Development and feasibility evaluation of a low cost smart voyage data recorder: Marine Black Box

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Abstract—**Dating from the dawn of water transportation, marine accidents have been major causes of concern for governments of nations regardless of being developed, developing or underdeveloped. Recalling the recent ferry sinking incidents in Bangladesh, a research was undertaken to develop a smart but yet low cost voyage data recorder namely Marine Black Box. Though it can never be guaranteed that marine accidents would not happen at all, this solution would help to provide an early warning before the onset of a total disaster and even in the scenario when there is indeed no chance to save the vessel, this system would provide a mean to analyze and investigate the true cause of the accident so that future accidents can be avoided or the perpetrators can be accounted for. What makes this Marine Black Box distinct from typical voyage data recorders is that it sends a vessel's number of passengers onboard, temperature, pressure and humidity along with GPS positional data in real-time to a centralized server which can be accessed through a smartphone app. In case when this real-time logging fails, data can still be retrieved from the SD card inside the black box where data is being constantly logged for redundancy. This paper discusses the details of the working principles, construction and practical evaluation of the system.**

Keywords—marine accidents; voyage data recorder; Marine Black Box; real-time logging;

I. INTRODUCTION

In a riverine country, marine transport is more than often the principle mode of travel. Bangladesh, a small country situated in South East Asia, is laden with at least 230 rivers and building upon that it is not surprising that despite being small, it has at least 6000km of navigable waterways [1, 2]. Small to medium sized boats and ferries chiefly cater to the demands of the common people for the purpose of daily commuting and also long distance travels within the country. While people are using waterways as their everyday transport medium, one fact that is very frequently overlooked is the increase in boat capsizes or in other words marine accidents. According to a recent study conducted by the country's waterways regulator, Bangladesh Inland Water Transport Authority (BIWTA), more than 10,436 people have died in over 20,000 accidents since 1972 and shipping safety recommendations is yet to be implemented strictly [3].

According to Al-Jazeera, in February 2015, the lives of at least five people including a minor were claimed when an overloaded ferry carrying around 200 passengers sank in an estuary in the south of the nation[2].In August 2014,a short of 50 people lost lives when a crowded ferry sank in rough weather in the Munshiganj district. In another incident few years back, about 150 people died after a ferry carrying about 200 passengers sank after being hit by an oil barge late in the night [4].

The failure to maintain water transport safety is partly due to the inconsiderate nature of the government in regulating vessels as ferries and boats are frequently overcrowded. However the major reason for the accidents amounts to natural causes whereby weather forecasts and meteorological department advisories are not interpreted properly or yet worse, such news do not reach the marine drivers or the vessels' captains at all. Oblivious of weather warnings, the captains venture into perilous waters risking the lives of hundreds.

It is not only Bangladesh which is plagued by marine crisis but other riverine nations too face similar fates. On April 16, the ferry Sewol sank killing 304 people, mostly high school students who were on their way to a field trip to Jeju Island, off of South Korea's southern coast [5].In China, a passenger ship carrying 458 people sank in the Yangtze River after encountering a cyclone attack mid water. According to a report by CNN on June 9, 2015, a total of 434 bodies had been recovered and 8 were still missing [6].

Our solution aims to mitigate these problems by letting the associated authorities know beforehand what the present condition of the vessel is onboard. What we have developed is a smart voyage data recorder that constantly monitors the number of passengers onboard, pressure, humidity and temperature aboard the vessel and also the GPS coordinates of the location the vessel is presently residing. All these data are compiled and periodically uploaded to a centralized server through GPRS and GSM network. The data is then parsed through a frontend and relayed to a smartphone application that we have developed to provide real-time update's to the vessel's captain as well as the regulator authority officials associated with the vessel. This helps to provide an early warning for any would be mishap. Alternately, the device acts as a normal voyage data recorder by logging all the information to an SD card sealed inside.

In the event when an accident is imminent and the vessel is sinking, the system would activate a locator beacon inside the Black Box and eject it by the help of a launcher so that its retrieval is facilitated. The Black box incorporates a rigid protective storage unit that is tamper-proof and designed to endure the tremendous shock, pressure, impact, and heat, commonly associated with marine accidents, complying with International Maritime Organization (IMO)'s standards [7].

