Investigation of a Prototype Naval Planning Tool for Tabletop Computing Research

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Abstract

An interactive tabletop computer is a computing device that offers a large, horizontal digital display and enables one or more users to interact 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. The ability to interact directly with one's data and to share those data with others provides opportunities for developing richer, more natural human-computer interaction metaphors and improved interaction metaphors for 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. This report details the development of an initial software application designed to enable the investigation of tabletop computing technology in Canadian Navy operations. The tabletop interface supports collaborative planning and decision-making in maritime operations. This report describes the user interface and software architecture of the developed application prototype, and provides recommendations for future investigations of this technology in the naval domain.

Résumé

Une table tactile multimédia est un système informatique offrant un affichage interactif sur une grande surface et permet à un ou plusieurs utilisateurs d'interagir simultanément, à l'aide de stylets ou directement avec leurs mains. Les tables tactiles fournissent une interaction fondamentalement différente des postes de travail traditionnels. La capacité d'interagir directement avec des données et de partager ces données avec d'autres utilisateurs offre de riches opportunités de développement, des interactions homme/machine plus naturelles et des possibilités de collaboration avancées. Alors que de nos jours, le personnel militaire fait face à une pression grandissante pour réagir rapidement à des situations complexes et avec des ressources limitées, les dirigeants réclament de plus en plus l'accès à des sources de données à jour et la possibilité de partager ces données avec d'autres dirigeants. Ce rapport présente le développement d'une première application logicielle créée pour étudier la technologie tactile dans les opérations de la Marine Canadienne. Cette interface tactile prend en charge la planification et la prise de décision collective dans des opérations maritimes. Ce rapport décrit l'interface utilisateur et l'architecture logicielle du prototype, tout en fournissant des recommandations pour des études futures de cette technologie dans le domaine maritime.

Executive summary

Investigation of a Prototype Naval Planning Tool for Tabletop Computing Research: Final Report

Stacey D. Scott, Antoine Allavena; DRDC Atlantic CR 2010-055; Defence R&D Canada – Atlantic; March 2010.

Introduction or background: Interactive tabletop computers introduce new opportunities for developing richer, more natural human-computer interaction metaphors and improved interaction metaphors for 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. Defence Research and Development Canada – Atlantic has begun to investigate the potential benefits of tabletop computing technology for supporting collaborative planning and decision-making in Canadian Navy operations. This report describes a software application prototype developed by the University of Waterloo that was designed to serve as an initial concept demonstration and extendible experimental platform to facilitate DRDC's investigations.

Results: Preliminary demonstrations of the developed application prototype to members of the Canadian Forces Maritime Warfare Centre (CFMWC) and to the wider military community at the I/ITSEC 2009 conference in December 2009, to the DRDC-Atlantic scientific community in January 2010, and to personnel from Waterloo-based emergency response organizations have had extremely encouraging subject-matter expert response. For the majority of the people, military and non-military alike, these demonstrations have been a first real opportunity to get hands-on with a digital tabletop system applied to command and control operations. The feedback received thus far indicates the developed tabletop system is easy to use, intuitive, and that there is much interest in seeing this project develop further, in both the military and other time-critical domains.

Significance: As a tool for enabling more effective collaborative planning and decision making, there is significant potential for interactive tabletop computing technology to improve military command and control operations. The positive feedback garnered from the initial concept demonstrations indicate the desire and need for more effective, and efficient collaborative support tools in Canadian Forces operating environments, along with other time-critical environments, such as emergency response.

Future plans: The initial informal subject matter expert feedback on this early concept prototype indicates that continued investigation of tabletop computing platforms for use in naval planning and decision making task operations is warranted. Recommendations are provided for further capabilities development of the software application prototype to facilitate DRDC Atlantic's continued investigation of tabletop computing for the naval domain.

Sommaire

Investigation of a Prototype Naval Planning Tool for Tabletop Computing Research: Final Report

Stacey D. Scott, Antoine Allavena; DRDC Atlantic CR 2010-055; R & D pour la défense Canada – Atlantique; Mars 2010.

Introduction ou contexte: Les tables tactiles multimédia offrent de nouvelles opportunités de développement, des interfaces homme/machine plus naturelles et des possibilités de collaboration avancées. Alors que de nos jours, le personnel militaire fait face à une pression grandissante pour réagir rapidement à des situations complexes et avec des ressources limitées, les dirigeants réclament de plus en plus l'accès à des sources de données à jour et la possibilité de partager ces données avec d'autres dirigeants. Recherche et Développement pour la Défense Canada–Atlantique à commencé à étudier les avantages potentiels des tables tactiles multimédia dans la prise en charge de la planification et de la prise de décision collective dans des opérations de la Marine Canadienne. Ce rapport présente un prototype de logiciel développé par l'Université de Waterloo créé en tant que logiciel de démonstration et en tant que plateforme expérimentale extensible pour faciliter les études de RDDC.

Résultats: Les premières démonstrations du logiciel aux membres du Centre de Guerre Naval des Forces Canadiennes, à l'ensemble de la communauté militaire à la conférence I/ITSEC 2009 en Décembre 2009, à la communauté scientifique de RDDC-Atlantique en Janvier 2010, ainsi qu'au personnel des organisations d'intervention d'urgence de Waterloo ont reçu des critiques très encourageantes de la part d'experts en la matière. Pour la plupart des personnes, militaires ou non, ces démonstrations ont été une première véritable opportunité de tester une table tactile multimédia dans un contexte d'opérations de direction et de contrôle. Les retours reçus jusqu'ici montrent que le logiciel est simple d'utilisation, intuitif, et qu'il y a de grands intérêts à développer ce projet, autant dans le domaine militaire que dans d'autres domaines.

Importance: En tant qu'outil permettant la planification et la prise de décision collective, les tables tactiles ont un fort potentiel pour améliorer le commandement militaire et le contrôle des opérations. Les retours positifs que le prototype initial a reçus montrent le désir et le besoin d'avoir des outils de collaboration plus efficaces dans le domaine des opérations des Forces Canadiennes, ainsi que dans d'autres domaines où le temps est une variable critique, comme les situations d'urgence.

Perspectives: Les premiers retours officieux sur cette version du prototype indiquent que l'étude des tables tactiles multimédia dans un contexte naval de planification et de prise de décision est justifiée. Des recommandations sont fournies pour le développement de capacités supplémentaires pour le logiciel afin de faciliter les études de RDDC-Atlantique dans l'utilisation des tables tactiles dans le domaine maritime.

