atlantic, aims to highlight the usefulness of a tabletop computer as a tool for the navy, and seeks to provide a platform to explore the optimal use of tabletops in the future.

The objective of this initial project is mainly to create a working prototype application, which, while providing basic functionality familiar to naval officers, does not seek to reinvent what other projects and applications already do. Rather, the focus is to use the basic application as an experimental test bed to explore functionality that is uniquely suited to a tabletop environment.

To guide the development of this experimental test bed, several design requirements were developed, based on the nature of the naval task environment and the tabletop literature. Key aspects of these design requirements included:

- **Provide access to dynamically updated, map-based data sources**. Access to large geographical and spatial data sets, such as maps, charts, etc. is fundamental to ship navigation, as well as mission planning and execution in naval operations. Modern naval operations also rely heavily on a wide variety of dynamically updated data sensors, such as radar, active and passive sonar, electronic support measures (ESM) and electro-optics. A digital tabletop environment provides both a large workspace for viewing and sharing area maps, and the computational capabilities to facilitate dynamic, real-time update of its information display. An example of a common, map-based task involved in maritime operations is the monitoring and modification of ship track data. Thus, the prototype system should have the capability to show and edit ship tracks, and display dynamically updated track data from data sources, either simulated or real.
- **Provide support for multiple co-located operators interacting with the system simultaneously; that is, a team standing around the table**. Command teams and operations rooms operate under a hierarchy of authority, and are supported by input from all the operators, both through the manipulation of digital information as well as through verbal user input and discussion. One particular need is for the commander to be able to see all the relevant mission and status information, as well as be able to discuss planning options with other team members. Enabling collaboration between the team members, such that all participants can interact and discuss plans, is central to this task. In terms of a tabletop environment this requires coincident, multi-user, multi-location system access.
- **Support operators standing at any position around the table (omnidirectional / 360-degree interface).** Given the flat table orientation, there is no concept of “up” or “down”. So as not to place any limit on the positioning of participating personnel, it is necessary that the interface be orientation independent. With current technology this means that the

- **Enable work to be done on a horizontal surface orientation (table format).** The table format is the traditional collaborative environment that many naval officers are familiar with, and is speculated to be a missing key ingredient in modern systems. Reproduction of the traditional chart based collaborative planning is the first step in investigating the actual cognitive requirements that underlie the attraction of such team environments.
- **Support the notion of operator roles and corresponding security**. By providing functionality tailored to operator roles, it is possible to hide low-level operator-specific functions (such as tweaking a sensor input) from other members, as well as to restrict command-level decisions (such as course changes or fire orders) from those not authorized to enter them. This both enhances individual operator abilities, while simultaneously de-cluttering input options, and providing security to prevent accidental changing of controls. Thus, the prototype must enable identification tracking/filtering of personnel and inputs – for example providing different functionality for different users.
- **Provide operator distinction by the system.** Beyond the interface tailoring that becomes possible with individual operator input tracking/filtering, distinguishing between operators with the same role or security level can be useful. As multiple users are sharing the same computational workspace, conflicts may arise in accessing certain functionality or system modalities. Therefore, the system must provide operator distinction to enable functionality to resolve object control issues amongst the multiple users.
- **Enable fine-grained input control**. Although tables can provide significant screen real-estate (depending upon pixel density and graphics processing), adding multiple users means the screen real-estate must be shared. In order to provide working space for multiple users the actual information inputs must be fairly fine-grained. For example the difference between a pen-width line and a finger-width one. Fine-grained input control also enables detailed, accurate annotation of interface content and media, as well as fine control for handwriting in the digital environment.
- **Enable input logging on a per-user basis**. When operating on an individual workstation, it is easy to log a history of what is entered and changed, both for troubleshooting and for tracing back events should the need arise. However, in a shared, multi-user environment input can occur simultaneously from multiple users. By recording a log of interactions based on operator distinguished input channels (developed under the previous requirement), it is possible to achieve the same, or even greater, level of detail in logging. A side benefit of this form of logging is that it permits capture of the sequence of the user interactions arising from the collaboration, enabling human-factors analysis of the collaborative work process.

The aim of the current project is to incorporate these key notions into the development of the prototype. The resulting system will combine the best aspects of current tabletop computing and collaborative research.

CURRENT PROTOTYPE

Combining the above system requirements, a concept for a naval planning support application incorporating the tracking of maritime vessels was developed to run on a pen-based tabletop computing environment.

