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# The Design of a Location Monitoring System for a Fleet of Electric Scooters

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***Abstract*** **- The development of geolocation systems( geostationary satellite networks), as well as devices capable of receiving signals and processing the data coming from them, makes possible the implementation of location monitoring systems for various purposes. Whether it's about security or optimizing travel times or routes, these systems are based on information in the form of global coordinates (latitude and longitude) from satellite systems or cell towers. The design of such a system is presented in this paper, being a good guide in the design and implementation of such a system, regardless of the application. Both, the hardware part (the designed equipment) and the software part (the backend component running on a virtual private server, as well as a mobile application) are presented in this paper. In the development of the system, was used only location provided by information from satellites, without using GSM cell signals. The entire system has been successfully tested in different GSM signal conditions as well as various locations to see the influence of environmental parameters on performance. The system described in the paper can be the starting point for the development of other systems for a variety of applications that require the management of the location of some devices.**

**Cuvinte cheie:** *geolocație, microcontroller, sateliti, framework, full-stack.*

**Keywords:** *geolocation, microcontroller, satellites framework, full-stack.*

## I.Introduction

As is known, positioning systems use networks of geostationary satellites that emit signals to the Earth's surface where they are received by the equipment that can process them. Currently, four global positioning systems are fully operational: the U.S. Navigation Signal Timing and Ranging (NAVSTAR) GPS, Russia's Global Navigation Satellite System (GLONASS), the EU's system named Galileo, and China's Bei Dou Navigation Satellite System. Japan and India are also well on their way with their regional systems, the Quasi-Zenith Satellite System (QZSS) and the Indian Regional Navigation Satellite System (IRNSS), respectively[1].

The most popular and widely used are the GPS and GLONASS systems. They emit signals that ensure positioning accuracy of a few meters for the general public, but also commercial signals for positioning with an error of only a few centimeters.

To receive signals from satellites, are used electronic devices consisting of an electronic control unit equipped with a dedicated antenna.

A GPS or GNSS antenna is a device designed to receive and amplify the radio signals transmitted on specific frequencies by satellites and convert them to an electronic signal for use by a receiver.

This receiver is represented by a dedicated electronic device with an integrated microprocessor that most of the time has a built-in component that ensures the connection to a mobile phone network and can be configured through a set of AT commands.

The picture below presents a board equipped with that kind of unit from Simcom(China) and a GPS active antenna.

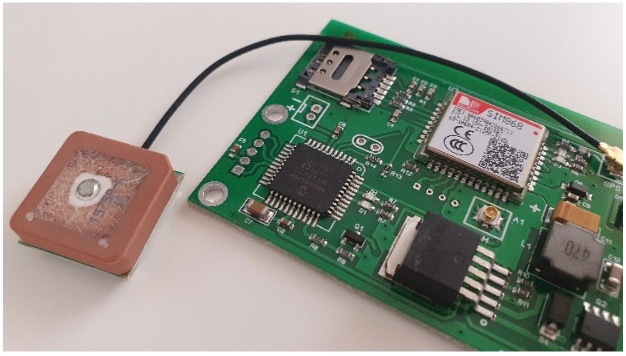

Fig.1 The GPS module with a dedicated antenna

## II.The System's Architecture

The role of this system is to connect a two-wheeled electric vehicle to the Internet network through which to transmit a series of data (location, battery level), as well as to receive various commands (software update for controllers, on/off, or lock commands).

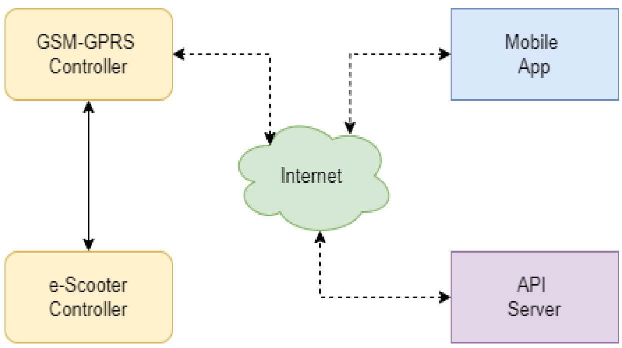


Fig.2 The block diagram of the entire system

To realize these tasks, the system is composed of several hardware and software components. The block diagram of the entire system is shown in the following figure.

The GSM-GPS Controller is a dedicated controller designed for the acquisition of the location and the Internet connection is plugged into a serial communication port to the vehicle controller which runs a firmware that is specially modified for this application.

The mobile application, which will be described later, allows viewing the data sent by this controller, as well as interacting with it.

The API server is represented by a software package developed in PHP and JavaScript run by Apache2 under Debian Linux on a VPS(virtual private server).

Next, the structure and operation mode of all these components will be presented.

## III.HARDWARE DESCRIPTION

### *A. The GSM-GPS Controller*

That controller(fig.3) is designed around of PIC18F45K22 microcontroller from Microchip. This microcontroller fulfills several distinct tasks:

- initializes and communicates with the Simcom SIM868 GPS-GPRS module,
- processes the data coming from it
- ensures serial communication with the vehicle's main controller.