II. EXISTING IMPLEMENATIONS

Voyage data recorders or VDRs have been in the industry for quite a long time, although, not much significant design overhauls took place in the years that have followed up. According to Nathaniel Bowditch from National Imagery and Mapping Agency, a modern VDR may log position with date and time using GPS, record speed, integrate gyro compass denoting direction heading, record audio from the bridge, including bridge wings, incorporate a echo sounder giving the depth under keel and log engine information [8]. Recently, Jin et al. from Wuhun University of China has developed a single chip VDR based on Nios II soft core processor which is essentially a system-on-a-programmable-chip (SoPC) [9]. The endeavor has helped to develop a small size VDR and compared to commercially available alternatives, this system is far cheaper to construct and implement. Furthermore, the use of an embedded controller would ensure a more fault tolerant operation and provide greater reliability in the long run. GPS based tracking systems and monitoring systems with GSM based network transmission of data is already in the industry and has grown to a level of maturity [10, 11]. However, there is no system as yet in the market or under development that would provide real-time data from a ship to any external device. Our solution aims to develop a novel approach for conducting that.

III. SYSTEM ARCHITECHTURE AND IMPLEMENTATION

The entire system can be considered a package comprising of:

i) The Black Box unit (containing the central transmitter and GPS module).
ii) A portable weather station.
iii) A passenger counter.
iv) A centralized server for data storage.
v) A smartphone application to access the data.

Working in tandem, these components provide the solution to mitigate marine accidents or aid in the investigation of post disaster situations. It is notable that all of the components that we incorporated in our system are relatively cheap in terms of price. The entire system can be built well under USD200.The sections that follow describe, in turns, the functionalities and construction of the aforementioned subsystems. The flowchart in Figure 1 illustrates the control flow of the underlying system.

