BoatSafe: A Smartphone Application for Safe Inland Waterway Transportation

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***Abstract* - Compared to oceanic waterway transportation, inland waterway transportation has not received the deserved attention on technological support. In the development of Boat Safe, we offer a mean of inland-waterway-oriented navigation, crash detection and post-crash emergency aid through smartphone application, which can be easily accessed at any time. We also propose the use of complementary filter on compass, gyroscope data for heading estimation with miniscule uncertainties.**

Keywords - waterway navigation, safe waterway transportation, smartphone application, Boat Safe

I. INTRODUCTION

Transportation is often considered to include but not limited to 4 mediums: land, air, water and space. While space transportation is still being prepared for the future, the other three have already become an essential part of life. With the rapid development of these modes, come the need for associating services such as navigation and post-accident services. Unlike aircrafts, high-end land and waterway vehicles which have their own dedicated navigation systems, old, mid- and low-ends models often depend on third-party aiding technologies. Our target in this development is to provide convenient support for those inland waterway vehicles which may require additional aid for navigation and post-crash solution.

In our modern world, Global Positioning System (GPS) is no longer a foreign term in navigation systems. It was initially developed by US Department of Defense for military purpose, but then made available for civil use. Uncertainties in GPS are often caused by ephemeris data, satellite clock, ionospheric and tropospheric delay, multipath interference, weather, constructions, receivers, etc. Dissimilar to oceanic waterway, GPS in inland waterway is susceptible to the influence of construction.

Since smartphone is now a nearly inevitable presence in daily life, many previous and current studies choose its applications as a solution. Nowadays, smartphone is not just equipped with GPS, but also multiple sensors such as accelerometer, gyroscope, magnetometer, etc. which can be configured as an Inertial Navigation System (INS). Although GPS can be seen everywhere, from the most cutting edge navigation systems to smartphones that we use each day, GPS is not perfect and under certain circumstances, the combination of it and other methods may yield a better result. INS offers a good tracking for short distance, resistant to the influence of construction. The use of GPS plus INS is a preferred method to maximize the advantages of both and is also our approach presented in the next sections.

In this paper, we propose the development of a smartphone application dedicated for inland waterway vehicles, which enhances navigation using our approach based on GPS, detects crash and provide post-collision aid.

II. RELATED WORK

The number of applications developed for boating is large, however in this study we only observe those which provide navigation or safety support. Various smartphone applications have been published and available for instant download. Among the most acknowledged, we can name Boating Marine and Lakes [1], SeaNav [2], Boat Beacon [3], NavShip [4], Discover Boating Safety [5], BoatUS [6], Mazu [7], etc.

Boating Marine and Lakes was developed Italian company Navionics, Garmin Ltd. The application excels at auto-routing and it offers advanced map showing fishing ranges, highlights shallow areas, provides both inland and oceanic navigation, shows weather and tides information. Moreover, Boating Marine and Lakes also features AIS, which further enhances its navigation capability. However, without the paid subscription, the features and charts are greatly limited and its location detection accuracy can be affected by construction, especially for inland waterway. Furthermore, the application offers limited chart for a few number of developed countries such as US, UK, etc. Therefore, boaters from countries out of the list can not have the full experience using Boating Marine and Lakes.

SeaNav is also considered an excellent application. Similar to Boating Marine and Lakes, it features route planning, real-time tracking, AIS. Moreover, SeaNav has a unique augmented reality view overlaid on camera view. In order to experience the application properly, the purchase is a must, since the free version comes without any bundled charts. The charts are, just like Boating Marine and Lakes, limited to a few number of countries and it is mostly for oceanic waterway, except for the Great Lakes in US.

Boat Beacon is originated from the same developer as SeaNav's. It features are mostly based on AIS. Apart from GPS location and real-time map similar to SeaNav, it has different and excellent features such as collision avoidance using Closest Point of Approach (CPA), messaging with other Boat Beacon users, Maritime Mobile Service Identity (MMSI) contact via VHF, Search and Rescue Transponder (SART) support, etc. With an amazing set of utilities, still it suffers from the same drawbacks as SeaNav: limited chart of countries. To use the application, user must pay 12.99$ on standard version, further purchases can be performed in-app.

