International Journal of Information, Control and Computer Sciences
ISSN: 2517-9942
Vol:11, No:1, 2017

Augmenting Navigational Aids: The Development of an Assistive Maritime Navigation Application

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***Abstract*—**On the bridge of a ship the officers are looking for visual aids to guide navigation in order to reconcile the outside world with the position communicated by the digital navigation system. Aids to navigation include: Lighthouses, lightships, sector lights, beacons, buoys, and others. They are designed to help navigators calculate their position, establish their course or avoid dangers. In poor visibility and dense traffic areas, it can be very difficult to identify these critical aids to guide navigation. The paper presents the usage of Augmented Reality (AR) as a means to present digital information about these aids to support navigation. To date, nautical navigation related mobile AR applications have been limited to the leisure industry. If proved viable, this prototype can facilitate the creation of other similar applications that could help commercial officers with navigation. While adopting a user centered design approach, the team has developed the prototype based on insights from initial research carried on board of several ships. The prototype, built on Nexus 9 tablet and Wikitude, features a head-up display of the navigational aids (lights) in the area, presented in AR and a bird's eye view mode presented on a simplified map. The application employs the aids to navigation data managed by Hydrographic Offices and the tablet's sensors: GPS, gyroscope, accelerometer, compass and camera. Sea trials on board of a Navy and a commercial ship revealed the end-users' interest in using the application and further possibility of other data to be presented in AR. The application calculates the GPS position of the ship, the bearing and distance to the navigational aids; all within a high level of accuracy. However, during testing several issues were highlighted which need to be resolved as the prototype is developed further. The prototype stretched the capabilities of Wikitude, loading over 500 objects during tests in a major port. This overloaded the display and required over 45 seconds to load the data. Therefore, extra filters for the navigational aids are being considered in order to declutter the screen. At night, the camera is not powerful enough to distinguish all the lights in the area. Also, magnetic interference with the bridge of the ship generated a continuous compass error of the AR display that varied between 5 and 12 degrees. The deviation of the compass was consistent over the whole testing durations so the team is now looking at the possibility of allowing users to manually calibrate the compass. It is expected that for the usage of AR in professional maritime contexts, further development of existing AR tools and hardware is needed. Designers will also need to implement a user-centered design approach in order to create better interfaces and display technologies for enhanced solutions to aid navigation.

***Keywords*—**Compass error, GPS, maritime navigation, mobile augmented reality.

I. Introduction

DESPITE digitization of navigation, mariners are trained that for safe navigation they must crosscheck what they visually see out from the bridge, with information provided by the radar and finally the charts [1].

Across the world, aids to navigation have been introduced to provide visual assistance for navigating officers [2]. They are devices or structures external to the ship, designed to assist in determination of position, to define a safe course, or to warn of dangers or obstructions [3], [4]. The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA)) states that these devices or structures include: Lighthouses, lightships, sector lights, beacons, buoys, and others [3].

Before 1977, there were over 30 different navigational aid systems which caused confusion and complications for maritime users [5]. Therefore, these were reduced to just two, approved by the IALA, which are in use today. This standardization allows mariners to easily recognize aids to navigation depending on their shape, color, top mark and characteristics of the light: intensity, sector, range, height, frequency, and color) [5].

Depending on the scale of the charts, aids to navigation are marked on a chart with a symbol primarily determining the type of aid to navigation and characteristics of the light (color, frequency sector and range) [2], [5].

Any further details about the lights are available by further enquiring a digital navigation chart. Traditionally the List of Lights and Fog Signals published by Hydrographic Offices presents in a table format the details about each light including position, height, and elevation, description of structure and characteristics of the light [5]. The List of Lights is currently available in analogue and digital format. The digital version is available only for desktop computers or laptops.

When approaching a port at night or in low visibility, it is increasingly difficult for mariners to distinguish between backgrounds with many other lights visible which are the aids to navigation. For example, a beacon could be confused with an intense street light or building light on the coastline or in the port [6].

