Location Monitoring System for Sailboats by GPS Using GSM/GPRS Technology

Rosa M. Woo-García, V. Herrera-Nevraumont, E. Osorio-de-la-Rosa, S. E. Vázquez-Valdés, and F. López-Huerta

***Abstract*—A monitoring and locating system for sailboats is developed using the general packet radio service/global system for mobile communications (GPRS/GSM) and global positioning system (GPS) technology. The implemented prototype can track the location of sailboats that do not go out more than 10 km into the sea. The system uses a GPS module to obtain the boat's coordinates; it has a sensing station: environmental temperature, humidity, barometric pressure, and the angular movement of the ship. A structured query language (SQL) database has been implemented to store data received via AVR-GPRS. System monitoring tests were carried out over a 24-km route onboard a sailboat, obtaining its location during the entire course along the coast of the Atlantic Ocean, Gulf of Mexico.**

***Index Terms*—General packet radio service (GPRS), global positioning system (GPS) tracking, GSM, monitoring, sailboat.**

I. Introduction

In THE early 1970s, the U.S. military developed the global positioning system (GPS) in order to improve existing navigation tracking methods. Since up to that time, navigation monitoring consisted mainly of radios, radars, and visual routes [1], currently, it is possible to monitor a vessel thanks to a tracking unit, using the GPS to identify the object's position, using at least four satellites. By carrying out the trilateration process, its location is calculated. GPS information is commonly associated with the automatic identification system (AIS), used to control vessel traffic on the busiest maritime routes [2] to analyze the recorded tracking data for the continuous improvement of the transport chain. The AIS system allows verifying the vessel's identity, position, course, speed, and estimated time of arrival at the port, in addition to receiving notifications about important events that occur during the vessel's voyage, such as deviations, adverse weather conditions, or problems inherent to the boat.

Since 2002, the International Maritime Organization (IMO) has been requiring the use of AIS on all vessels, national and international, as long as the total volume of the vessel's enclosed spaces is greater than or equal to 300 t. The requirement is also mandatory for any passenger's boat. On the other hand, the rule does not apply to fishing vessels, traditional boats, and recreational crafts with a length of fewer than 45 m from bow to stern [3]. Thus, vessels with smaller dimensions and whose route is restricted to a local area do not necessarily have a location system.

The main challenges of maritime communications are the lack of a preprovided infrastructure for supporting connectivity with the land and the adverse transmission conditions. The evolution, adoption, and massive use of the Internet of Things (IoT) has been allowing exploring a lot of communication technologies for maritime communications. However, to get it developed, it is necessary that some requirements must be met, such as infrastructure, communication range, power consumption, and details about the data to be transmitted. For instance, implementing a tracking network for IoT applications that can work on technologies such as long range (LoRa) may imply a higher initial cost; this will require a lot of base stations or gateways. In particle, the global system for mobile communications (GSM) connectivity is already covered in several countries, and GSM/general packet radio service (GPRS) may be the best choice for IoT applications. This means that any application based on cellular communication will not cost a lot as the network infrastructure is already in place, also solutions based on mobile cellular communications (3G, 4G, and 5G) could ensure a larger transmission range. It is a technology that is very mature, cost effective, readily available, and widely deployed [4].

In this sense, Sanchez-Iborra *et al*. have reported the tracking and monitoring system for lightweight boats using low-power–wide-area network (LP-WAN). A real LoRa network has been deployed. They reported that the levels of transmission reliability above 97% of PDR were attained with the most robust LoRa configuration. A transmission range study has also been presented, showing a maximum distance of 4 km under the conditions of the deployed test bench [5].

Several authors report location tracking systems for small vessels using GPS technology, Sanchana *et al*. made a low-cost GPS receiver integrated with GSM service, a friendly user application was developed using MIT App Inventor, an opensource software [6]. Rao and Lokesh [7] created an alarm system based on GPS that indicates the location of the boat: its value is given to the microcontroller and is continuously compared with the predefined values and the current location; when the boat crosses the predefined latitude and longitude, it alerts the fishers through the buzzer. Sudheera *et al.* proposed a GPS tracking system for offshore fishing boats, the purpose of the device is to minimize illegal, unreported, and unregulated fishing and develop sustainable fishing [8].