Different to previously mentioned applications, CproSoft's NavShip is a full inland-oriented navigation assistant. Compared to Boating Marine and Lakes, SeaNav or Boat Beacon, this application offers a shorter but adequate range of utilities: online, offline routing, travel time and distance, anchor alert, weather, etc. Though NavShip focuses on inland waterway, it is also capable of routing through ocean, for example between London and Rome, Chicago and Toronto or Paris and Amsterdam, etc. With free version, user can access nearly every features that the application can offer, however, important services like long tracking or route planning require a monthly subscription to work after 5 miles for tracking or 25 miles for routing. The downside is that the NavShip only in some European countries, USA and Canada just like above application. Moreover, some features are even limited in Germany only. Overall, it is not suitable any countries rather than the ones from the list.

Discover Boating Safety's main purpose is safety aid. It provides not only safety guideline to check before each departure, but also helps plan the trip, accesses to weather data, gives tips and visual references to navigation buoys, etc. It also has emergency contact numbers for Search and Rescue, Royal Canadian Mounted Police (RCMP), marine polices and basic emergency procedures. The application is essential for new boaters and can sometimes provide helpful information for even veterans. Unfortunately, the last and most important feature is only available in Canada.

As perceived from above applications, it is possible to perceive that a number of applications are now capable of providing a wide range of features, however, at the cost of limited access to a few number of countries, which are all among the most developed nations. This does not show just the diversity of development between countries, but also shows how little the provision for other less wealthy areas is. It is understandable that the infrastructure and services of less developed countries do not meet the requirement for the development of such applications. Hence, the need for waterway services in these areas is becoming greater. Another problem from above is that the application is either excellent at navigation or safety service, but not both. It is important to provide both a comfortable boating navigation and safety precautions or accident aid. Having acknowledged these issues, it becomes our top priority in Boat Safe development.

III. PROPOSED METHOD

A. Boat Safe Summary

Our current Boat Safe offers two main features: navigation and crash-related utilities. Its features are summarized in Figure 1 below.