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Acknowledgements

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1 Introduction

1.1 General

This report documents the work undertaken by the University of Waterloo to address the Statement of Work (SOW) contained in the PWGSC Contract W7707-098229/001/HAL, entitled Investigation of a Prototype Naval Planning Tool for Tabletop Computing Research, which details work requested by Defence Research and Development Canada (DRDC) – Atlantic. This work focused on the development of a software application prototype designed to run on an interactive tabletop computer platform. This report provides background for this software development project, including how it relates to the Crown's underlying research objectives and how this work relates to and builds on existing tabletop computing research initiatives. Details of the user interface and software architecture of the developed application prototype are reported, along with a discussion of project limitation and future recommendations.

1.2 Interactive Tabletop Computers

An interactive tabletop computer is a computing device that offers a large, horizontal digital display and allows 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. Interactive tabletop computers provide a fundamentally different type of user interaction environment, compared to traditional computing platforms such as personal computers and 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 group work. The new form factor and new interaction capabilities of tabletop computers also introduce significant software design challenges, as current operating systems and most available software applications assume a one-person/one-computer interaction paradigm and a vertical display orientation. Research, government, and industry are just beginning to explore the use and feasibility, of this computing platform for various application domains.

1.3 Project objectives

As the Canadian Forces faces increasing pressures to respond quickly to complex situations with limited resources, there is an 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, the Crown has begun investigating the potential for interactive tabletop computing platforms to support collaborative planning and decision making in the military domain, and in particular in the naval domain.

The objective of the work performed under this contract was to support the Crown's investigation by providing a computer software application designed to run on a tabletop computing hardware platform agreed upon in negotiation with the DRDC Project Authority (PA). The goal of this software development effort was to demonstrate an initial set of user interaction capabilities and software functionalities, as detailed in the SOW, and provide a software architecture that can be extended as desired by the Crown for the purposes of further investigation.

1.4 Project team

The main project team consisted of University of Waterloo personnel, Prof. Stacey Scott, as project lead, and Mr. Antoine Allavena, as project engineer. The project was also able to leverage additional resources through the NSERC Digital Surface Software Application Network (SurfNet), a strategic research network with which the University of Waterloo is affiliated. A key SurfNet industrial partner, Gallium Visual Systems, provided in-kind software support in the form of their InterMAPhics map visualization engine, as well as development support in the form of a dedicated student intern, Mr. Chris Colliver, who worked with Mr. Allavena to develop all supporting InterMAPhics functionality for the developed application prototype. This additional support enabled the team to take advantage of an unexpected opportunity to demonstrate an early working prototype at the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2009 as an invited part of the Canadian Forces Maritime Warfare Centre (CFMWC) exhibit. As discussed in Section 5 of this report, this opportunity provided the team valuable insights and feedback from military personnel, and provided an excellent opportunity to showcase Canadian defence-related research.

1.5 Report outline

This report documents research conducted to meet the objectives outlined in Section 1.3. It is organized as follows:

- Section 1 – Introduction
- Section 2 – Background
- Section 3 – Tabletop Design Requirements for Naval Operations
- Section 4 – Software Application Prototype: User Interface and System Architecture
- Section 5 – Project Results
- Section 6 – Conclusions, Limitations, and Recommendations

2 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.

2.1 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, which are 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

[1] http:// www.perceptivepixel.com

[2] http:// smarttech.com

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

2.2 Tabletop Software

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.

[3] http://anoto.com

2.3 Previous Work on 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 software development project described in this report represents another step towards understanding the utility of this new computing technology for supporting collaborative military, and in particular naval, operations.

[4] http://touchtable.com

[5] http://perceptivepixel.com

3 Tabletop Design Requirements for Naval Operations

The navy has a rich history of using working tables (chart tables, plot tables) in maritime environments. With advances in computing technologies, charting information has migrated away from tables and traditional paper-based systems to individual workstations. Charting data are now typically available digitally at individual workstations controlled by single operators.

In the last few years, however, command and control 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 collaborative team working areas, something with which the military is very familiar. 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 exploited.

In conjunction with this project, 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 tabletop computers in future operations. The main objective of this project is to create a working application prototype, which provides basic functionality familiar to naval officers. The project does not seek to reinvent existing work. Rather, the focus is to create an experimental platform to explore functionality that is uniquely suited to a tabletop environment.

To guide the development of the software application prototype, 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 map data, along with the computational capabilities to facilitate dynamic, real-time updates of map information. 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**. 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 located 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 tabletop interface must allow for arbitrary rotation and placement of windows and user interface elements, without restriction.
- **Enable work to be done on a horizontal surface orientation.** 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 in 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 when needed. 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.

These identified requirements were then operationalized into specific project requirements set out in the SOW this contract, and are listed below in Table 1. Each row of the table contains a specific project requirement (labeled to correspond to the requirements list contained in the SOW), and a description of how the developed application prototype addresses the requirement.

Table 1. Overview of the project requirements and how the developed application prototype addresses these requirements.

Req.	System Capability	Overview of how the application addresses the requirements
1a	Is capable of running on a Windows XP operating system.	The application prototype runs on Windows XP.
1b	Is written in an object-oriented programming language, either Java, C++ or C#.	The application prototype was written in the C# language, and uses the Windows Presentation Foundation development framework.
1c	Is capable of running on a tabletop surface computing environment.	The application prototype runs on an Anoto-based tabletop surface computing environment. See Section 4.2 for more details.
1d	Can support input from multiple users simultaneously.	The application prototype is designed to handle simultaneous multi-user interaction. The software is currently designed to handle up to 6 concurrent users, though more are technically possible.
1e	Supports a level of security unique to each user at the table, and has the ability to track the user throughout interaction.	The application prototype currently tracks unique user input via multiple Anoto pens with unique system identities. The software uses this unique user input information to enable multiple levels of security. This security level information is currently mapped to decision authority in the software, which is then in turn, used to reveal or hide certain system functionality. The system also distinctly logs all pen interaction. The pen interaction logs can be viewed in the History Logs window, accessible from the system-level menu. See Section 4.3 for more details.
1f	Supports display of information in windows that can be arbitrarily rotated, sized and moved by different users.	The application prototype allows any user to rotate or move any system window to an arbitrary location and orientation in the interface using a simple touch-and-drag pen interaction. Any displayed information inside a rotated window is re-oriented automatically by the Windows Presentation Foundation (WPF) graphics engine. See Section 4.3 for more details.
1g	Supports the concept of assets, which are any unique physical property, containing a set of associated attributes.	The application prototype provides basic support for naval task group ship assets. Task group assets are tracked by the dynamic map display and visualized as friendly ships. Additional information for these task group assets can be displayed in the interface, including which onboard assets these ships contain (e.g. UAVs, helicopters, weapons, etc.)