Navigating with a sailboat has advantages, it is environment friendly and marine fauna, and it does not require fuel

Manuscript received 6 June 2022; revised 28 June 2022; accepted 30 June 2022. Date of publication 6 July 2022; date of current version 29 May 2023. This manuscript was recommended for publication by L. De Micco. *(Corresponding author: F. López-Huerta.)*

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Digital Object Identifier 10.1109/LES.2022.3188935

to navigate, in addition, since there is no motor that drives the boat, it is possible in the future to characterize the shape of the waves, without interference from waves produced by the propulsion motor, and could measure wave crest, trough, height, wavelength, period, frequency, and amplitude. This monitoring system aims to provide a reference for future critical decisions that must be chosen to improve navigation conditions.

In this work, we present our implementation of a low-cost prototype that allows tracking the location of a sailing boat for five crew members through a GPS module, in addition to monitoring parameters: temperature, humidity, barometric pressure, and angular movement; the latter to determine if the boat has suffered a capsize. Along with the navigation system, a mobile application is implemented; it can transmit and collect data through GSM technology, displaying the information on a mobile device. Also, a structured query language (SQL) database has been developed to collect information through general packet radio service (GPRS).

The main contributions of this project were: 1) to make a monitoring and locating system for small boats using mature and low-cost technology; 2) the system provides a position with a latency of 4–7 and 9–12 s for GPRS and GSM, respectively, to improve the nautical routes reducing navigation times; and 3) the monitored system allowed an estimate of the breaking point of a possible overturn at 59° for the x-axis, $-258°$ for the y-axis, and $-6°$ for the z-axis.

II. Proposed System

Our sailing boat used for training in the port of Veracruz generally does not go more than 10 km out into the sea. This type of boat is commonly used by the crew of the Universidad Veracruzana, Mexico, to teach the process of sailing with the wind. Onboard the ship, they practice steering maneuvers according to the wind direction, tack or change the sailboat course, and hoisting and lowering sails. However, being entirely dependent on the wind to execute the vessel's forward motion, it is vital to know the location, as more extensive crafts are usually found around the periphery of the harbor. In addition, if there is a change in the atmospheric pressure and it drops, the air is warm but still light, which causes the phenomenon of depression to occur, which added to a drop in temperature and an increase in humidity could herald a change in the direction of the wind or rainy weather.

All of the features mentioned above are of high importance for trainers directing inexperienced sailors from land.

A. Global Positioning System

The GPS makes it possible to determine the exact location of a vehicle, person, vessel, or item [9]. The positioning system employs three elements: 1) a network of satellites in orbit around the planet; 2) tracking and controlling ground stations; and 3) GPS receivers owned by the users as shown in Fig. 1. Each satellite around the earth transmits its location information and current time at regular intervals. The GPS receiver intercepts the signals and calculates the distance each satellite is positioned based on the message arrival time. The GPS receivers obtain latitude, longitude, and altitude coordinates, as well as the local time through signals transmitted via the satellites [6].

To implement GSM/GPRS and GPS communication technologies, AVR-GSM cards were used to make and accept calls, send and receive simple message service (SMS), and connect to the Internet using the GPRS service.

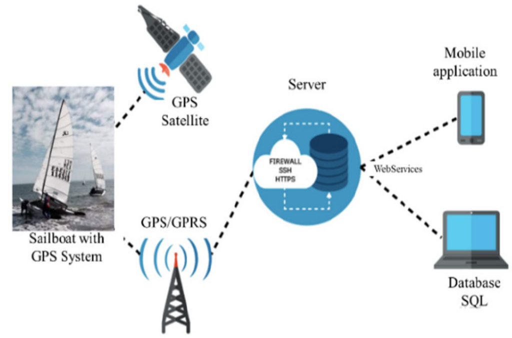


Fig. 1. GPS/GPRS location monitoring architecture.

B. Global System for Mobile Communication Technology

GSM technology uses the cellular telephone system to transmit information via a signal from a reference station to a mobile receiver. GSM is based on radio links that provide digital access to the telephone network using mobile terminals. The GSM allows voice transmission as well as data transfer (SMS and Internet) at a limited speed of 9.6 kb/s [10].