AR has been used successfully previously in offering visual clues to assist navigation and localization of places of interest for other purposes such as tourist guides [7], [8]. In this paper, we present our exploration of employing AR to assist with the visual identification of aids to navigation at sea.

To date, applications featuring AR for maritime navigation have been developed to run on laptops connected to cameras installed on the ship and the sensors of the ship: Global Positioning System (GPS), gyroscope, compass, and the electronic charts data. The development of such applications has mainly focused on the military sector. Developed by the

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Office of Naval Research with industry partner Technology Systems Inc., AR Visualization for the Common Operational Picture (ARVCOP) system, runs on a laptop and overlays in the real world view information that is important to the situational awareness [9]. The displayed information includes: position of aids to navigation, ship's course and route.

Applications running on tablets or mobile phones featuring AR to assist navigation at sea have currently been limited to leisure users [9]-[11]. These include: Marine Traffic - Ship Tracking, Pocket Mariner Ltd (Boat Beacon - AIS Marine Navigation, Compass Eye Bearing Compass & Marine Navigation, SeaNav - HD Nautical Charts and Marine Navigation, Boat Watch; Now Technology Systems Inc. (TSI) (SmartChart AIS). However most of these applications need a good internet connection which is not widely available for the commercial navigating officers or are limited to United States and United Kingdom chart areas [10].

II. Aim

This paper presents the development of an AR list of lights prototype application to assist navigation at sea. The application is running on an Android tablet and has been specially developed to assist the navigation of not only commercial ships, such as container, tankers and passengers' ships, but also naval ships. The paper aims to highlight issues identified so far in the development of such an application and the usage of AR on the bridge of a large ship.

III. Methodology

The development of the application follows a User Centered Design (UCD) process. This approach has been selected in order to insure that the outcome product is developed according to requirements formulated from end-user research and is validated with user tests running within the environment where the application is to be used. Such approach minimizes risks and increases the usability of the product [12].

The application is currently in its third development iteration. This paper presents the initial end-user research and the completed two design iterations. The data available within the List of Lights managed by Hydrographic Offices have been used to build the application.

The development team also decided to develop the application first in Android and then extend it to iOS.

IV. User Research

The concept for the application is based on an in-depth ethnographic research conducted on board of a variety of different ships, commercial (cargo and passenger) as well as naval. The study concentrated on the interaction between the navigating officers and the current devices which they used for navigation. One of the emerging themes, from the analysis of the interviews with navigation crew and contextual observations, was the usage of aids to navigation such as lights.

A number of insights regarding lights were identified:

- Regardless whether the ship was navigating on digital or paper nautical charts, the officers of watch, the captain and the pilots were using lights as marks for navigation.
- In day light and good visibility, officers identified the lights based on the structure of the lights and not the characteristics of the light.
- At night, providing that the visibility allowed for sighting of the light, the officers were able to identify the lights based on their characteristics: Light color, frequency, elevation and sector.
- In poor visibility, the officers of watch used the fog signals installed on some of the lights to identify them.
- The gyroscope installed on the bridge of the ships and the bridge wings is used to take visual bearings to a light. These visual bearings are used for plotting the positon of the ship on a chart and checking the GPS accuracy.
- Sector lights and lights of direction are used to check the course of the ship.
- Close to shore areas, the light emitted by street lighting or from buildings can easily be confused with an aid to navigation particularly at night or in poor visibility. It is challenging for the crew to identify the aid to navigation with all the other lights on the background.
- Identifying the correct light is very important for the safety of navigation. Waypoints in the passage plan and particularly the ones with course changes are strategically positioned next to an aid to navigation to allow position and direction checks.
- The list of lights is usually consulted at the back of the bridge where second officer creates the passage plan. The List of Lights and Fog Signals have not changed their design. The information about lights is presented in a table format. The lack of pictures of the actual lights makes it difficult for the mariners to identify a light based on these publications.
- Officers use the position of a light and its characteristics to distinguish between several lights.
- Accessing detailed information about lights is very time consuming and officers would only do this if they have to in order to resolve issues or confusion regarding light navigation.
- Officers are using major lights with range of over 15 nautical miles (nM) during costal navigation. They include the minor lights and buoyage (with range of less than 15 nM) for shallow waters navigation.
- Mariners are familiar with the usage of applications on mobile devices. However, the majority of companies ban mobile phones and tablets on the bridge of the ships so that the attention of the navigating crew is not disturbed by their usage.
- Accessing the Internet on board of a ship is restricted by the band width.
- The data about aids to navigation are updated weekly. It is the duty of the second officer to update the products presenting aids to navigation, such as charts and publications. The ship might be carrying only analogue, digital product or a mix of the two. Updating the analogue products can only be done manually and it is very time