Table 1. Overview of the project requirements and how the developed application prototype addresses these requirements (cont'd).

1h	Supports input of track information reports (track reports contain reported time and position information for entities tracked by an external system, together with an identifier unique for each track).	The application prototype dynamically displays (simulated) track information. Track data are provided to the application prototype by a real-time track simulation engine (provided by the DRDC PA) via a network socket. Tracks are visualized on a geospatial coordinate system using the InterMaphics mapping library. See Section 4.3 for more details.
1i	Supports a temporal display element.	The application prototype provides temporal information through the ability to visualize historical track location information in the map window. See Section 4.3 for more details.
1j	Supports the concept of assigned roles, where a role has certain specific abilities and security associated with it.	As described above, under requirement 1e, the application prototype provides user differentiation via uniquely system pens (Anoto digital ink pens). The software then uses this unique user input information to enable multiple levels of security. This security level information is mapped to decision authority in the software, which is then in turn, used to reveal or hide certain system functionality. See Section 4.3 for more details.
1k	The system shall support some level of configurability, where some options may be able to be specified on prototype instantiation or from a config file.	The application prototype provides a set-up screen on start-up to enable the user to configure the system before proceeding. For example, different maps or data files can be loaded.
1l	The system should support the ability to load and show different 2D and/or 3D maps.	The application prototype enables the user to load a selected map from a set of predefined 2D maps, both on system start-up or once the system is running. The map configuration option can be accessed through the system-level menu. There is currently no support for 3D map visualization.
1m	The system should support MIL-STD-2525B.	Track information is displayed using MIL-STD-2525B symbology. This functionality is provided by the InterMaphics mapping library being used in the application prototype.
1n	User interface tools should support the editing and addition of tracks and assets.	The application prototype allows dynamically updated tracks, originating from the track generator, to be reclassified by a user. In addition, simple, non-dynamically updated tracks can be added to or deleted from the geospatial map. A new track can be named and classified/reclassified as needed.

Table 1. Overview of the project requirements and how the developed application prototype addresses these requirements (cont'd).

1o	The system should support the ability to save the current display (all objects, windows, views, etc.) and the ability to restore a previous view.	The application prototype saves the following session data: • The current date/time. • All track information (track name, position, affiliation) for both simulator-based and added tracks. • All open window types and positions. • Any extra maps that have been displayed on top of the base map. Though all of these data are saved in the session file, the interface currently only makes use of the stored track information when restoring a saved session. This information is used to restore all tracks to their previous positions and affiliations in the maritime picture. If the stored scenario differs from the position pushed by the track simulator, the stored position is used. However, the logic of loading previous positions while a simulator is running needs further investigation as to the most suitable behaviour upon start-up. Also, further work is recommended to restore the non-track elements of the saved session due to programmatic issues of loading selected maps from InterMAPhics and identifying the contents of non-map windows (e.g. if a track window was open, which track was it displaying information for? Or, if the intelligence report window was open, which intelligence report was it displaying?).

4 Software Application Prototype: User Interface and System Architecture

Combining the system design requirements discussed above, a software application prototype was developed. In particular, an application prototype was developed that provides a generalized interface structure that supports access, manipulation, and sharing of geospatial and related data.

The application prototype is designed to support any number of modern naval mission scenarios, involving cooperative planning and decision making around maritime geospatial situation data. An operations team using the application interface could either be located at a land-based operations centre or on one of the task group ships equipped with a tabletop computer (or other location with access to data feeds related to building the maritime picture). The particular mission scenario currently implemented in the application prototype, chosen to demonstrate the system's capabilities for a modern naval mission scenario, is discussed in Section 4.1.

The remainder of this section details the design of the developed software application prototype, and is organized as follows:

- Section 4.1 describes the representative mission scenario that was chosen to demonstrate the application prototype's potential for use in modern naval operations.
- Section 4.2 describes the features of the targeted tabletop computing hardware platform for which the application prototype was designed
- Section 4.3 describes the user interface of the software application prototype
- Section 4.4 describes the system architecture of the application prototype

4.1 Representative Mission Scenario

A representative naval mission scenario was developed between the University of Waterloo and DRDC to facilitate the demonstration of the developed application prototype's utility for supporting naval operations. The DRDC PA provided a software engine to provide simulated track data to populate the maritime picture visualized in the developed application prototype.

As the Canadian Navy have recently played key roles in supporting international maritime interdiction operations, especially related to anti-piracy along important trade and shipping routes, a maritime piracy interdiction scenario was chosen.

To demonstrate how a collaborative, tabletop computer interface could be used by a naval team to foster collaborative planning and decision making during this type of maritime situation, the developed maritime piracy interdiction scenario was implemented in a track simulation engine by the DRDC Project Authority to emulate a live sensor data stream that is read by the developed prototype and displayed on the geospatial display of the developed prototype (see Section 4.3 for more details). Furthermore, the historical activity reports were made available in the application prototype via an Intelligence Report window.

4.2 Target Tabletop Hardware Platform

The developed application prototype is designed to run on a custom-built, top-projected Anoto-based tabletop computer hardware platform (Haller, 2007; Haller et al., 2006). This tabletop hardware platform enables user interaction using the Anoto digital ink pen technology[6]. This technology enables any flat surface to be turned into an interactive computer surface by using four main components:

1. a sheet of paper printed with a fine grid containing Anoto's proprietary dot-pattern,
2. a computer with a Bluetooth receiver,
3. a projector connected to the computer, and
4. an Anoto pen, which determines its precise position on the paper by reading the unique dot pattern using a tiny on-board camera.