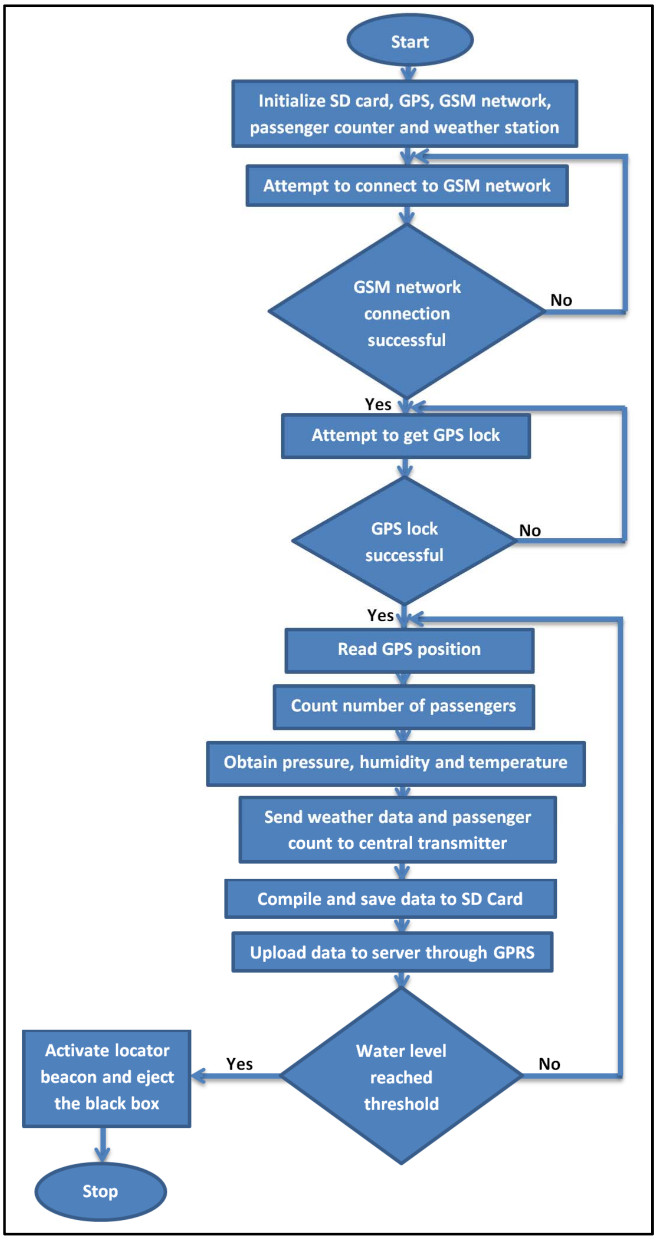

Fig. 1 Control flow diagram of the entire process

A. *The Black Box unit*

The Black Box unit resides at a strategic location inside the vessel. We chose a spherical design for the Black Box with the aim to ensure that it stays afloat when released on water. It contains an Arduino Uno microcontroller board with a GPS Module, a GSM/GPRS module, an RF receiver and an SD card module complete with a high capacity lead-acid battery. The RF module receives weather data and passenger data from the portable weather station and passenger counter respectively. The GPS module reads GPS coordinates after getting a lock from GPS satellites. The microcontroller then compiles all these data and uploads them through GPRS to the centralized server. Additionally, it saves the data to an SD card through the SD card module. Figure 2 shows the Black Box and its internals.

Fig. 2 The Black Box unit

The power is managed by a 40Ah 12vdeep cycle lead acid battery. With a peak current requirement of 500mA at 5v, for worst-case scenario, the estimated minimum runtime on a single charge is 8 days. On typical usage, this figure would be higher.

B. Portable Weather Station

The portable weather station is comprised of a temperature, humidity and an air pressure sensor, all of which are connected to the main microcontroller board Arduino Uno. Additionally this unit is equipped with another sub unit, mainly dedicated to transmit the weather values to the main black box unit. This sub unit consists of an RF transmitter module connected to a microcontroller board Arduino Mini. To accomplish the prime objective of this unit, the main board acquires the necessary data from the connected weather sensors and utilizes the sub unit to transfer these data to the mother unit in the Black Box. The RF transmitter used here has a signal transmission rate of 2.4GHz at 1-2MHz bandwidth. This device can operate at a range of 100m radius. Typically, a passenger carrying ship has an average length of about 50 to 60 meters; therefore, we used this RF transmitter to establish wireless communication between two units. Here, the power is also managed by a 40Ah 12v deep cycle lead acid battery. Moreover, this power unit is continuously fed to charge from the onboard power system. Therefore, during a voyage it is predicted that this unit would not run out of power. Figure 3 shows the developed system. We did a research about the weather station and came up with some works where similar approaches have been used to determine weather conditions remotely. Some paper also emphasized on getting GPS location of the weather collection site, which we also appreciated and endorsed in our research [12, 13, 14, 15, 16].