The concept behind the current prototype is to have a basic map display system, capable of showing and editing ship tracks, and supporting data input from an arbitrary data source. Track histories are shown, and reports can be queried to get more information to help establish the recognized maritime picture (RMP). Note that the application prototype is not designed to streamline the current process of establishing the RMP, nor does it provide additional analysis tools. Rather, it is designed to showcase the manner in which relevant maritime data can be accessed and shared in a collaborative environment.

The application prototype is designed to enable collaborative exploration of a dynamic maritime tactical picture and of related information sources. The prototype provides an intuitive, direct (pen) touch interface that supports both individual and shared access to geospatial and other key mission-related information and media.

Figure 1 shows the current user interface of this software application prototype running on a 3x4 foot, dual-projected display tabletop hardware setup equipped with multiple Anoto digital pens.

Figure 1. The application prototype interface running on a pen-based, collaborative tabletop system.

The software prototype is designed to run on a custom-built, top-projected Anoto-based tabletop computer hardware platform (Haller, 2007; Haller et al., 2006). This hardware platform provides the ability to track unique user input using multiple Anoto digital ink pens. This unique user tracking enables interface customization (Ryall et al., 2006), such as tailored views based on security clearance level or on individual task role informational needs. Our software application prototype was developed using the Windows Presentation Foundation (WPF) software development framework and the C# object-oriented language. Gallium Visual System's InterMAPhics[6] geospatial visualization engine is is used to render the operational picture in the user interface. The prototype runs on the Windows XP operating system.

Beyond providing standard operator access to map and track data capabilities, the user interface of the application prototype provides several additional features designed to address the unique project requirements, discussed in the previous section. Many of these features relate to providing improved window management in the digital workspace to better support the large, horizontal nature of a tabletop computer.

360-DEGREE, COLLABORATIVE INTERFACE

In order to accommodate multiple users who may be interacting with the interface from different sides of the table, the interface content is provided in individual windows, which can easily be moved or rotated with a simple touch and drag gesture anywhere on the window border. The map content windows can also be resized to accommodate personal or shared use of the geospatial data. Thus, the layout of interface content can be easily adjusted to accommodate a wide variety of individual and shared content use, anywhere on the table. The software also enables simultaneous user interaction; thus, users are free to work in parallel, for instance an operator could be checking on a particular piece of information in a separate content window while others at the table discuss tactical strategy over a shared map. Figure 2 demonstrates the interface being used by three users, with a variety of individual and shared windows in use.

The interface also provides some automated support for orienting interface components in order to facilitate interaction from any position around the table:

- *Oriented system-level menus*. The system-level menus automatically orient towards the nearest table edge