The Anoto pen streams its position data to the computer in real-time via Bluetooth protocol. This paper-based position is coupled with the known location of the pixels in the projected display (based on a calibration process) to determine the pen's location in the projected display. The Anoto dot pattern is proprietary and can currently only be obtained for use in interactive surface solutions by becoming an official Anoto partner or by purchasing an Interactive Surface Development Kit, which includes rolls of paper from the Media Interaction Lab[7], in Hagenberg, Austria.

To protect the paper from damage due to repeated use, a thin sheet of acrylic can be placed on top of the paper. This approach also has the added benefit of keeping the paper fixed in place on the table, enabling accurate calibration with the projected surface. The custom-built tabletop platforms developed at the University of Waterloo currently use this approach. However, the acrylic layer tends to cause glare from the projector and from other point light sources in the room when the tabletop surface is viewed from certain angles. Another approach, recently developed by the Media Interaction Lab, is to laminate the Anoto paper using a durable matte laminate that can be affixed to a table or wall surface (Haller et al., 2010).

The Anoto-based tabletop hardware platform was selected for this project, over the more common multi-touch vision-based tabletop platforms discussed in Section 2.1, as it provides more of the desired system capabilities identified in Section 3, including:

- The ability to support multiple, co-located users interacting with the system simultaneously. Multiple Anoto pens can be tracked by the system simultaneously, enabling multi-user interaction on an Anoto-based surface.
- The ability to support operators located at any position around the table. The wireless tracking of the Anoto pens via Bluetooth enable mobility around the table. Thus users can move to any position around the table and still interact with the system.
- The ability to support user interaction on a horizontal surface orientation. As the Anoto paper can be placed on any surface, it enables interactive systems to be built at horizontal, vertical, and angled surface orientations.

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[6] http://www.anoto.com

[7] http://mi-lab.org

- The ability to support distinct operator roles and corresponding security, and operator distinction by the system. As the Anoto pens are uniquely tracked by the system (based on the unique serial number of each pen), pens can be assigned to specific users, and then can subsequently be associated in the software to a unique user profile that contains unique task role and/or security level information. Such 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, as described in Section 4.3.1.1.
- The ability to enable fine-grained input control. The Anoto pens provide stylus-tip accuracy. Moreover, the Anoto pens have a 75 Hz camera refresh rate in reading the Anoto fine grid pattern, providing a tracking resolution of 0.03mm. Another factor in providing fine-granted input is the display resolution provided by the table. The Anoto-based tabletop hardware platform at the University of Waterloo provides a tiled, dual-projector system that provides a 1536x2048 pixel virtual workspace across a 3'x4' physical surface. This provides acceptable resolution for a research prototype, but increased resolution would be recommended for an operational display, especially to support the display of detailed content or fine-grained annotation or hand-writing input.

In summary, the Anoto-based tabletop hardware platform provides the necessary features to enable the types of user interactions that were identified in the design requirements section. 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 thin sheet of plexiglass and a top projection set-up. Vision-based multi-touch tables typically require an assortment of other special-purpose pieces for a functional set-up, increasing both the cost of set-up and construction effort.

4.3 User Interface

Combining the system requirements described in Section 3, a tabletop interface concept was developed for supporting the mission scenario described in Section 4.1. The interface incorporating the tracking of maritime vessels was developed to run on the pen-based tabletop computing environment described in Section 4.2.

The concept behind the developed 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 user interface of the developed application prototype running on a 3x4 foot, dual-projected display tabletop hardware setup equipped with multiple Anoto digital pens.

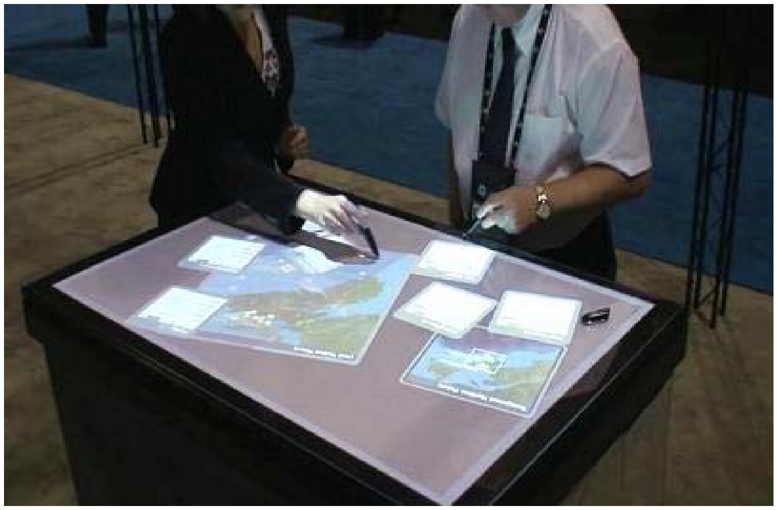

Figure 1. The application prototype interface running on a pen-based tabletop system.

When first initiated, the application prototype contains two map windows, one large and one small, each containing a different view of the maritime picture within an area of interest for the naval task group involved in the maritime piracy interdiction mission. The small window contains a high-level overview of the recognized maritime picture (RMP) for the task group's area of interest. The larger window contains a zoomed in, more detailed view of this maritime picture. This map window provides the team a local "sandbox" in which to make modifications to the RMP, based on incoming intelligence or local information. Changes made in this local window - for instance, an added or modified track - do not immediately appear in the RMP window, nor would they be propagated to the rest of the task group. Once the system users are satisfied with their modified picture, they can promote this picture via the tabletop interface; these changes are then applied to the RMP window and would also shared with the rest of the task group.

A number of additional windows can also be invoked in the interface to support the mission scenario, such as track information windows, intelligence report windows, and system configuration windows.

The value of the developed application prototype is not in the manner in which maritime picture data is visualized, in fact no new contributions are made on visualizing such data, but rather, the value of the developed application prototype is that it provides new interface mechanisms for accessing, manipulating, and sharing such data. The application interface provides a number of interaction and interface components optimized for collaborative use on a horizontal (i.e. tabletop) workspace. More specifically, the user interface enables simultaneous use by multiple people, who each 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; that is, users can interact with the system from any side of the tabletop workspace, and multiple people can be interacting with the system from different sides of the table simultaneously. The following sections described the interface components and functionality that enable these capabilities.

4.3.1 Multi-user Support

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 action, initiated anywhere on the window border. The map 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 interface 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.

Figure 2. The system provides adjustable windows to enable use from any side of the table.