C. General Packet Radio Service

The GPRS system establishes a connection in which the data to be sent are divided into packets and sent independently. Once the data arrive at the destination, they are sorted again. This service is very efficient for data communications, especially for Internet access, as the maximum speed of GPRS is 144 kb/s in theory [11].

Multiple factors influence the quality of the network connection, such as the distance between a cell phone and a cell tower, unfavorable weather conditions, physical obstacles, and signal interference caused by circuit components or natural disturbances capable of distorting or interrupting transmissions. In addition to these factors, the towers designed by the telephone companies intend to cover small areas, being a maximum distance between a mobile phone and a telephone tower of 34 km. For this reason, if the vessel goes several kilometers out to the sea, it is possible to lose connectivity.

The proposed system uses a SIM808 module that integrates a GSM antenna interface and a GPS antenna interface. This module has its own power supply because it requires a higher power consumption under specific modes of use. The Atmel ATmega328P 8-bit microcontroller is used, polarized at 5 V, employing a 9-V battery. The communication of the AVR-GSM card is executed through programs using AT commands, which are instructions that constitute a language and have the purpose of forming a link with a MODEM terminal. The barometric pressure sensor used is the BMP180 GY-68, the AM2301 sensor monitored the temperature and humidity, a 3-D accelerometer ADXL345 was also used to measure the angular movement inclination is a process detected by a sensing accelerometer, in this case, a dagger board box surface was used as the reference frame, and the accelerometer is fixed in an upright position, in which the 1 g ($9.8 m/s^2$) force of gravity is directly being read on the positive z-axis, sensing the values of x-, y-, and z-axes.

Previously, in the same conditions, minimum and maximum values of x-, y-, and z-axes were measured. These values were necessary for the calculation and minimization of the offset

Small Vessels Monitoring			
Latitude:	19.352842	Humidity	70.50%
Longitude:	-96.430878	Temperature:	31.90 ºC
Pressure:	1006.05 mb	Coordinates:	X:31, Y:-8, Z:285
Date:	2021-12-06 23:47:54 UTC		
Latitude:	19.337653	Humidity	71.45%
Longitude:	-96.323002	Temperature:	32.00 ºC
Pressure:	1013.69 mb	Coordinates:	X:6, Y:9, Z:233
Date:	2021-12-06 23:42:41 UTC		
Latitude:	19.340253	Humidity	70.40%
Longitude:	-96.320505	Temperature:	32.00 ºC
Pressure:	1013.10 mb	Coordinates:	X:15, Y:11, Z:246
Date:	2021-12-06 23:37:23 UTC		
Latitude:	19.320263	Humidity	69.70%
Longitude:	-96.310723	Temperature:	32.30 ºC
Pressure:	1017.00 mb	Coordinates:	X:21, Y:2, Z:240
Date:	2021-12-06 23:32:16 UTC		
Latitude:	19.2500757	Humidity	69.30%
Longitude:	-96.265982	Temperature:	32.40 ºC
Pressure:	1011.59 mb	Coordinates:	X:14, Y:12, Z:265
Date:	2021-12-06 23:26:50 UTC		

Fig. 2. Display of the information in the App.

and gain errors. The ADXL345 is a small, ultralow power, 3-axis accelerometer with 13-bit resolution, measurement at 3.9 mg/LSB enables the measurement of inclination changes less than 1.0°. Accelerometer was configured at 100-Hz data rate and a sensitivity of ± 2 g resolution, it has been set to low power consumption, enabling smart power management based on motion with detection threshold.

III. Mobile Terminal

The mobile app that manipulates the system has been created to run on the Android operating system; this Linux-based operating system is opensource, free of charge, and multiplatform. The app's programming language is Kotlin, a language developed by the JetBrains team, compatible with Java, based on existing languages such as Java and C# [13].

The app's user graphical interface (GUI) presents the data of the sensed parameters to the user, allowing access to the information at any time. The GUI comprises a list filled with the data collected by the temperature, humidity, and position sensors. Within the GUI, there is the option to visualize the location logged by the GPS on a Google Maps map; this is possible by enabling the Google Maps Application Programming Interface (API). This API made by Google is a type of identification that allows apps to make different use of the Google Maps service; in this case, it is used to indicate the location on the map according to the coordinates obtained by the GPS antenna of the SIM808 module, Fig. 2 it is a screenshot of the mobile application. In the app, the user can select any element (coordinates) previously stored to be represented on the map.