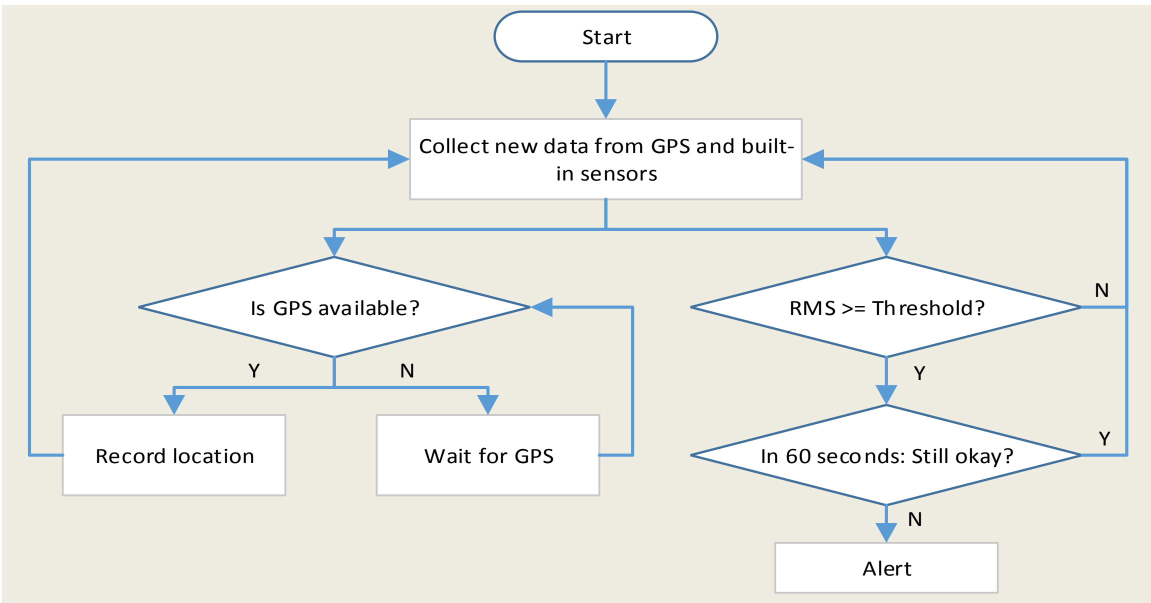

Figure 1. Flowchart of Boat Safe features

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The first feature is the combination of GPS and smartphone INS. Our application records user's location every 5 seconds with the proposed heading estimation. However, there are times when GPS is unavailable. During these time, Boat Safe's location detection is set to "wait", which ceases when the GPS reconnects. Further on how this system works is presented in the next section.

The second feature provides safety utilities concerned detected crash. When Boat Safe detects a possible crash, it gives user a prompt to perform a condition check. Should the user is still okay, the application neglects the incident, however if the confirmation does not happen in a predefined time, action will be taken. In our study, the algorithms are designed with smartphone held on the hanger.

B. The Proposed Combination of GPS and Smartphone INS in Boat Safe.

In order to access location in Android devices, Google Application Programming Interfaces [8] (APIs) are utilized. Android Location API [9] and Google Play Service API [10] are often the most used ways for this purpose. Google Play Service API is usually preferred to the old Android Location API due to the accuracy and efficient energy consumption. In Boat Safe, we propose the use of either one of them, since some devices are not compatible with the Google Play Service API such as Blackberry 10 [11].

In our current version, Boat Safe offers heading estimation along with GPS location detection. This is achieved by

B1. Heading Estimation

Gyroscope and built-in compass are susceptible to interference. In order to yield an accurate result, their data has to be pre-processed. We propose using the complementary filter in Boat Safe. Its model can be seen in the following Figure 2:

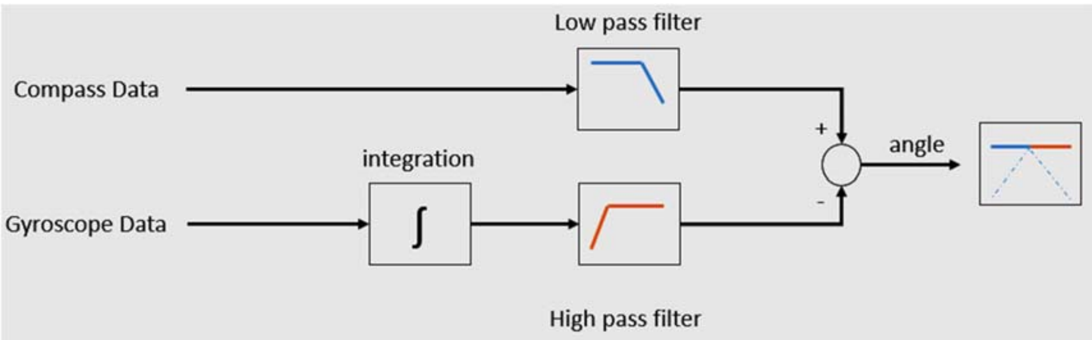

Figure 2. Boat Safe Complementary Filter Model

As seen in Figure 2, the complementary filter includes a low-pass filter (LPF) for compass data and a high-pass filter (HPF) for gyroscope data. The compass data is prone to even the slightest change or influence, like gravity [12]. With the LPF to filter out the long-term change, what is left of the data is consisted of more reliable part. Unlike compass data, gyroscope is much more resistant to interference, however when it is integrated to get angle velocity, it becomes affected by drifting [14]. Drifting is caused by accumulation error of multiple continuous integration. Given that, our aim is to neglect the short-term change, which can possibly be diminished by using a HPF.