As mentioned in Section 4.2, the application prototype 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 interacts with the table. Thus, this input technique enables each pen, and thus each associated user, to be uniquely tracked by the system. Unlike many popular “multi-touch” tabletop computing platforms (e.g. Microsoft Surface[8], or Perceptive Pixel’s Multi-touch Wall and Table Systems[9]), the ability to distinguish between different users interacting with the system

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[8] http://www.microsoft.com/surface

[9] http://perceptivepixel.com

provides a true “multi-user” system. This information can then be used to tailor the interface based on the interacting user’s security level or task role, as described in the following section.

4.3.1.1 Per User Interface Tailoring based on Security Level or Role

The unique pen tracking provided by the Anoto digital pen technology 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 application prototype, this distinct user information is used to associate a particular security level to each pen, though this information could easily be mapped instead to another distinct user characteristic, such as task role. The security level maps to various levels of decision authority within the system, and again, this functionality could be modified to map security level to, for instance, data access privileges.

The use of this authority/security information in the application prototype is currently limited to determining which system options are displayed in the pop-up menus available in the map windows. For example, only a user with the highest authority/security level (Level 4) is presented the options to add a track to the maritime picture or to promote the changes made to the situation map to the entire task group. Users with less system authority do not have access to these capabilities when they invoke the same menu, and thus these system options are grayed out on the menu (Figure 3).

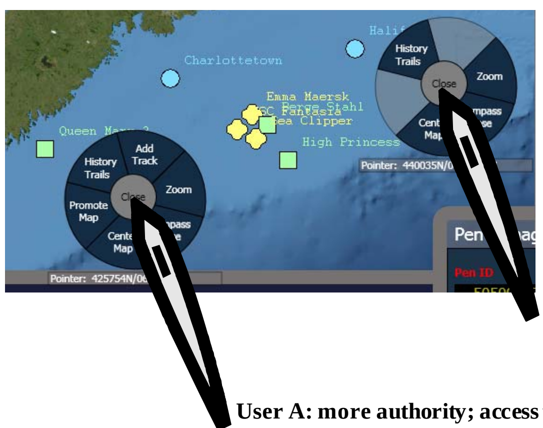

Figure 3. Interface tailoring for users with different security levels.

4.3.2 360-degree, Collaborative Interface

The application prototype also provides improved window management techniques in the digital workspace to better support the large, horizontal nature of a tabletop computer that invites multiple people to gather around its surface while collaborating over shared data. As mentioned above, and shown in Figure 2, any interface window can be easily rotated to enable the interface content to be viewed from any angle around the table, with a simple touch and drag pen motion, called Rotate ’N Translate, or RNT, which is a commonly used manual rotation interaction technique used on interactive tabletops (Kruger, Carpendale, Scott, & Tang, 2005).

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 (see Figure 4). These menus are invoked by touching the virtual border surrounding the tabletop interface (the grey border shown in Figure 4). The menu then appears at the selected location, appropriately oriented, to facilitate various seating positions around the tabletop interface.

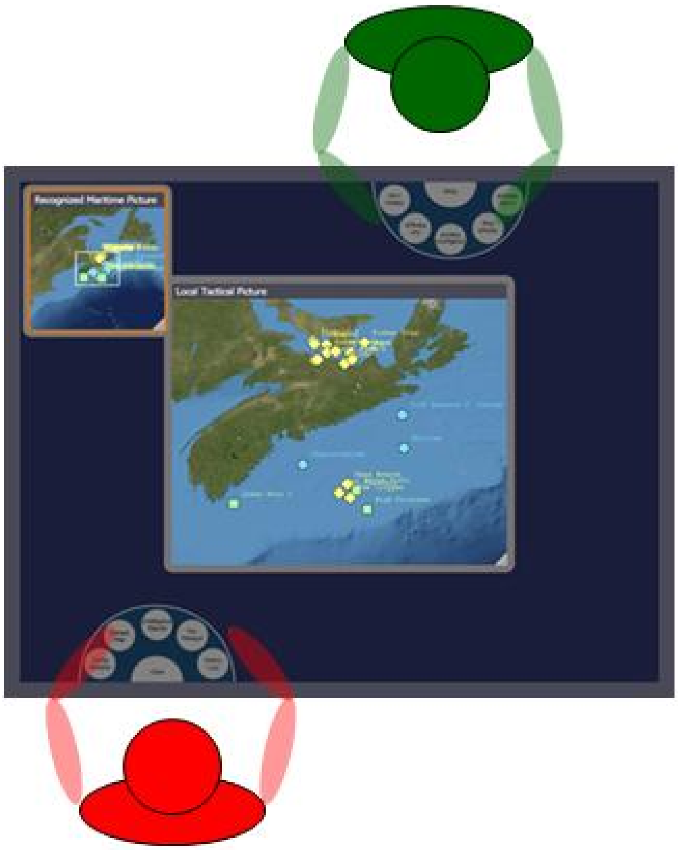

Figure 4. System-level menus are accessible from any side of the table.

- *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 in the map window toward the side of the table associated with the activating pen (Figure 5). This system feature is only partially working; due to issues with tracking the various coordinate systems used in the application software, and in particular some automatic component rotation handled by the Windows Presentation Foundation (WPF) rendering framework, the rotation offset is not displaying accurately when the main map window is re-oriented away from its initial orthogonal position. Further investigation is needed into WPF component handling to address this issue.