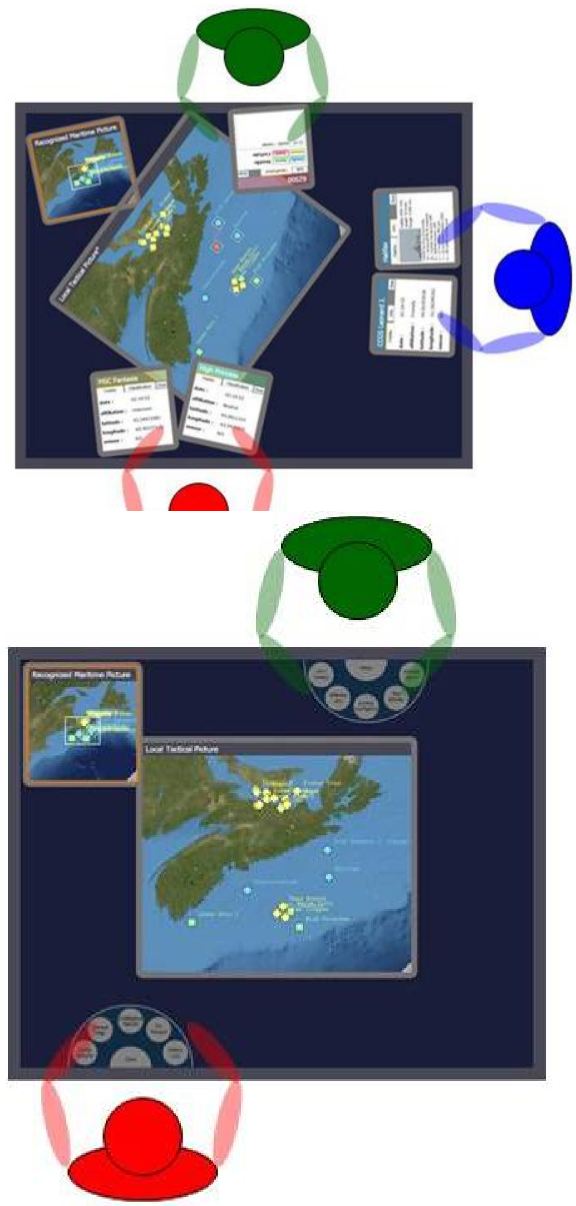

Figure 3. System-level menus are accessible from any side of the table.

[6] http://gallium.com

(see Figure 3). These menus can be invoked by touching the virtual border surrounding the tabletop interface (the grey border shown in Figures 2 and 3).

- *Oriented pop-up menus.* The system allows each digital pen to be associated with a particular side of the table. This information is then used to automatically orient pop-up menus toward the side of the table associated with the activating pen (Figure 4).

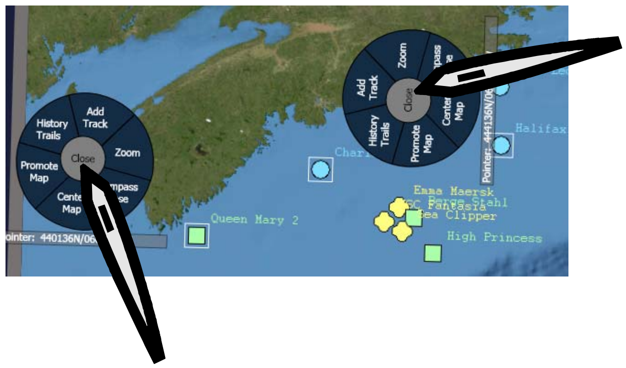

Figure 4. Pop-up menus are automatically rotated toward the table edge associated with the activating pen.

INTERFACE TAILORING FOR SECURITY LEVEL OR ROLE

As mentioned above, the current interface is designed to work with the Anoto digital pen technology. Each Anoto pen has a unique identifier that is communicated to the system whenever it touches the table. Thus, this input technique enables each pen, and thus each associated user, to be uniquely tracked by the system. This unique tracking enables the system to tailor the interface's response to each pen, based on stored characteristics of the user profile associated with that pen. In the current prototype, this distinct user information is used to associate a particular security level to each pen. This security level maps to various levels of authority within the system. For instance, different system options are displayed in the pop-up menus available in the interface, based on the user's authority level. For example, in the map window, only a user with the highest authority/security level is presented the option to promote changes made to the tactical map to the entire task group, while users with less system authority do not have access to this functionality when they invoke the same menu (Figure 5).

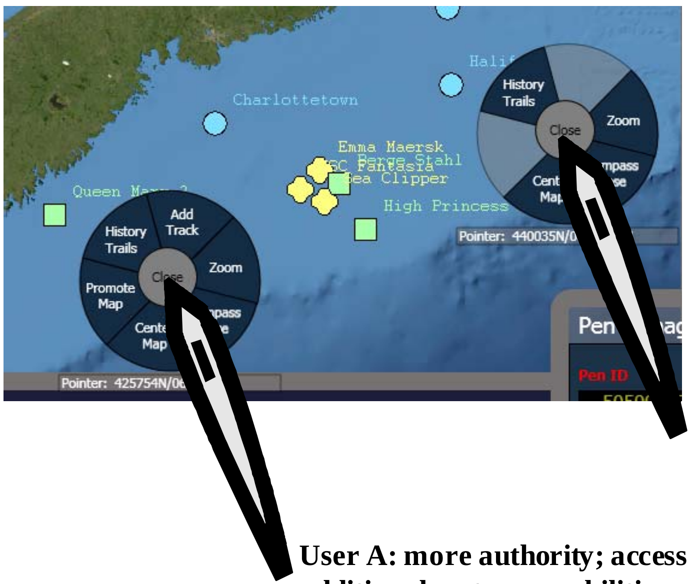

Figure 5. Interface tailoring for users with different security levels.