The formulas of HPF and LPF are listed below, respectively:

$$y_n = a\left(y_{n-1} + x_n - x_{n-1}\right) \tag{1}$$

$$y_n = \left(1-a\right)y_{n-1} + ax_n \tag{2}$$

where yn, yn-1 are outputs at n and (n-1), xn, xn-1 are inputs at n and (n-1), and a is filter coefficience.

At the end of the model, the angle can be updated as below:

$$angle = a*(angle + gyroData \times dt) + (1-a)*CompassData \tag{3}$$

where gyroData is angle velocity, compassData is data from compass sensor, and dt is sampling period.

B2. Alternatives to GPS During Outage and Travel History

From the location data collected, Boat Safe offers a timeline of travel so that users can back track their travel history. For every 5 seconds since the activation, the database is updated with a new location. If the GPS is unavailable during one or many occasions, the first available GPS after that is chosen to be the next node, with the path drawn following the waterway between these two nodes.

With data collected, the application can calculate the distance, velocity between nodes, travel time, departure location, destination, etc. Those information can be found in History at the center of the taskbar:

Figure 3. Travel history

C. Crash Detection and Post-Crash Aid.

The second feature of Boat Safe is to detect crash and perform post-crash aid. Our approach in this feature is to use accelerometer with a threshold-based method to detect accident [15]. The threshold is not compared with each data from accelerometer's three axes, but Root Mean Square (RMS) calculated as follows:

$$\text{RMS} = \sqrt{A_x{}^2 + A_y{}^2 + A_z{}^2} \tag{4}$$

where Ax, Ay, Az as accelerometer data from 3 axes.

In Boat Safe, the threshold is set at 2G (G=9.8 m/s2), which will set the application to an alert-hold state if exceeded. The state lasts 30 seconds with a message board as in Figure 4.

If the user choose "HELP" or does not confirm during the time, he/she is considered to be in danger. Previously, we designed Boat Safe to send SMS of the user location along with an alert to the emergency list, but since Google banned third-party application to send SMS, we change to email as the medium, which will be available in the upcoming patch. In the meantime, our temporary solution is call making to the top priority of the emergency list.