As for the app controller, its functionality is to make the hypertext transfer protocol (HTTP) requests sent to the database server. If the request is processed correctly, then the data are stored and sorted in the model format. Once all the model fields have been completed, an adapter is created to assign the filled model to the list that comprises the view so that the information is displayed. If there are no data in the database, a message is shown in the app communicating the error. A design pattern has been incorporated, for the facility of the organization of the HTTP requests in a queue-type system, for the application, this is indispensable since it allows the server not to be saturated and to be an order for the revision of requests.

The database displays the values of the sensed environmental parameters through tables, as shown in Fig. 3. An API has been used to process the HTTP requests sent by the app controller. This API also creates a new record in the database each time the microcontroller sends further information from the sensing process. Once the microcontroller has collected the data, they are displayed and stored in the database and then shown in the app. The database is organized in descending order, revealing the last record obtained first.

id	Latitude	Longitude	Pressure	Humidity	Temperature	Coordinates	date_created
1	19.070134	-96.080625	1017.13 mb	71.40%	32.50 ºC	X:12, Y:13, Z:238	2021-12-06 22:57:22 UTC
2	19.102381	-96.116502	1014.59 mb	69.33%	32.10 ºC	X:17, Y:11, Z:265	2021-12-06 23:03:19 UTC
3	19.170269	-96.157653	1007.87 mb	69.90%	32.00 ºC	X:11, Y:2, Z:239	2021-12-06 23:09:43 UTC
4	19.2000876	-96.174929	1000.31 mb	68.55%	31.70 ºC	X:3, Y:12, Z:249	2021-12-06 23:15:17 UTC
5	19.230413	-96.220378	1004.97 mb	70.73%	32.15 ºC	X:8, Y:11, Z:239	2021-12-06 23:21:35 UTC
6	19.2500757	-96.265982	1011.59 mb	69.30%	32.40 ºC	X:14, Y:12, Z:265	2021-12-06 23:26:50 UTC
7	19.320263	-96.310723	1017.00 mb	69.70%	32.30 ºC	X:21, Y:2, Z:240	2021-12-06 23:32:16 UTC
8	19.340253	-96.320505	1013.10 mb	70.40%	32.00 ºC	X:15, Y:11, Z:246	2021-12-06 23:37:23 UTC
9	19.337653	-96.323002	1013.69 mb	71.45%	32.00 ºC	X:6, Y:9, Z:233	2021-12-06 23:42:41 UTC
10	19.352842	-96.430878	1006.05 mb	70.50%	31.90 ºC	X:31, Y:8, Z:285	2021-12-06 23:47:54 UTC

Fig. 3. Database (reading period every 5 min).

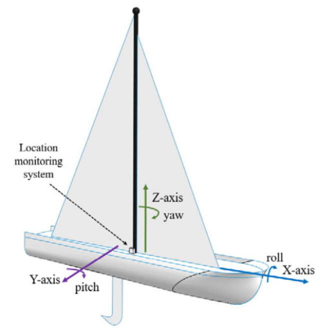


Fig. 4. Orientation of the sailboat axis.

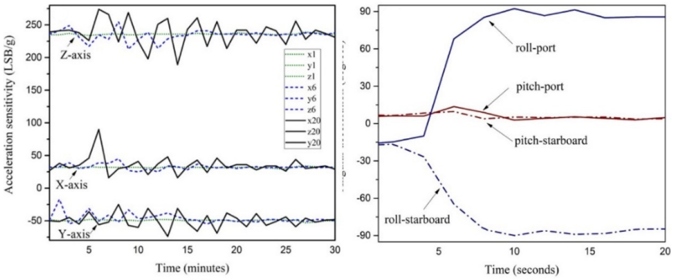
IV. Sailboat Monitoring and Results

Field tests have been conducted in the maritime area of the Veracruz-Boca del Rio conurbation, Mexico, as it is a region with a seaport. The Universidad Veracruzana, located in Boca del Rio, has a Naval Engineering Educational Program. It is desirable to have a navigation registry for university sailboats that travel the Playa Marti–Anton Lizardo route. There have been capsizing events; generally, these accidents result from neglecting the safety parameters.