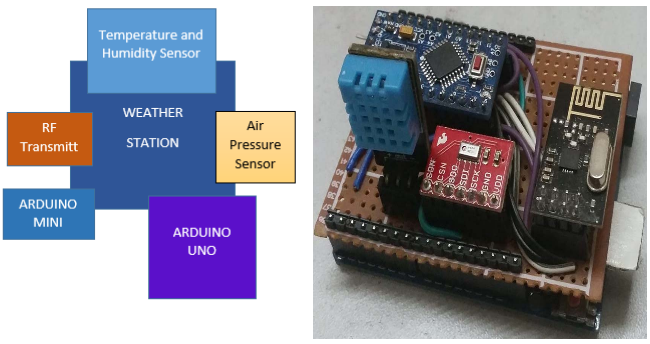

Fig. 3 Block diagram and actual circuit of portable weather station

C. *Passenger Counter*

The passenger counter circuit is equipped with two sonar sensors, an RF transmitter and a microcontroller board Arduino Uno. The main operation of this unit is to spontaneously calculate the total number of passengers boarding the ship and subsequently, the number of passengers residing in it at any given time. To detect the passengers, the unit has to be placed at the entrance of the ship. The sonars are placed at a vertical orientation in order to sense the passengers with minimal amount of error. Sensors are place at a distance of 30cm apart from each other. This distance provides the confirmation of a passenger boarding the ship when one passes the entrance gate. The counter is incremented whenever a passenger enters the ship and decremented whenever a passenger leaves the ship. This data is fed to the mother unit via wireless communication using the RF transmitter equipped with this unit. Here, the power is likewise provided by a 40Ah 12v deep cycle lead acid battery. In addition, this power unit is persistently sustained to charge from the on board power framework. Accordingly, amid a voyage it is anticipated that this unit would not come up short on power. Figure 4 gives the block diagram and image of the developed system. A background research has been undergone regarding the technology to be used for the passenger counting system. We came up with a number of similar projects where they suggested for using infrared and sonar technology for detecting the passenger [17, 18, 19].

D. Centralized Server

The centralized server containing all the logged data checks the box for typical attributes of any Black Box since it ensures the entire history of events a water vehicle has potentially gone through. Since one single set of data consists of exact location co-ordinates along with values of weather variables and passenger count, study of such historical dataset can assistin predicting the risks concerned with a certain marine route during a certain period of a year. The Black Box deliberately logs two consecutive sets of data with an interval of around five minutes in between allowing the smartphone

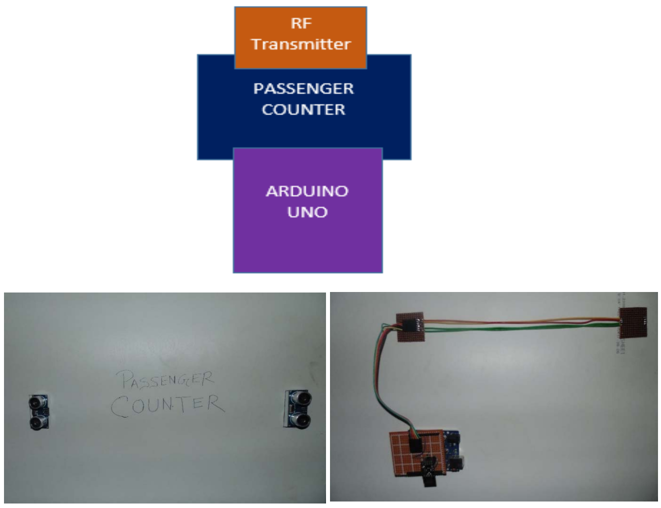

Fig. 4 Block diagram and actual circuit of passenger counter

application enough timeframe to fetch and parse data. The smartphone application is primarily developed to echo the existing information of centralized server. JSON (JavaScript Object Notation) is used to interchange data across the platforms, which has the data structure based on key/value pairs. The application presents significant real time information regarding particular marine vehicle's location, surrounding weather condition and total passengers on board as demonstrated by Pandini et al. [20] and Nagesh et al [21]. With the incorporation of Google Maps API v2, the application points to the exact location of the marine vehicle on Google map by placing a marker. Moreover, a driving route to the nearest bank from the current location of the end user also gets drawn for convenience [22]. While making the location request, the priority has been set to PRIORITY_HIGH_ACCURACY with an interval of 10 seconds to map our appropriate current location in real time. Figure-5 show the database and the smartphone application graphical user interfaces (GUI) while figure 6 shows the working principle of the application.