RESULTS

Within the current research program the prototype's usage has been limited to exploratory experimentation and demonstration, rather than full hypothesis based experimentation. The prototype has been demonstrated to members of the Canadian Forces Maritime Warfare Centre (CFMWC) and to the wider military community at the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2009 in order to obtain initial feedback on the system concept. In addition, the project has been briefed to the wider DRDC Atlantic scientific community.

As an initial concept demonstrator, the prototype has had enough positive subject-matter expert response that the team is investigating long-term research support. For the majority of military people, this has been a first real opportunity to get hands-on with a digital tabletop system applied to operations planning. The feedback received so far indicates that it is easy to use, intuitive, and that there is much interest in seeing this project develop further. The concepts of pen-based security were easily understood, and the prototype system, despite certain limitations, was well accepted.

Based on this initial usage feedback from the user community, we have already identified the following additional design criteria:

1. The Anoto digital pens provide an intuitive and user-friendly experience due to the wireless, non-tethered use enabled by Bluetooth communications. While enhancing the experience and enabling user security tracking, though, it is exactly this use of wireless technology that is the biggest obstacle to access the operational community for user trials, as wireless is restricted in many military complexes.

2. Though the current Anoto digital pen approach has operational challenges in military contexts, the pen-based interaction style is easily understood by users. First-time users who have tried the system were able to easily pick up a pen and begin interacting with it. Unlike gesture-based input enabled on many multi-touch tabletops, the simple pen interaction is extremely intuitive, and should be retained for future technologies. Adoption of multi-touch approaches that require users to learn any amount of complex gestures should be approached with caution.

3. A limited pixel density can quickly become a hindrance to operational ability. While initial requirements outlined no minimum required display resolution, this aspect needs to be considered in future designs, as it becomes easy to run out of screen real estate. This has been particularly evident with arbitrarily-rotated windows, as they require more screen space (in terms of pixels) than regularly-aligned windows.

4. With the overlap of multiple windows there is a need for window management analogous to the shuffling of paper or charts on a real table. This is not unexpected given the amount of window management conducted on a normal workstation but is extenuated by multiple users.

Given the positive feedback to the project thus far, we intend to continue this research program, incorporating the additional design criteria discussed above. The next section discusses additional directions we intend to explore in future phases of the research.

FUTURE DIRECTIONS

It is hoped that by opening the door to tabletop computing for use in the maritime environment, and in ways applicable to the Canadian Navy, that future projects will be able to take the work into directions that provide more complete and integrated command and control (C2) and mission planning tools that will be utilized by the navy. In addition to investigating methods of addressing the additional design criteria identified in the previous section, we intend to more formally test the current prototype to gather more empirical results related to its usability and effectiveness for our target user population.

Another key direction that will be explored is the use of private displays in conjunction with the tabletop interface. This research direction is motivated by situations where someone may need to access highly classified information during a collaborative session, but others at the table do not have the appropriate clearance level to view this information. As the table is a shared interface, they would not be able to display this information. Having access to an additional private display may facilitate this information need. Additionally, users may simply wish to incorporate information and media from a personal device into the tabletop interface to share with others. Often data that a team may wish to discuss will originate from other external computers, such as an operator’s workstation. Enabling users to bring data with them to the table and, conversely, enabling them to take data away from the table back to their workstations will be an important step towards facilitating the overall workflow of team-based operations.

REFERENCES

Ashdown, M., & Cummings, M. L. (2007). *Asymmetric Synchronous Collaboration Within Distributed Teams.* Paper presented at the 7th International Conference Engineering Phsycology and Cognitive Ergonomics.

Brandl, P., Leitner, J., Seifried, T., Haller, M., Doray, B., & To, P. (2009, April 4-9, 2009). *Occlusion-aware menu design for digital tabletops.* Paper presented at the Extended Abstracts of CHI 2009: 27th International Conference on Human Factors in Computing Systems, Boston, MA, USA.

Carruthers, J. F. (1979). The Automatic Data Link Plotting System (ADLIPS). *Naval Engineers Journal, 91*(2), 185-191.

Clark, H. H., & Brennan, S. E. (1991). Grounding in Communication. In L.B. Resnick, J. Levine, and S.D. Teasley (Eds.). In *Perspectives on socially shared cognition* (pp. 127-149). Washington, DC: APA Books.

Deitz, P., & Leigh, D. (2001, November 5-8, 2000). *DiamondTouch: A Multi-User Touch Technology.* Paper presented at the Proceedings of UIST’00: ACM Symposium on User Interface Software and Technology, San Diego, CA.