The angular movement that exists around a rotation axis is produced by applying a force that acts at a certain distance outside the axis of rotation, in this sense, an excessive tilt to larboard or starboard due to a strong wind or an aggressive swell can produce a capsize of the small vessel. Fig. 4 represents the accelerometer orientation as the principal factor in the placement of the device. The axes of the sensors must be aligned with the axes of the sailboat, where a significant movement in the roll direction consolidates a capsize at the port or starboard.

Fig. 5(a) shows the boat movement based on the accelerometer sensor in terms value 8-bit register representing 1 g. To read the movements experienced by a sailboat, which are generated from the sea current, the wind force or the waves swell itself, movement is observed when there is little swell, wind at 1 knot on average, $(x1, y1, z1)$, movement at 6-knot wind $(x6, y6, z6)$, and movement at 20-knot wind $(x20, y20, z20)$.

A test was also performed simulating the movement of the boat and the sea swell to determine a collapse in the boat, showing the change of position in the x-, y-, and z-axes. Calculate the roll (φ) and pitch (θ), or the rotation around the x-axis and the rotation around the y-axis in degrees, using



(a) (b)

Fig. 5. (a) Sailboat movement at different speeds. (b) Collapse behavior on port and starboard.

the following:

$$\tan\varphi_{xyz} = \frac{G_{py}}{\sqrt{G_{px}^2+G_{pz}^2}} \quad (1)$$

$$\tan\theta_{xyz} = \frac{-G_{px}}{\sqrt{G_{py}^2+G_{pz}^2}}. \quad (2)$$

Rewriting roll and pitch angles define the sailboat's orientation relative to the starting position with the sea surface, assuming the aerospace rotation sequence xyz below, (3) and (4). Fig. 5(b) shows the pitch and roll of the vessel system

$$\varphi_{xyz} = \tan^{-1}\left[\frac{Y_{\text{out}}}{\sqrt{X_{\text{out}}^2+Z_{\text{out}}^2}}\right]\frac{180}{\pi} \quad (3)$$

$$\theta_{xyz} = \tan^{-1}\left[\frac{-X_{\text{out}}}{\sqrt{Y_{\text{out}}^2+Z_{\text{out}}^2}}\right]\frac{180}{\pi}. \quad (4)$$

The trajectory of the sailboat in a 2-h and 12-min course distance traveled in 23.8 km displacement is 18.7 km. Position update is every 5 min, on average, sailboat moves at a speed of 5.8 knots (10.8 km/h), in general, every 6 min, the boat moves 1 km, which is usually between 6 and 14 knots. The wind speed during the sailboat navigation was 12–14 knots on average. The sending data latency is programmable for up to seconds. In this work, a sailboat whose total journey is less than 3 h is followed up. Therefore, we programmed the follow-up by sending the position every 5 min, which is equivalent to 0.78 kb, reaching a total of 28.08 kb. In the case of Mexico, the leading cell phone company supports 3G, 4G, 4.5G, and LTE, where its telephony plans and rates are very accessible and the sending of SMS is unlimited. With a simple scan it is possible for the sailboat to complete the tracking. For this case study, where the consumption of the tracking system consumption every 5 min is 2.5024 W, reaching 90.08 W per trip. While the smartphone is monitoring position for 2 h 12 min, the battery consumption is 13% at 38% [13].

V. Discussion and Conclusion

The location in real time of a private transportation unit while traveling from Playa Marti to Anton Lizardo route has been monitored resembling the mobility of small sailboats, which was possible by using an ATmega328P microcontroller that controls the SIM808 module that implements a GPS antenna. Likewise, the microcontroller is also responsible for measuring environmental factors that are of interest, such as barometric pressure, temperature, and relative humidity of the environment by employing sensors.

The movement behavior of the boat is reported in three days, one when there is almost no wind (1 knot on average), one day with favorable conditions for sailing (6 knots), and when there is wind at 20 knots on average.

This produces variations in the position of the monitoring system detected by the accelerometer ADXL345 ranging in amplitude for the windiest days waves from 25 to 45 on the x-axis, from -55 to -17 on the y-axis, and from 213 to 249 on the z-axis, and for medium wind days, the waves from 19 to 90 on the x-axis, from -74 to -25 on the y-axis, and from 189 to 274 on the z-axis; in this way, the angular position changes experienced due to the waves are established.