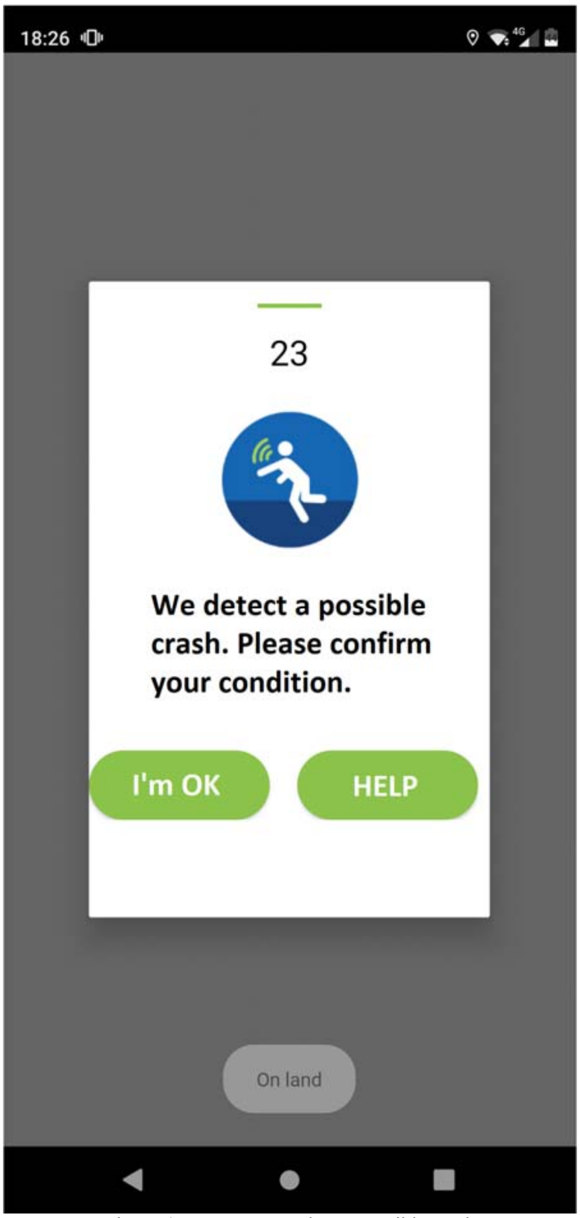

Figure 4. Message Board on a possible crash

IV. RESULTS AND DISCUSSION

Boat Safe is now available on Google Play Store. At the current downloadable version, Vietnamese and English are supported. On the startup, user is requested to grant permission to location service and contacts.

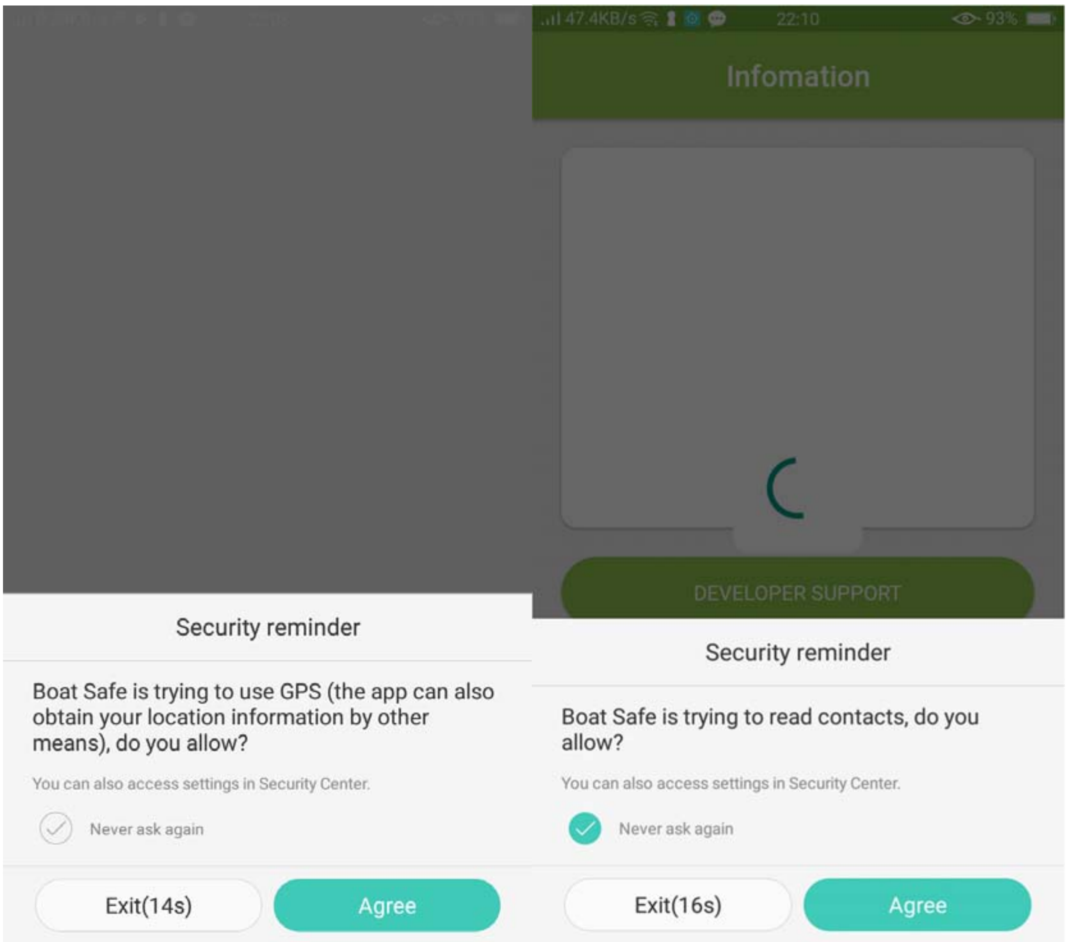

Figure 5. Asking for permission

User is given the option to active or disable crash warning as in Figure 6.