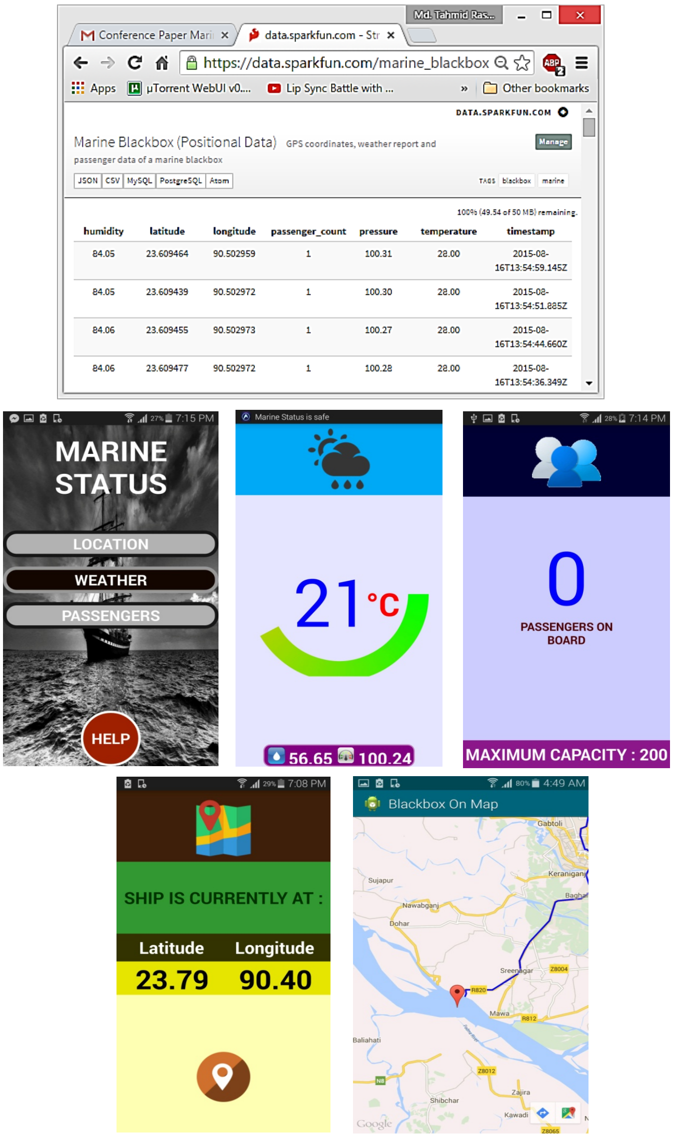

Fig. 5 Data stored in web database (top) and screenshots from the developed smartphone application (bottom).

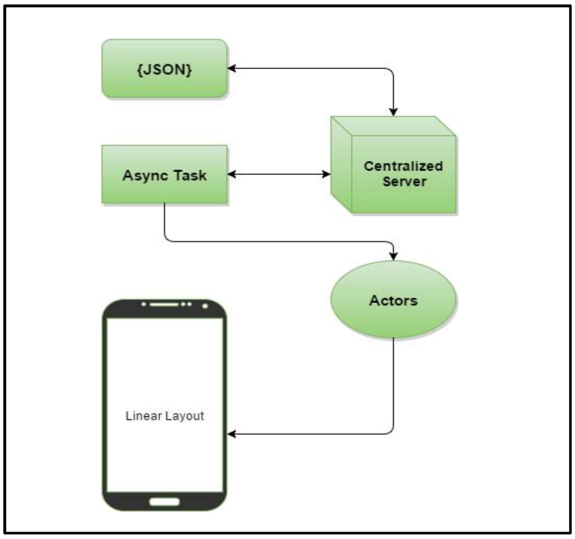

Fig.6 Working principle of the smartphone application for data delivery

IV. TESTING AND EVALUATION

A. Passenger Counter Accuracy: We acquired 10 sets of results for testing our passenger counter. Every time, we recorded the amount of time taken for the passenger to cross the sensors and from the distance between the sensors, we were able to calculate the speed of the passengers passing the passenger counter using formula v= s/t. The chart in Figure-7 illustrates the speeds and hence the detection level of the passenger counter for each set of experiment.

From the above results, it is observed that the sensor for the passenger counter is going to work for a specific range , which is about 0.20m/s to 0.28m/s of speed, beyond this range, the passenger getting into the ship cannot be properly recognized and thus render inaccurate information about the passengers on-board. Therefore, it would tend to work best when people get on board in queue and move inside the ship at a moderate pace. This was a sheer demonstration of a worst-case scenario