Finally, with the tests carried out when simulating the movement that exists in a small boat when it capsizes, in order to know the breaking point of a possible overturn, the data collected indicate that at a rotational speed of approximately 6 °/s, the system indicates the breaking point at 59° for the x-axis, $-258°$ for the y-axis, and $-6°$ for the z-axis.

The data obtained with the system are also stored in a database on an online server and then transmitted to a mobile application developed for the Android operating system. The information is accessible from anywhere and at any time.

With the results obtained, it can be concluded that it is possible to develop a monitoring and locating system for small boats using GPRS/GSM and GPS technology, which allows the location data to be sent to the user's mobile phone. Implementing this system can provide relevant information to improve the nautical routes, obtaining advantages, such as avoiding maritime danger zones depending on the year's season in which the course is traveled, reducing navigation times and knowing the boat's position during the whole journey.

References

[1] C. J. Hegarty, "The global positioning system (GPS)," in *Springer Handbook of Global Navigation Satellite Systems*. Cham, Switzerland: Springer, 2017, pp. 197–218.

[2] S. P. Fancello, A. Schintu, and A. Zoratti, "Performance evaluation of a tracking system for intermodal traffic: An experimentation in the Tyrrhenian area," *Eur. Transp.*, vol. 76, no. 8, pp. 1–12, 2020.

[3] R. Balkin, "The international maritime organization and maritime security," *Tulane Martime Law J.*, vol. 30, nos. 1–2, p. 1, 2006.

[4] W. Zheng, K. Sun, X. Zhang, Q. Zhang, A. Israr, and Q. Yang, "Cellular communication for ubiquitous Internet of Things in smart grids: Present and outlook," in *Proc. IEEE Chin. Control Decis. Conf. (CCDC)*, Aug. 2020, pp. 5592–5596.

[5] R. Sanchez-Iborra, I. G. Liaño, C. Simoes, E. Couñago, and A. F. Skarmeta, "Racking and monitoring system based on LoRa technology for lightweight boats," *Electronics*, vol. 8, no. 1, p. 15, 2019.

[6] S. Sanchana, A. P. Manjari, and B. N. Jythi, "Application development for real-time location tracking for underwater vehicles using low-cost GPS with GSM," in *Proc. IEEE 6th Int. Conf. Wireless Commun. Signal Process. Netw. (WiSPNET)*, 2021, pp. 108–112.

[7] S. S. Rao and B. S. Lokesh, "Border alerting system for fisherman using GPS module," *Int. Res. J. Eng. Technol.*, vol. 4, no. 6, pp. 5–7, 2017.

[8] K. L. K. Sudheera, G. G. N. Sandamali, W. N. D. C. Sandaruwan, and N. D. Jayasundere, "Offline tracking system for deep sea going vessels using GPS and GPRS," in *Proc. IEEE 8th Int. Conf. Ubi-Media Comput. (UMEDIA)*, 2015, pp. 55–60.

[9] J. I. Miano *et al.*, "Microcontroller-based vessel passenger tracker using GSM System: An aid for search and rescue operations," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 9, pp. 1–19, 2019.

[10] K. M. Ghazi, T. O. Al-Mukhtar, and H. Q. Shihab, "Design and implementation of a smart home automation system based on global system for mobile communications," *J. Appl. Eng. Sci.*, vol. 16, no. 4, pp. 471–479, 2018.

[11] C. Iswahyudi, M. A. Novianta, and H. P. Suseno, "Application of greenhouse gas monitoring system using general packet radio service on GSM network," in *Proc. IOP Conf. Mater. Sci. Eng.*, vol. 807, 2020. Art. no. 012013.

[12] B. Mateus and M. Martinez, "An empirical study on quality of Android applications written in Kotlin language," *Empirical Softw. Eng.*, vol. 24, no. 6, pp. 3356–3393, 2019.

[13] M. Tawalbeh, A. Eardley, and L. Tawalbeh, "Studying the energy consumption in mobile devices," *Procedia Comput. Sci.*, vol. 94, pp. 183–189, Aug. 2016.