The option above provides energy conserve when the phone battery is nearly depleted and the user's main focus is on navigation.

In Boat Safe, we choose Google Map overlay for map navigation. This decision offers a familiar visual experience along an enormous data which can be used all around the world. Our features are available to all users without any purchase or advertisement.

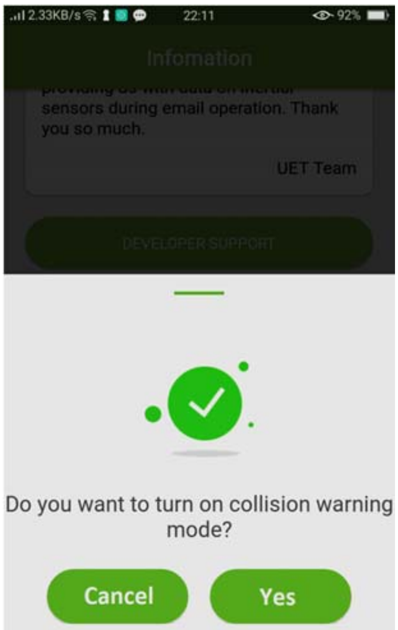

Figure 6. Option to active/disable crash warning

A. Our Proposed Complementary Filter

To test our heading estimation algorithm, we pick five scenarios: 1) the phone is stationary; 2) the vehicle moves straight on water; 3) Three perpendicular turns; 4) Moving in circle; 5) Phone rolls around its center. Our test site for the first two cases was West Lake, Hanoi with little wind, small ripple. The latter three were performed on land to ensure the angle requirement. The time in all tests is formalized after Unix Time [13], which starts from 00:00:00 of January 1st, 1970. The result of these scenarios can be seen in Figure 7, 8, 9, 10 and 11 respectively:

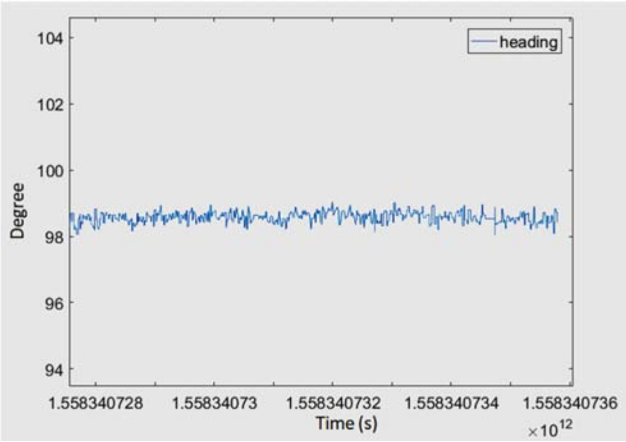

Figure 7. Heading estimation in Scenario 1

As in Figure 7, the angle estimation varies but only in an acceptable range. The deviation can be explained by the gyroscope drift, minuscule change of Earth magnetic field or wave ripple.