consuming. Updating digital products can be done automatically, it saves time and it is preferred by the interviewed second officers.

The conclusion of the in-depth ethnographic user research identified the need for quick access to information about lights at the front of the bridge which would help navigating officers identify the aids to navigation during day, night and in diverse weather conditions.

V. Concept Development

The concept has been developed based on the requirements gathered during the user research. Six main functions have been identified for the prototype:

- *Presentation of lights in “highway” view mode* - This enables the users to identify quickly the position of lights in the proximity of the ship. The highway view is meant to enable a real-life view of the lights. While in highway mode, the users can point the touchscreen device to a selected location and visualize on the screen the lights located in that direction. In the highway mode, the lights are to be displayed in format on the background captured by the digital device’s camera.
- *Presentation of lights in “birds eye” view mode* - The birds eye view displays the lights in the proximity of the ship on top of a simplified geo display. By zooming in and out and panning the geo display will also present the lights located further away from the user’s location.
- *Presentation of the characteristics of the lights* - This function allows the users to access detailed information regarding the lights: Name of light, position, bearing to the light, range, sector, elevation and structure of the light.
- *Presentation of bearing and distance to a light* - During navigation and planning specific information about the bearing and distance to the light is required. This function helps facilitate the estimative identification of position of the seafarer compared to the lights.
- *Filtration of lights function of their visibility (15 nm), type and location* - Depending on the ship’s position to the shore the seafarers will use as reference specific lights during navigation. The convention is to rely on lights that have a visibility spectrum of over 15 nm while navigating in the open waters. Seafarers rely on lights with under 15 nm visibility as they are approaching the shore. While navigating seafarers have reported to trust their eyes they will wherever possible try to view the light with the binoculars.
- *Installation /uninstallation; registration and update* - This function will enable users to easily install the application and its weekly updates. The updates must be made available offline as well as online.

The AR application is aimed to help seafarers identify the position of lights in the proximity of their ship and facilitate efficient access to the lights’ characteristics information. Although some companies do not allow the usage of tablets on the bridge of the ship, the prototype for the application has been developed for an Android tablet with the hope that if it proves that it helps navigation it will open the door to the development of other AR products within the industry.

The development team established that in order to meet all of the six functions the application needed access to the GPS, the gyroscope, the accelerometer, the compass.

From the Android tablets available on the market at the time of the development Nexus 9 was selected as the most suitable device to use. It features all the necessary sensors and it is at a mid-range price.

VI. AR Tool Selection

There are several AR development toolkits available in the current market. The selection of the most sustainable one has been done based on these main considerations:

- The toolkit can be embedded into a native Android application.
- The toolkit’s ability to interact with objects.
- Geographic location based toolkit.
- Other factors that influenced the selection were:
- Easily portable to iOS. This will help with extending the application to iOS end-users.
- Well documented. By having good documentation about the AR toolkit, it will be easier for the developers to use it.
- The toolkit is in active development.

Community support/Stack Overflow presence: When first line support fails developers relay on help from other developers.

The AR development toolkits that have been considered were the Moodstocks, ARTollKit, Catchoom, ARLAB and Wikitude.