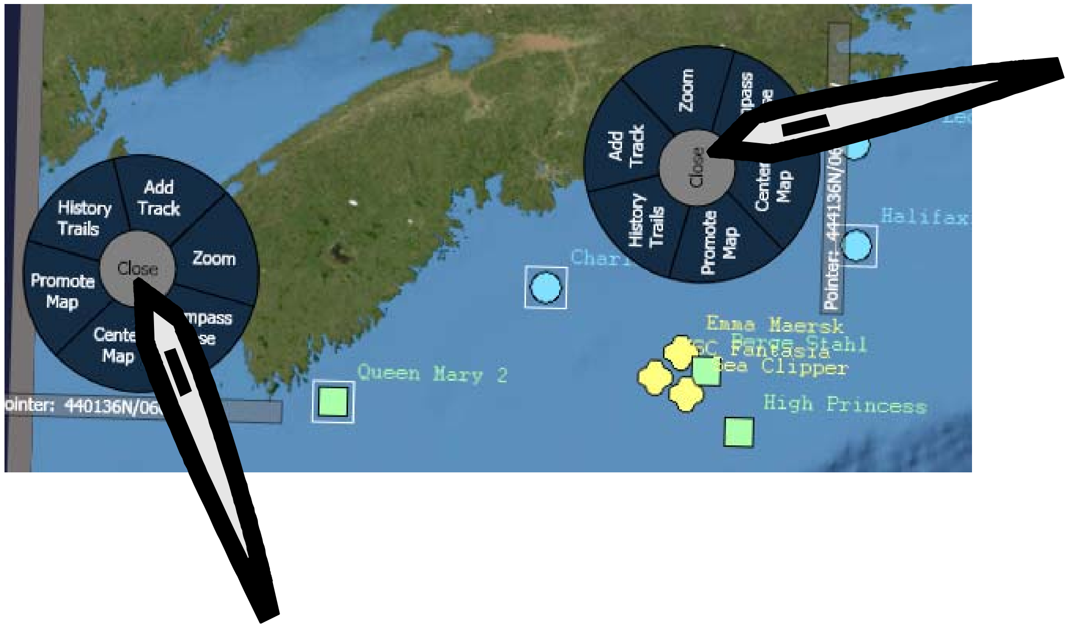

Figure 5. Pop-up menus are automatically rotated toward the table edge associated with the activating pen.

This section outlined the main features of the user interface of the developed application prototype.

4.4 Overview of the Software Architecture

This section outlines the design of the software architecture of the developed software application prototype. The aim, here, is to give the reader a broad understanding of how the developed software interacts with other software technologies.

The application prototype was developed using the Windows Presentation Foundation (WPF)[10] software development framework (version v3.5.40619.1) and the C# object-oriented language. Gallium Visual System's InterMAPhics[11] geospatial visualization engine (v7.10.1000 for Windows XP[12]) was used for visualizing map data in the user interface. The prototype runs on the Windows XP operating system.

Figure 6 shows a high-level system overview of the developed prototype, called ASPECTS (Asset Planning Employing Collaborative Tabletop Systems). This diagram illustrates the dependencies of the ASPECTS software with other technologies, including:

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[10] http://windowsclient.net/wpf

[11] http://gallium.com

[12] A customized version of this InterMAPhics library was used, which addressed a conflicting window-handling issue between the original InterMAPhics and the WFP rendering engines.

- the simulation engine (Data Simulator) provided by DRDC-Atlantic that supplies the track data visualized in the ASPECTS user interface,
- the InterMAPhics library that provides support for map visualization and track management,
- the Windows XP operating system that provides basic input/output events, including limited mouse interaction and output display capabilities, and
- the Anoto-based digital pen technology that provides positional and identity data for the Anoto pens.

This figure demonstrates, at a high-level, how the application software interacts with the software operating system platform and the tabletop hardware platform.

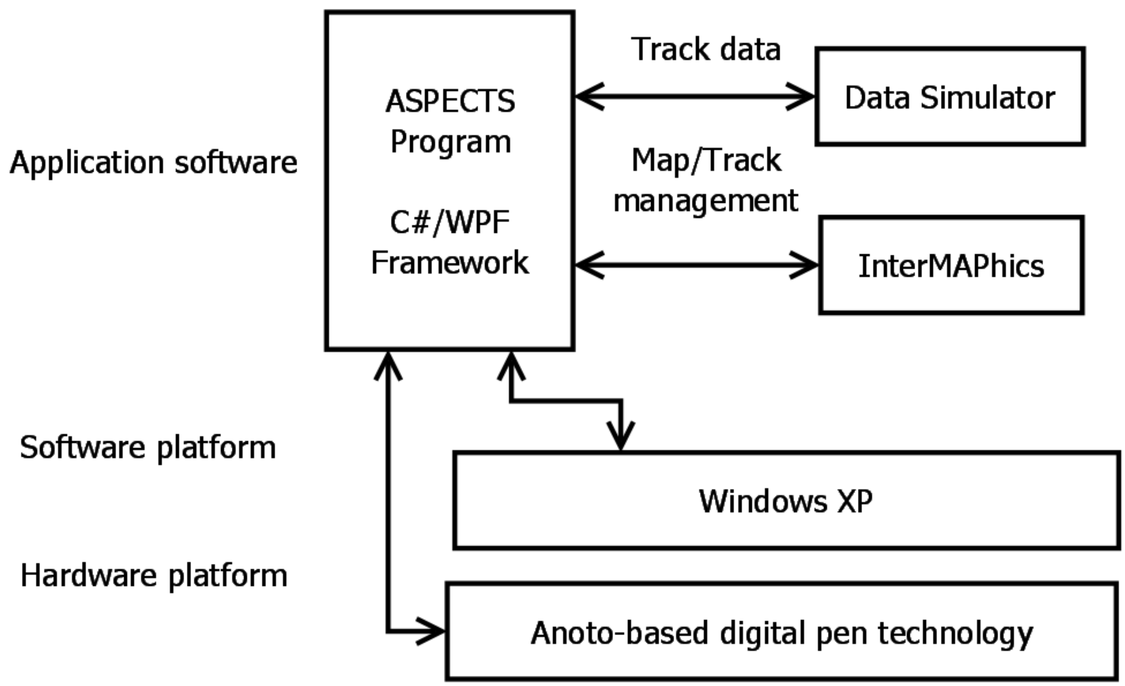

Figure 6. High-level system overview of the application prototype (called the ASPECTS program), showing its connections to support technologies.

Figure 7 provides an overview of the main software components included in the ASPECTS software application, and the connections between these components and the external dependencies discussed above. In particular, the ASPECTS application includes two main internal components, TestApp and AspectsControlLib. TestApp contains the software program's entry point, including its "main" method, its main interface window, and its instantiating classes. AspectsControlLib contains all the helper classes that provide the core software functionality of the application prototype.

AspectsControlLib comprises four main class packages:

- Simulator. This class package handles all interaction with the Data Simulator, which provides the simulated tracks used in the application prototype.

- InterMAPhics. This class package provides all map-related software functionality, based on the InterMAPhics software library capabilities.
- AspectsUserControl. This class package provides the functionality for all user controllable objects in the interface, including content windows, menus, rotation interactions, etc.
- Anoto. This class package manages the input data from the Anoto digital pen technology.