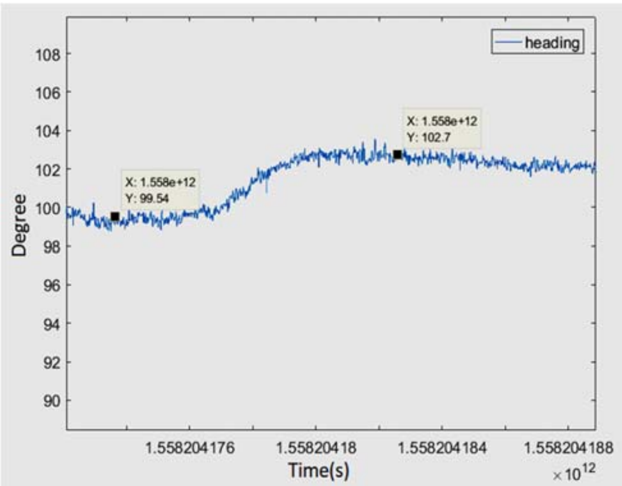

Figure 8. Heading estimation in Scenario 2

In Scenario 2, the variation is larger (but still acceptable) than the previous case. This is understandable as the vehicle was moving, not staying still in the same place.

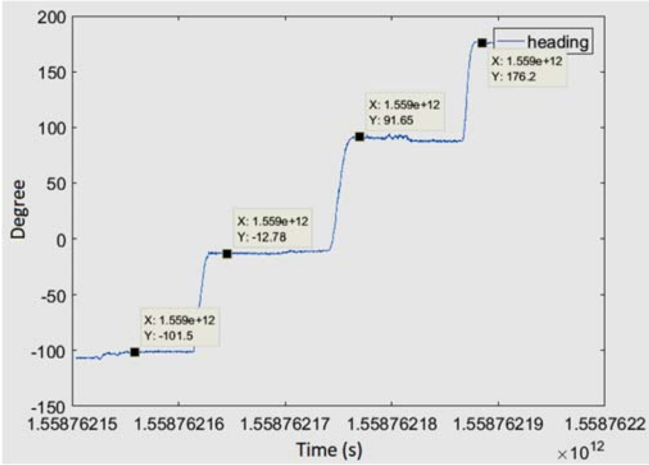

Figure 9. Heading estimation in Scenario 3

Figure 9 presents three clear turns of approximate 90 degrees as intended in the test. Our proposed method is yet proved reliable.

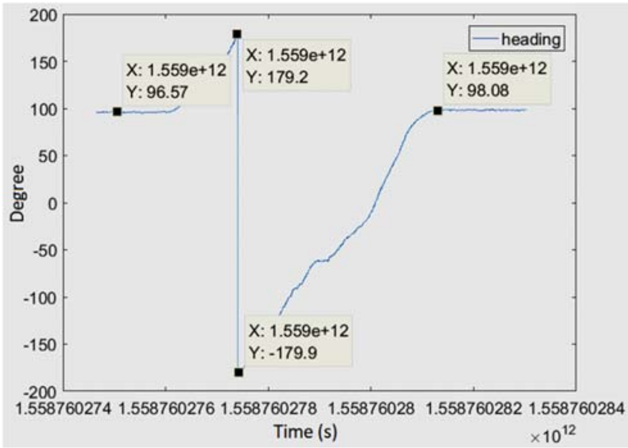

Figure 10. Heading estimation in Scenario 4

Unlike previous scenarios, in Figure 10, angle change can be perceived clearly. This case was performed on land to ensure the phone was moving in as close as a circle as possible. The difference between the maxima and minima is nearly 360 degrees, with less than 1 degree deviation. During waterway travel, the deviation is expected to be larger, but the amount is insignificant. Our method still proves to be effective in this scenario.