Dohse, T., Still, J., & Parkhurst, D. (2008). *Enhancing Multi-User Interaction with Multi-Touch Tabletop Displays using Hand Tracking.* Paper presented at the IEEE Advances in Computer-Human Interaction.

Edwards, J. L. (2003). *LOCATE Analysis of Halifax Class Frigate Operations Room - Final Report* (No. CR 2003-124): DRDC Toronto.

Haller, M. (2007). *Pen-based interaction*. Paper presented at the ACM SIGGRAPH 2007 courses.

Haller, M., Leithinger, D., Leitner, J., Seifried, T., Brandl, P., Zauner, J., et al. (2006). *The shared design space*. Paper presented at the ACM SIGGRAPH 2006 Emerging technologies.

Han, J. Y. (2005). *Low-Cost Multi-Touch Sensing through Frustrated Total Internal Reflection.* Paper presented at the Proceedings of UIST'05: 18th Annual ACM Symposium on User Interface Software and Technology Seattle, WA.

Hancock, M. S., Carpendale, S., Vernier, F. D., Wigdor, D., & Shen, C. (2006). *Rotation and Translation Mechanisms for Tabletop Interaction*. Paper presented at the TABLETOP.

Hinrichs, U., Carpendale, S., & Scott, S. D. (2006). *Evaluating the effects of fluid interface components on tabletop collaboration*. Paper presented at the Proceedings of the working conference on Advanced visual interfaces.

Hodges, S., Izadi, S., Butler, A., Rrustemi, A., & Buxton, B. (2007). ThinSight: versatile multi-touch sensing for thin form-factor displays. *Proc. UIST 2007,* 259-268.

Leithinger, D., & Haller, M. (2007). Improving Menu Interaction for Cluttered Tabletop Setups with User-Drawn Path Menus. *TABLETOP*, 121-128.

Nóbrega, R., Sabino, A., Rodrigues, A., & Correia, N. (2008). *Flood Emergency Interaction and Visualization System.* Paper presented at the International Conference on Visual Information Systems, Salerno, Italy.

Regal, R., & Pacetti, D. (2008). Extreme C2 and Multi-Touch, Multi-User Collaborative User Interfaces. *23th International Command and Control Research and Technology Symposium*.

Rekimoto, J. (2002, April 20-25, 2002). *SmartSkin: An infrastructure for freehand manipulation on interactive surfaces.* Paper presented at the Proceedings of CHI'02: ACM Conference on Human Factors in Computing Systems, Minneapolis, MN.

Rosenberg, I., & Perlin, K. (2009). *The UnMousePad: an interpolating multi-touch force-sensing input pad*. Paper presented at the ACM SIGGRAPH 2009 papers.

Schoning, J., Hecht, B., Raubal, M., Kruger, A., Marsh, M., & Rohs, M. (2008). *Improving Interaction with Virtual Globes through Spatial Thinking: Helping Users Ask "Why?"* Paper presented at the 13th Annual ACM Conference on Intelligent User Interfaces.

Scott, S. D., Carpendale, S., & Habelski, S. (2005). Storage Bins: Mobile Storage for Collaborative Tabletop Displays. *IEEE Computer Graphics and Applications: Special Issue on Large Displays*, *25*(4), pp. 58-65.

Scott, S. D., Grant, K. D., & Mandryk, R. L. (2003, September 2003). *System Guidelines for Co-located, Collaborative Work on a Tabletop Display.* Paper presented at the Proceedings of ECSCW'03: European Conference on Computer-Supported Cooperative Work, Helsinki, Finland.

Scotta, A., Pleizier, I., & Scholten, H. (2006). *Tangible User Interfaces in Order to Improve Collaborative Interactions and Decision Making.* Paper presented at the 25th Urban Data Management Symposium, Aalborg, Denmark.

Szymanski, R., Goldin, M., Palmer, N., Beckinger, R., Gilday, J., & Chase, T. (2008). *Command and Control in a Multitouch Environment.* Paper presented at the 26th Army Science Conference, Orlando, Florida.

Wellner, P. (1991, November 11-13, 1991). *The DigitalDesk Calculator: Tangible manipulation on a desktop display.* Paper presented at the Proceedings of UIST'91: ACM Symposium on User Interface Software and Technology, Hilton Head, SC.

16.