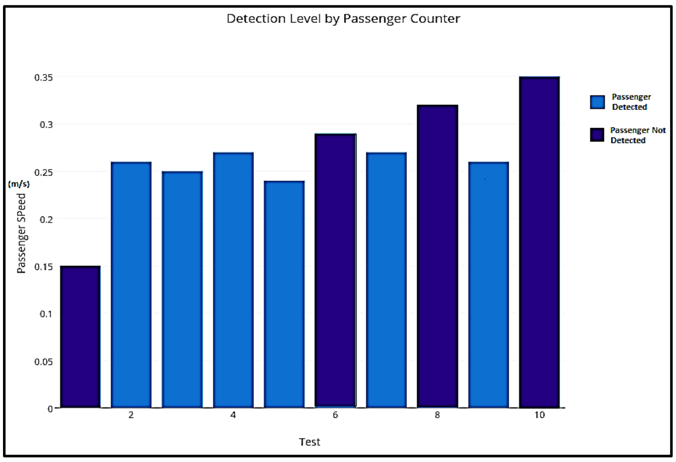

Fig. 7 Detection level of passenger counter

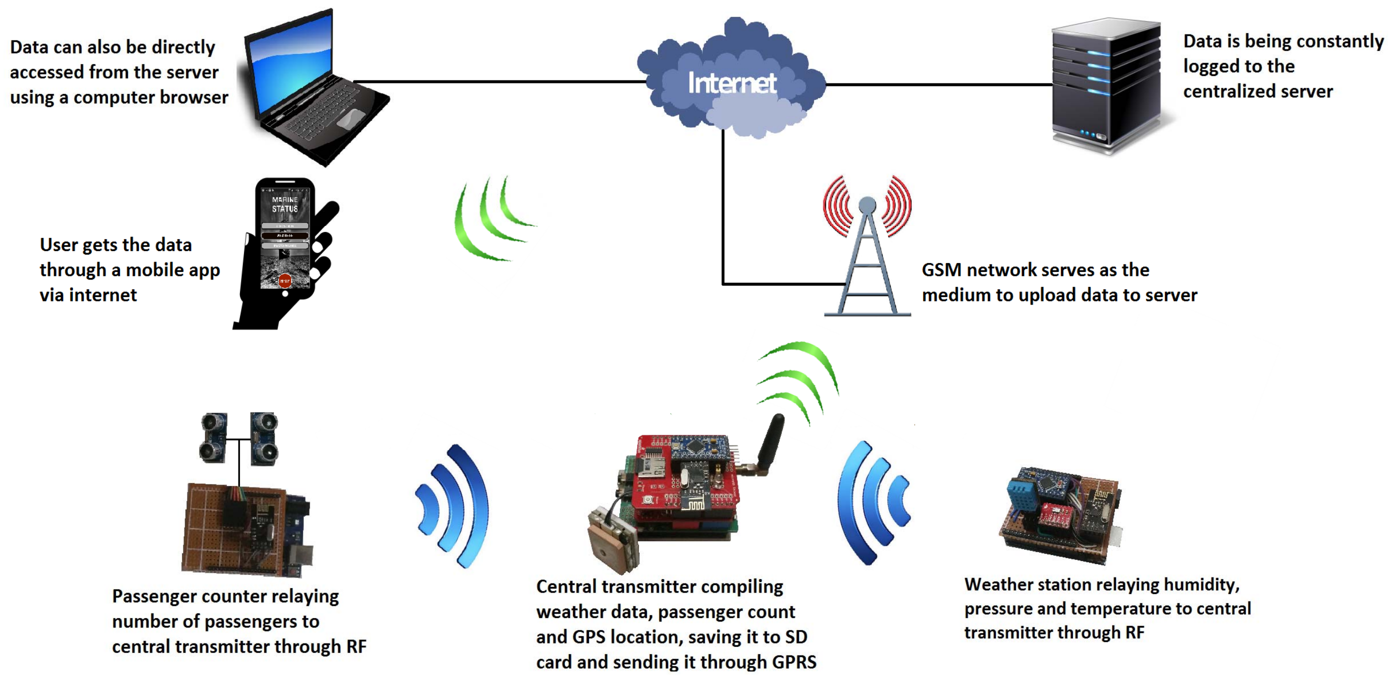

Fig. 8 Complete functional diagram of the developed system

and on typical cycles, the speeds rarely exceed 0.25m/s according to our findings from practical field tests. Therefore, it can be concluded that, if with such pace the entry of passengers are performed, the passenger counter can surely detect and calculate the total number of passengers boarding the ship and so can give an early warning to the administrators before exceeding the limit.