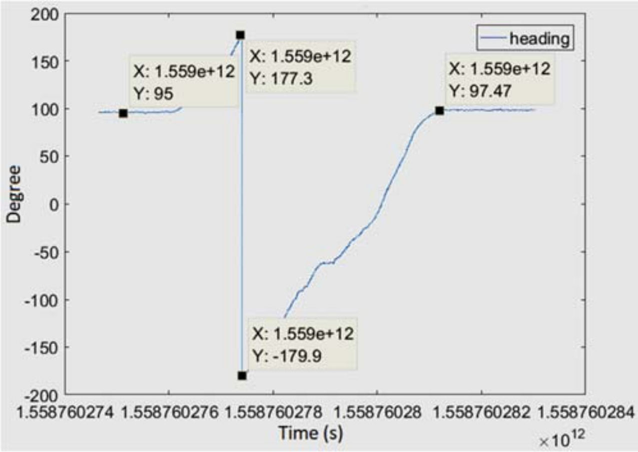

Figure 11. Heading estimation Scenario 5

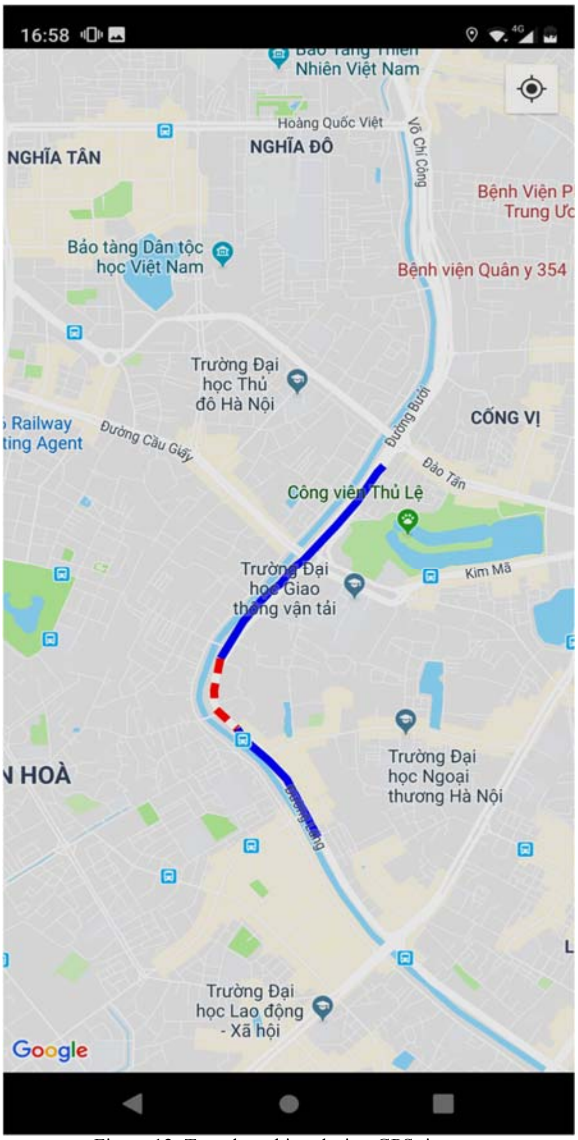

Figure 12. Travel tracking during GPS timeout

Scenario 5 is proposed to test how our method fares in moving 360 degree, which is a bit similar to our previous case. However in Scenario 5, the phone was laid on surface and manually rotated 360 degrees around its center. The result is close to Scenario 4's with the final angle is only less than 3 degrees deviated from the initial point.

In conclusion from the tests, we can see that out proposed complementary filter works as intended in heading estimation. The algorithm still can be improved for new features in the future.

B. Travel Track During GPS Outage

To evaluate our travel track feature during GPS outage [16], we performed an on-land test.

In Figure 12, blue line indicates when GPS was available and red dashed line was for GPS outage. The travel way is tracked every five seconds, but when GPS is down, the tracking stops until it is connected again. To compensate the loss of data during that time, the last one before and the first one after this period is connected as the possible track.

V. CONCLUSION

In this work, we present a new Android application for inland waterway transportation, Boat Safe. Boat Safe is developed with an enhanced GPS and INS combination to offer users convenient and accurate navigation, crash detection and post-crash aid. With a user-friendly interface, it can be used with ease and it can be a trusted partner for boat occupants. The application is already available free of charge on Google Play Store [17].

In future work, our priority is improving the algorithm in order to give Boat Safe user the best experience. Crash detection and navigation will be improved with sensor fusion. During the outage of GPS, we will present our proposed distance tracking using INS. More utilities are being developed and will be featured in the upcoming updates.

ACKNOWLEDGMENT

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