- Moodstocks: The only main focus for this toolkit is image recognition. It allows applications to recognize real world images and then overlay content/actions on top of it.
- ARToolKit is multi-platform. While it maintains functionality on any version, its performance is influenced by the hardware configuration [13]. The plus points for this was the multi-language support; however, at this time it was not top priority and with the minimal amount of user interface (most is names of lights, distances, range), translations would not be a difficult task. The main focus of this AR SDK would be for tracking virtual-world objects in a real-world environment there was not much focus on geo location based positioning.
- Catchoom: Its main focus is on Image Recognition. There was no mention of geo location.
- ARLAB has good support of geo-location based API. It is very heavy on the quick to get started / really easy to use API. It has premium support answering questions within 24 hour (max). But, it had no trial or test SDK available.
- Wikitude is especially focused on geo-location based AR. This is supported via their JS API. This should mean that porting the code across to iOS would not create too much of an issue. Supports both Android and iOS (with support for smart glass). It has image recognition and 3D tracking.

The team selected Wikitude as it best meets the set considerations.

VII. Prototype

An initial paper prototype was created using Power Point, demonstrating the flow of the application. Figs. 1-4 are extracts from the paper prototype.

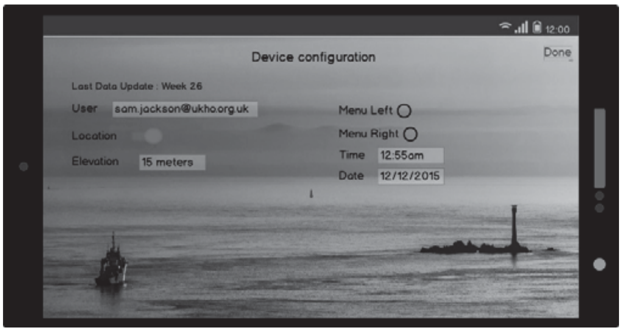

Fig. 1 Device Configuration in the paper prototype

Fig. 2 AR view in the paper prototype

Fig. 3 AR Light information presentation in the paper prototype

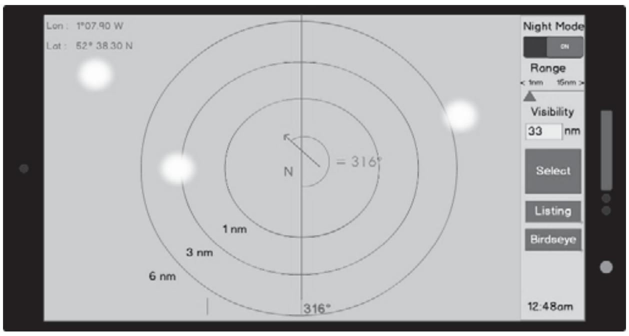

Fig. 4 Birds eye view in the paper prototype

Informal feedback was obtained from a group of six mariners that included: Two Captains on commercial ships, one Navy Captain and 3 second officers on cruise and commercial ships. Each of them was presented the concept and how it would function. Slight changes were implemented to the initial prototype mainly linked to the position of the buttons, units of measure used and the names of the buttons from their feedback.

The prototype has then been coded using Wikitude.

Figs. 5 and 6 are print screens of the digital prototype during the usability tests conducted at sea.