B. GPS Data Accuracy: Conferring to the system proposed, on a critical maritime situation the black box is to be ejected away from the marine vehicle with which it will remain attached with until. In such cases if the black box can be tracked down, the water vehicle that potentially faced an accident may also be located since the black box is designed in such way to remain floating on the water, attached with a string to it. This makes the accuracy of the logged location co-ordinates from the black box to the centralized server extremely significant. The location co-ordinates the black box retrieves using its GPS module which gets logged to the centralized server and the actual location co-ordinates may vary due to various circumstantial reasons. Therefore, a set of logged entries from the black box to the server has been compared with the actual exact location to find the inconsistency of the GPS data. As the results suggest in the graph in Figure 9, the location co-ordinates the black box receives using the GPS module and the actual co-ordinates are almost identical if not same.

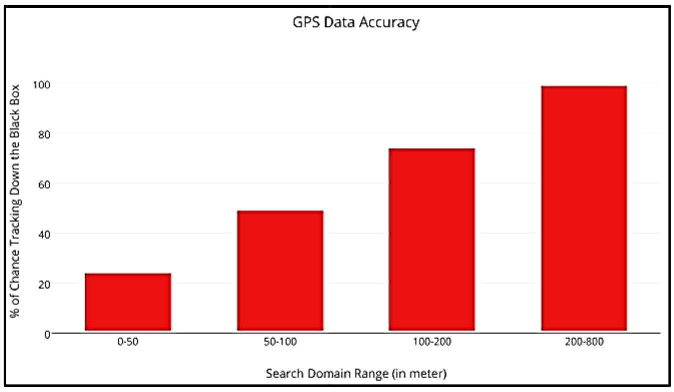

Fig. 9 GPS Data Accuracy

On basis of numerous location co-ordinates logged, it has been found that searching within 50 meters domain of the location co-ordinates logged to server from the black box will have 25% chance of being tracked down.

Again if the search domain is increased to 100 meters the percentage of chance to track down the black box successfully, reaches to 50. The threshold of search domain range has been set to 800 meters considering the worst case conditions, which suggests if the black box is searched with a domain of the threshold, rescue team is bound to successfully retrieve the black box, even if it is being drifted away by the river currents. Therefore, compared to a regular black box, our solution of this functional composite system has an added advantage of being discovered by means of GPS tracker, and that, at a very high accuracy as well.

V. Discussion

Real life application of this project is projected to see a sharp decline in number of marine mishaps. In spite of existence of several layers of warning mechanisms, if a water vehicle fails to avoid an accident, the string attached to the ejected Black Box will be logging data and transmitting location signals to get discovered. Discovery of the Black Box would also mean the retrieval of noteworthy facts and figures recorded during the critical period, enabling the possibility to figure out the concrete causes behind the failure. The passenger counter presently implemented using the sonar sensors can be made more efficient with the use of fingerprint signatures of the passengers boarding the vehicle. Supposedly, unique fingerprints would help recognizing each individuals precisely on board, in case of any probable accident faced by the marine vehicle. The smartphone application developed presently shows the values of weather variables such as temperature, pressure and humidity, which is planned to be upgraded to spontaneously warn concerned authorities on board regarding expected critical weather conditions functioning almost like a local weather station. The decision to declare a weather condition critical is to be made based on the historical analysis of the weather variables values obtained through a long period of time.

VI. Conclusion

The black box system implemented is highly reliable due to the fact that it has two methods of saving data, which includes data logging into SD card and at the same time transmitting the data to a web server. The latter feature is the unique feature of this developed system and has not been implemented as yet in any voyage data recorders. By both means, it is being ensured that the significant data to analyze any naval accidents are being saved remotely and simultaneously. This saving pattern may profoundly define this as the black box system, typically used in aircrafts, but differs notably both in terms of materials used and cost of such system implementation. We believe, our system might encourage viable information to be processed for analysis of critical marine catastrophes and applying such system in practice might in turn save thousands from facing disaster and develop a safer and secure marine travels in the future.

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