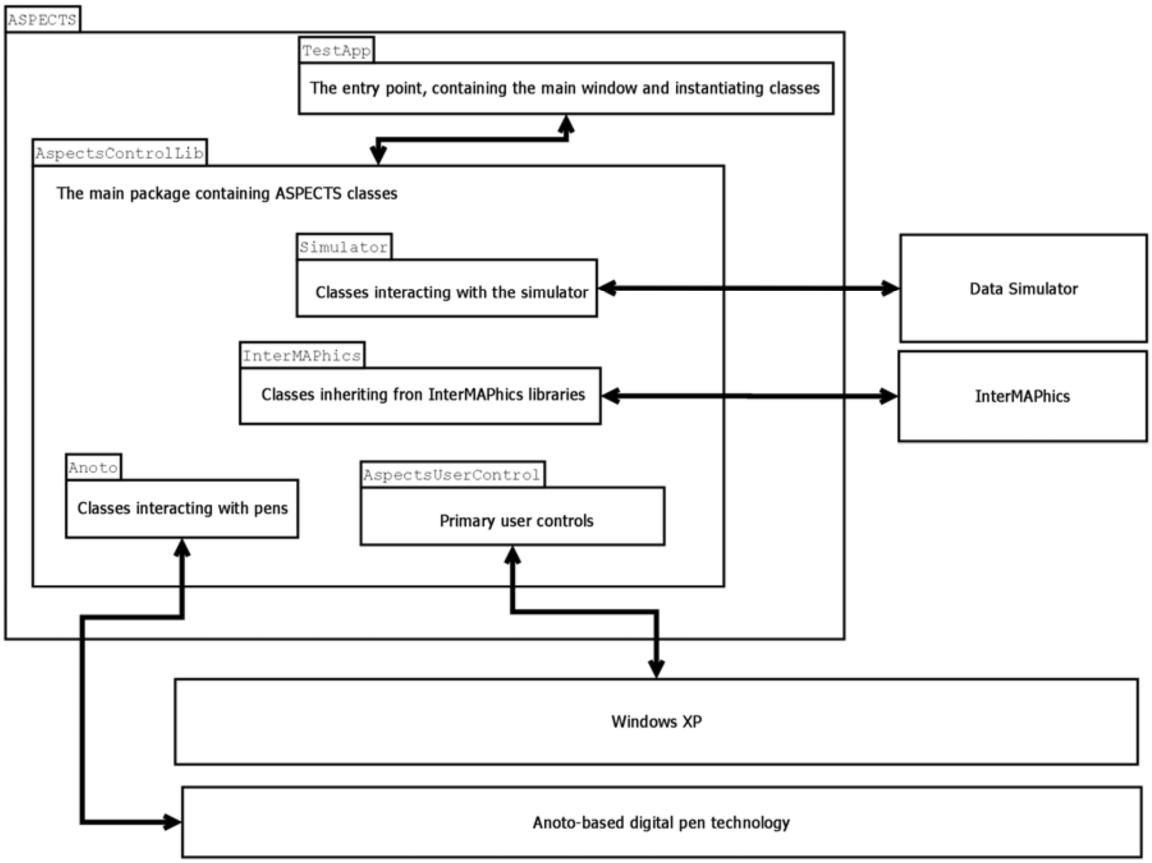

Figure 7. Overview of the internal structure of the application prototype.

5 Project 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 was 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 December 2009 in Orlando, Florida in order to obtain initial feedback on the system concept. In addition, the project has been briefed to the wider DRDC-Atlantic scientific community in Dartmouth, Nova Scotia in January 2010.

The application prototype has also been demonstrated to personnel involved in the emergency response / first responder domains: at a recent Open House event at the University of Waterloo in February 2010, which showcased Dr. Stacey Scott's ongoing tabletop research, personnel from the Waterloo Region's emergency response organization (called REACT), and a Waterloo-based company (Aeryon Labs) that develops micro-Unmanned Aerial Vehicle (UAV) systems designed to support first responder situations, had the opportunity to interact with the prototype.

For the majority of these people, military and non-military alike, these demonstrations have 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, in both the military and other time-critical domains. 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, the following additional design criteria have been identified:

- 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 potential obstacle to access the operational community for user trials, as wireless (including Bluetooth) is restricted in many secure military complexes.
- 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 the gesture-based input used in 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.
- 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.
- 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.

In summary, the application prototype has already begun to serve the intended purpose of concept demonstrator. The initial demonstrations have had extremely encouraging response from subject-matter experts, indicating that continuation of the Crown's research program is justified.

6 Conclusions, Limitations, and Recommendations

This project has produced an initial software application prototype that has already begun to serve its intended purpose as a concepts demonstrator of potentially new ways to support collaborative planning and decision making activities during naval operations. Initial feedback from subject matter experts at several technology demonstration events has been very positive and provides solid encouragement for DRDC Atlantic's continuation of the project. This feedback also helps to identify additional insights and design criteria that should be take into consideration in future iterations of tabletop computing technology for naval, or other, contexts.

It is hoped that by opening the door to tabletop computing for use in the Canadian Naval environment 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.

6.1 Limitations

As an initial software development project in a new arena of applications, and in a limited time scale, there are not surprisingly several limitations to the developed application prototype. This development project involved the development of a user interface involving many technologies that have never before been used together (for example, InterMAPhics has never before been used with the WPF software development framework), and as such contains several first attempts in unexplored areas. Some of these attempts led to effective solutions that should be maintained, where other attempts led to solutions that provided working functionality for demonstration purposes but provide non-ideal, in some cases non-scalable, in other cases, inelegant, solutions that need further investigations. And finally, in a few cases, the challenges posed by this technology integration and novel application area led to unsuccessful attempts to produce the desired functionality. These software limitations are outlined below.

Scale limitations:

- Though the Anoto digital pen technology can handle up to seven pens per Bluetooth receiver attached to the system, enabling a large number of possible users, the developed prototype only currently supports the use of six pens. This decision was made based on the expected needs of a demonstration prototype at a 3'x4' table; thus, only six pens are tracked by the system, and subsequently displayed in the History Logs window.
- The Intelligence Reports window currently displays a fixed number (three) reports from the intelligence report XML file. This functionality was sufficient for setting up the mission scenario for demonstration purposes, but the software should be extended to read an unknown number of reports. Further improvements would involve pushing the intelligence reports to the interface from a full experimental simulation engine (discussed in the next section), rather than pulling the information from an XML file, as is currently done. This would enable reports to appear in the interface at predetermined (or random) times during a running mission scenario.