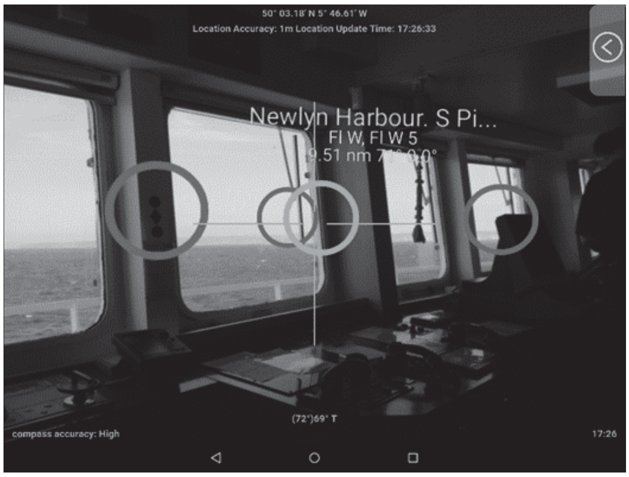

Fig. 5 AR mode in the digital prototype during sea trials

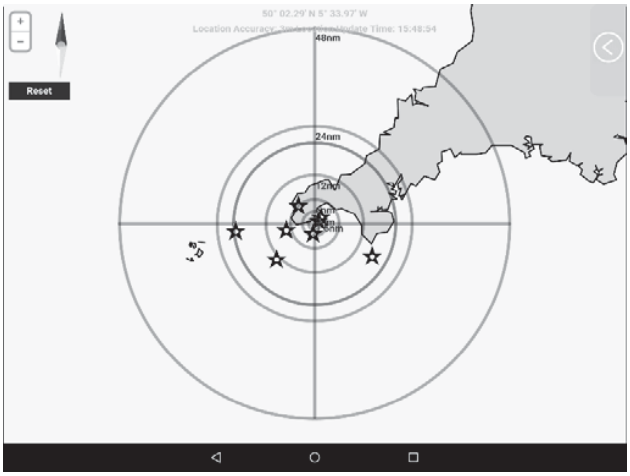

Fig. 6 Birdseye mode of the prototype during sea trials

VIII. Usability Testing

At the start of the project the development team has identified several areas of concern related to the usability and performance of the application.

It was not known how Wikitude will manage with loading the objects in AR. In ports, there can be over 100 aids to navigation. The screen might become cluttered and the application might take very long to load the data.

Another concern was linked to the precision of the prototype in displaying the aids to navigation in the correct position. This was particularly due to the environment in which the application will be used: offshore, in the bridge of a ship where there might be interference with the navigation devices.

The first test of the application was conducted on board of a surveying ship during its navigation on the English Channel. The application was tested as the ship was navigating along the UK coast between Flamouth and Dartmouth and between Penzance and Dartmouth. The tests were conducted during day and night and concluded:

- At sea loading the data of the aids in AR mode took over 1 minute when initially starting the application.
- The application was displaying correctly the distance and bearing to the aids to navigation in the area.
- When compared to the GPS of the ship the application was displaying the position of the ship correctly.
- The compass was completely offset. At times by even up to 180 degrees.
- The application became slow to respond on the bridge, taking up to 10 seconds after a button has been activated for the application to react. This was an improvement on the previous version where it was taking up to 50 seconds.
- A compass error that can vary inside the bridge from 30 to 180 degrees was observed. On the bridge wing, the compass error was about 10 degrees. This affected the display of the objects in AR.
- The magnetic field reading within the bridge was stable regarding of location.
- The officers were very interested and positive about the possibility of using the application on the bridge and made a series of recommendations as to features that could be integrated. The Captain said: *Mariners are used to be in this situation where they will take all the clues that they could use, whether is from the navigation, from the radar, from visually just looking at the window. Lights are there to help them. But even if lights are out of position, at least I can see from where the lights are going, yes, I am going in the right direction. Your tool [the application] will be really useful for that, to be able to say … which light is which… Because sometimes unless I get my stopwatch out it would be really difficult for me to say which is which.*

Following the initial test, the developers worked on increasing the reaction time of the application and fixing the bearing error. The second round of usability testing was conducted on board of THV Patricia. The vessel was navigating in the same area as the survey ship within the English Channel. The testing was carried out over two days. Fig. 7 and 8 have been taken with one of the officers and the captain while trying the application.

Two identical Nexus 9 tablets were used during the tests to allow comparison.

Compass Bearing Observation: During testing, it was observed that the compass error varied between 5 and 100 degrees.

