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Supporting intelligent and trustworthy maritime path planning decisions

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Abstract

The risk of maritime collisions and groundings has dramatically increased in the past five years despite technological advancements such as GPS-based navigation tools and electronic charts, which may add to, instead of reduce, workload. We propose that an automated path planning tool for littoral navigation can reduce workload and improve the overall system efficiency, particularly under time pressure. To this end, a maritime automated path planner (MAPP) was developed, incorporating information requirements developed from a cognitive task analysis, with special emphasis on designing for trust. Human-in-the-loop experimental results showed that MAPP was successful in reducing the time required to generate an optimized path, as well as reducing path lengths. The results also showed that while users gave the tool high acceptance ratings, they rated the MAPP as average for trust, which we propose is the appropriate level of trust for such a system.

Keywords: Path planning; Decision support; Trust; Maritime; Navigation

1. Introduction

After a significant worldwide decline in serious navigation-related commercial maritime accidents from 1987 to 2002, the past five years have seen a significant spike in these accidents to levels not seen in more than 20 years (Richardsen, 2008). This recent trend is also reflected in the United States maritime operations with a recent similar spike in the US Navy accidents. Furthermore, in the past 25 years, the National Transportation Safety Board (NTSB) has investigated more than 50 collisions (with other ships and infrastructure such as bridges), and running aground incidents[1]. Collisions and groundings now account for 60% of the most costly maritime accidents, and in the current climate, a ship is twice as likely to be involved in a serious grounding and collision as compared to only five years ago (Richardsen, 2008). In all cases, human error is cited as a central cause, but other more latent causes that have been identified include a lack of situation awareness, an undersupply of crew, and high workload in navigation settings.

In coastal and high density traffic settings, when unexpected events occur that require immediate route re-planning, such as erratic movements of other maritime traffic, resultant plotting and charting can take several minutes, even with electronic displays. Navigation in congested and littoral regions causes significant navigator stress (Grabowski and Sanborn, 2003), as course replans and small adjustments occur frequently, increasing the navigator workload. Increases in mental workload, shown to be intricately linked with losses of situation awareness (Endsley, 1993), can lead to increased chances of allisions or collision (Grabowski and Sanborn, 2003).

Navigation is an inherently complex cognitive task since it typically involves multiple variables, many of which are uncertain (such as currents and other ships' movements) that must be optimized to some objective function, often under time pressure (Hutchins, 1995). Moreover, navigation in coastal and especially harbor areas is especially demanding and in military settings can require up to ten

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[1]The NTSB does not investigate every incident, only those of major significance.

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different people: the navigator, assistant to the navigator, navigation plotter, navigation bearing recorder/timer, starboard and port pelorus (a compass attached to a sighting telescope) operators, restricted maneuvering helmsman, quartermaster of the watch, restricted maneuvering helmsman in after-steering and fathometer (depth) operator (Hutchins, 1995). Planning courses under time pressure, while not typically an issue for open ocean vessels, is particularly problematic for military littoral warships and fast patrol boats.

For ships equipped with the most modern technology (typically large commercial vessels), a merchant ship navigator can plot a course on an electronic map with zoom capability, which can be configured to show different layers of information such as weather and depths. In addition, some ships have radar systems that automatically identify and track other vessels in the water, such as the Automatic Identification System (AIS), which can transmit positions and speeds to an electronic display, if a ship has that capability. However, there is currently a lack of sufficient integration between the systems (Lee and Sanquist, 1996; Perrow, 1984), creating more demand on operators to process and integrate the data presented to them (Lee and Sanquist, 2000; Urbanski et al., 2008). Moreover, such electronic aids have been shown to be useful in low stress settings, but problematic in high stress scenarios (Grabowski and Sanborn, 2003). This problem is not just a maritime one, as the aviation industry has struggled with similar issues of increased workload with increased automation (Billings, 1997).

Not all maritime organizations use these electronic tools, and many ships, including most US military ships, still rely on the traditional paper chart method for navigation. The tools used in plotting ships' path can include an alidade, which is a device that sights a landmark to measure the spatial relationship between the home ship and that landmark, the hoey, which is a one-arm protractor used in translating the angular relationship between the home ship and a landmark into a map bearing, parallel rulers, parallel motion protractors, compasses, distance scales and dividers for measuring distances (Hutchins, 1995). These devices all have degrees of error in accuracy and training and experience play a significant role in path quality and time to plot a path.

Time to plot a path can be a significant stressor in high workload navigation environments such as dense coastal settings. Personnel who plot courses on paper charts experience high mental workload when faced with the need to rapidly replan and chart in the face of new information, such as the presence of unexpected radar contacts or rapidly advancing weather. In some military operations, some ship captains will bring their vessels to a halt while attempting to replan a new course because of an unexpected event, which has clear negative mission implications, particularly in terms of time pressure.

We propose that both in paper and in electronic chart systems, what is needed to reduce workload in time-pressured navigation tasks is a decision support tool that integrates various sources of critical navigation information via an automated path planner and a user-centered visualization. Leveraging an intelligent path planning tool could greatly increase the accuracy and speed of planning a path, as well as reduce workload and error, and possibly manning requirements. While current electronic displays provide descriptive representations of the navigation environment and some limited predictions (e.g., where contacts are likely going), no tool currently in operational settings has effectively leveraged some form of intelligent decision support to aid humans in this demanding task.

Little research has investigated the use of automated path planning in maritime navigation. Rothgeb (2008) demonstrated that a fuzzy logic neural net could be used to identify high risk areas of transit given known contacts, as well as generate a recommended course based on safe areas. However, this research was focused on contact management, and not on the more holistic problem of path planning given additional variables such as weather and operator experience. In another related effort, Smierzchalski and Michalewicz (1998) developed an automatic path planner that accounts for surrounding contacts and their future positions, as well as physical characteristics of the ship such as weight, center of gravity and size of control surfaces. Their proposed algorithm, EP/N++, a variant of the evolutionary planner/navigator (EP/N) algorithm for mobile robots (Xiao et al., 1997), randomly generates acceptable paths for getting a ship from one point to another as a function of least cost. This randomized approach causes the solutions to be near-optimal at best, with the optimal solution traded for algorithm speed. This research is somewhat limited, as the proposed algorithm only takes into account up to three contacts in the vessel's area of observation, and it does not address uncertainties for future contact positions. In addition, while the algorithms were tested in limited scenarios, no human-in-the-loop trials were ever conducted with any functional decision support tool based on the automated path planner.

Although automated path planning research in maritime navigation is limited, there is extensive research in the field of robotic path planning, which can provide useful insights to maritime navigation. Path planning in navigation is a large area of research in the computer science field (Winston., 1992), with significant research conducted in robotic path planning (e.g., (LaValle, 2006; Russell and Norvig, 2003; Thrun et al., 2005). As will be discussed in more depth in the next section, given this previous research, we elected to use the A^* algorithm for our automated path planner, which is an informed search method that can quickly find an optimal path to a destination, given our relatively constrained state space.

While an automated path-planner algorithm that is accurate and fast is critical for the maritime navigation problem, equally as important is the development of an