Performance limitations:

- Resizing a map window can be quite slow. The source (or sources) of this lag is currently unclear, but is likely due to a work around currently used for drawing InterMAPhics map viewports in WPF windows. This resizing occasionally results in the application crashing.
- The Save Session functionality is currently limited. In the current prototype, all track-related information is restored when a saved session is loaded upon application start-up, but the previously opened windows, and any unpromoted tracks in the Local Tactical Picture window are not restored. Additionally, if the track simulation engine is not running when the session is restored in the application prototype, the MILSTD-2525B symbology is not loaded, but instead black dots appear in the locations of the loaded tracks. Further investigation is needed to determine why the InterMAPhics draw commands are not producing the desired graphics in this particular situation. More importantly, it was decided to omit additional save functionality, such as historical states of tracks, and unpromoted tracks, in lieu of a full experimental simulation engine (discussed in the next section). The addition of such a simulation engine would simplify (and generalize) saving and restoring this type of information.

Interface behaviour limitations:

- The automatic re-orienting of the map menu based on the side of the table a pen is registered to is currently not working correctly if the Local Tactical Picture map window is adjusted away from its original orientation: the map menu is oriented using an absolute angle and does not account for the additional rotation angle of the Local Tactical Picture. Further investigation is needed to clarify how WPF handles its component rotation in order to gain access to this information on-the-fly and include this rotation angle to properly determine the angle needed to place the map menu to face the appropriate table edge. The challenge here is dealing with multiple levels of coordinate systems involved in the WPF application environment, especially as it natively handles rotation of windows, hiding much of this functionality (and subsequent rotation matrices) from the application developer.
- The application prototype sufficiently demonstrates the system's ability to track unique pens and to use this information for interface tailoring, e.g. displaying or hiding certain menu options based on a pen's associated security level. However, significant improvements could be made to display or use this information more elegantly in the application interface. For example, each pen contains an ID, an orientation, and a security level. It could contain additional features that could be used by the interface, including a name (or full user profile) or color to better link the pen and the user. This information could then be used in the interface; for example, tracks selected by a certain user could be highlighted by their associated color.
- The application prototype currently provides limited ability to modify added tracks to the Local Tactical Picture. It allows a user to rename the track from a default numeric identifier that is automatically assigned, to classify the track and set the certainty of that classification, and to delete the track once created. There is currently no functionality to reposition the track from its original location, or to provide any related positional information (e.g. speed or heading). These types of functionalities would be greatly facilitated by the creation of a full experimental simulation engine (discussed in the next section).

- Finally, the application prototype does not currently provide support for 3D map viewing. As the map windows can be rotated in the interface, multiple people can simultaneously view the maps from different angles. Thus, it was unclear how best to provide the 3D views to prevent confusion during shared viewing over the data, as 3D views on a 2D computer display typically relies on various shading techniques to show depth and contours. Such shading assumes a certain viewing angle, which may not be the case when a window is rotated. As this issue requires further investigation, potentially involving comprehension studies being conducted to determine appropriate 3D views for multi-user tabletop viewing, this it was determined to be beyond the scope of the project.

6.2 Recommendations

As an initial foray into the development of a tabletop interface for supporting naval planning and decision making, this project sets the stage for several continuing lines of research and development. This initial development project uncovered several key challenges in developing more complex tabletop interfaces, as useful supporting technologies (e.g. mapping technologies, and native windowing technologies) do not currently support the multi-user paradigm nor are they designed to provide 360-degree interfaces. Thus, should DRDC-Atlantic continue with this project, it is strongly recommended that software engineering efforts be undertaken to further investigate software compatibility issues between the current set of technologies used. Investigations of potential replacement technologies may be warranted to discover whether more compatible technologies exist, or need to be developed. In particular, the InterMAPhics map visualization engine, while providing an extremely useful set of mapping tools (currently under utilized by the application prototype), provides a fundamental graphics rendering conflict with the WPF development framework (as discussed on p. 19), which is currently resolved with a non-optimal work around provided by Gallium Visual Systems. This issue needs to be resolved to improve interaction performance in the interface.

It is also strongly recommended, should DRDC-Atlantic choose to continue with this project, that a fully functional simulation engine be developed, as mentioned in the preceding section. Such a simulation engine, similar to a gaming engine, would interact more closely with the tabletop interface, to fully enable pre-scripted, or Wizard-of-Oz type[13], interface behaviours, beyond the track data supplied by the current track simulation engine. Though beyond the scope of this project, it quickly became clear during the development of this project that such a simulation engine would have been very useful for designing scenarios for demonstrations, and ultimately for supporting user experimentation of the development application prototype. In particular, more communication channels are recommended between the application prototype and the simulation engine, so that user interaction can be fed back into the simulation engine to keep the current "game state." If all state information were kept in the simulation engine, this would simplify saving and restoring sessions and user logging. It would also enable "scrubbing" through

[13] A Wizard-of-Oz experiment involves "faking" some of the system's capabilities by manually driving inserting behaviours into the system for a study participant/user to respond to a given times or situations during an experiment. An example of this would be if, while a user is enacting a mission scenario in a simulated virtual world environment, the experimenter could initiate particular system behaviours, for instant, sending the user a certain piece of intelligence, once the user reached a certain state, or made a certain decision. This method is used enables the testing of certain, usually artificial intelligence, or advanced automation, capability before they are fully implement (or even feasible).

historical data to support debriefing scenarios during or at the end of a mission to support personnel training or retrospective interviews during user experiments.

Formal testing of the application prototype for both usability and performance effectiveness is also recommended. Though the prototype has garnered positive feedback from subject matter experts during initial technology demonstrations, more rigorous data collection in a more controlled setting is recommended in order to isolate the strengths and weaknesses of the current prototype design. It is also recommended that a series of empirical evaluations be undertaken with the explicit goal of identifying the specific benefits offered by tabletop computing technology in naval / military operational contexts. This recommendation stems from feedback gained from Canadian Forces personnel that indicated that such empirical evidence would be needed to justify the inclusion of tabletop computing requirements in future naval platforms.

Finally, another direction that warrants further investigation 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.

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