Fig. 7 Officer using the prototype in AR mode

Fig. 8 Captain trying the application in the birdseye view mode

When the application has been switched on the first time on the upper deck of the ship, the compass error varied between 40 to 50 degrees. With the continuous usage of the application and maintaining the position on the upper deck the error started to drop to about 10 degrees. Within the bridge the bearing error has varied between 5 and 10 degrees. When observing Wolf Rock as the ship was heading towards this lighthouse, it was observed that one of the tablets had a positive 5 degrees error while the other one had a negative 5 degrees error.

The magnetic interference was therefore measured on the upper deck and inside the bridge. The team observed high magnetic interference on the upper deck and low magnetic interference inside the bridge. The team concluded that there was no correlation between the magnetic field value and positive or negative error of the compass.

Under 5 degrees compass error has been recorded when the ship was heading towards the light and the tablet was aligned with the heading of the ship and positioned in the center of the bridge. While maintaining the same position the error was increasing as the lights were situated at a greater angle.

While holding the tablets aligned with the center of the bridge and the ship's heading compass readings have been taken from the prototyped application and 4 other compass applications. The error in the reading was similar. On one tablet it was maintained to 18 to 19 degrees and on the other tablet it was 5 to 12 degrees. While maintaining the tablet in the same position over one hour during ship navigation the bearing error maintained its values. Although there had been significant improvements made to the compass bearing results compared to the previous prototype it highlighted that further work needed to be done on improving the compass readings.

GPS Observation: Another observation has been made regarding the GPS. On rebooting the tablet, it was taking between 30 to 40 seconds before the GPS signal was acquired. After 5 seconds, the GPS was recalibrating and it was taking another 30 seconds to stabilize. Once the GPS signal was acquired the application was maintaining it and updating the location every 10 seconds. When comparing the GPS reading with the ship's GPS the values were almost identical. (Slight differences only in the seconds). The GPS was maintained accurate only if the Wi-Fi was deactivated on the tablet.

Light Information Observation: The information about lights was accurate. The officers commented: *This application could successfully replace the List of Lights we are currently using. It is so much quicker to find the information about the lights (Second Officer).* The participants found it a lot easier to access information about the lights from the application rather than using their digital List of Lights or ECDIS. The application was accurate in giving the bearing to a light value. When using the application, the user was able to read the bearing to a light within seconds. Compared to performing the same task on an ECDIS that requires the user to identify the light on a chart and then do a series of clicks to find the information. The team concluded that the color scheme for the lights in AR and the labelling were not easy to read. There were issues with doubling of labels when selecting the light from a list and with the label partly going out of the screen as the ship was passing ahead of a light.

Other Observations: Other AR applications are maintaining the possibility for the camera to zoom in and out. The labelling on the Marine traffic application appeared to be more clear compare to the solution adopted in the prototype. Having a radar view in AR view was also a good feature for appreciating distances to a light.

At night, the camera was not strong enough to capture all the lights. The team concluded that for night there should be an emphasis on the characteristics of the light rather their name.

IX. Conclusion

Following the usability tests conducted on the two ships the development team concluded that the compass error is a limitation of the tablet and it can vary from device to device and from one ship to another. The calibration of the compass of the device as recommended by the manufacturer is insufficient for this context.

The team is currently looking to develop in collaboration with Wikitude manual calibration of the compass. This would allow users to manually adjust the compass according to the reading from the sensors of the ship prior to using the application.

The future development will also address the considerations of how the interface is presented so that the screen will become less cluttered.

There is an increased enthusiasm within the professional sector for AR applications to be made available to support navigation. The creation of such applications depends on increasing the capabilities of hardware and AR toolkits in order to manage large datasets and increased precision.

Nevertheless, designers will also need to follow a user-centered design approach in order to address the issues associated with the presentation the high volume of information on limited sized screens in order to create useful applications and enhanced user experiences.

Acknowledgment

The team would like to thank to SWIRE China Navigation, The Royal Navy and Thrinity House for their participation in the user research. The researchers would like to also thank United Kingdom Hydrographic Office for providing the aids to navigation data and providing match funding for the studies. The prototype has been developed in collaboration with SCISYS and xibis.

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