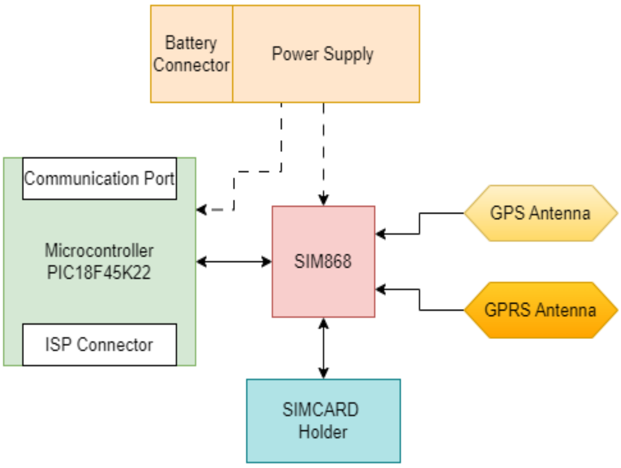


Fig.3 The GSM-GPS Controller Schematic

The microcontroller is a high-performance 16-bits RISC CPU. Its main features are:

- A C Compiler Optimized Architecture;
- Up to 1024 Bytes Data EEPROM;
- Up to 64 Kbytes Linear Program Memory Addressing;
- Up to 1024 Bytes Data EEPROM;
- Up to 16 MIPS Operations;
- 16-bit Wide Instructions, 8-bit Wide Data Path
- Priority Levels for Interrupts

Two serial ports of the microcontroller are used to communicate simultaneously with the SIM868 as well as with the main controller of the scooter (located in the scooter's display element).

All the code run by PIC18F45K22 was written in C language and compiled with the CCS Compiler.

SIM868 module is the complete Quad-Band GSM/GPRS module which combines GNSS( GPS/GLONASS/BDS) technology for satellite navigation. It has strong extension capability with interfaces including UART, USB 2.0, and GPIO[2].

Designed for a global market, SIM868 is integrated with a high-performance GSM/GPRS engine and a GNSS engine.

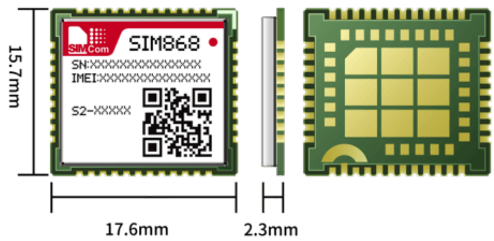


Fig.4 SIM868's dimensions

It has low power consumption, embedded TCP/UDP protocols, and multi-constellation GNSS receiver support: GPS, GLONASS, and Bei Dou.

This module can also be used to find the location using the intensity of the GSM signals coming from the cell towers. Also, using the capabilities to make calls and send SMS, a set of short messages can be designed to configure certain system parameters. However, there is a limitation, namely that, when the GPRS connection to the Internet is initiated, the voice and SMS services cannot be used.

The only limitation of this model is that it cannot operate in 4G and 5G networks. For these networks, it can be successfully replaced by the Simcom SIM7070G model.

The entire operation of the SIM868 is controlled through AT commands.

The "AT" or "at" or "aT" or "At" prefix must be set at the beginning of each Command line. To terminate a Command line enter <CR>.

Commands are usually followed by a response that includes "<CR><LF><response><CR><LF>".

Communication between the microcontroller and SIM868 is done using a master-slave protocol through AT commands at a transfer rate of 115200 bps. The response time to AT orders is of the order of tens of milliseconds.

Both the microcontroller and the GSM-GPS module require a supply voltage of 3.3V. Since the energy source is the scooter's battery, whose voltage is between 36V and 48V, a buck DC to DC Converter was used.

The XL7005a model was chosen, due to its capabilities. It has the following features [3]:

- Maximum Input Voltage 100V
- Output Adjustable from 1.25V to 20V

- Maximum 0.4A Output Current

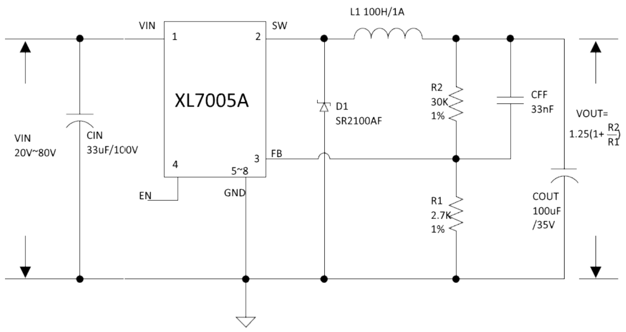


Fig.5 XL7005A usage diagram

For radio communication, as shown in Figure 3, two antennas are needed: one for GSM communication and one for receiving GPS signals.

Fig.6 The GPS and GPRS antennas

The GPS antenna has a working frequency of 1575.42 ± 2.0 MHz with a bandwidth of 10 MHz and a gain of 1 dB. The impedance is 50 ohms, and the supply voltage is 3V.

The GPRS antenna is a 3DBI GSM/GPRS/3G PCB Antenna with IPEX13 Connector.

It has an impedance of 50 ohms, a gain of 3dB, and can operate in the frequency range 824M-960MHz 1710M-1990MHz.

## IV. Software

The software package contains 4 components:

- the software for the microcontroller on the board with the GPS receiver;
- the server's software for the backend part;
- the administrator software for the frontend accessible from the browser,
- the smartphone application for scooter user.

The microcontroller software is responsible for operating the GPS-GPRS module.

It was developed in the C++ language, using the CCS compiler, the transfer to the microcontroller being done with the help of the PicKit3 programmer.

This software follows the diagram in the following image 7. All the code has been structured in reusable blocks and parameterized for possible future development or improvement.

After initializing the hardware resources of the microcontroller (clocks, digital ports, serial communication), the code runs a series of routines that ensure the connection, maintenance, and interruption of the connection to the GSM network and the mobile data connection, receiving data from satellites, filtering them for elimination altered data, Internet communication with the system server.

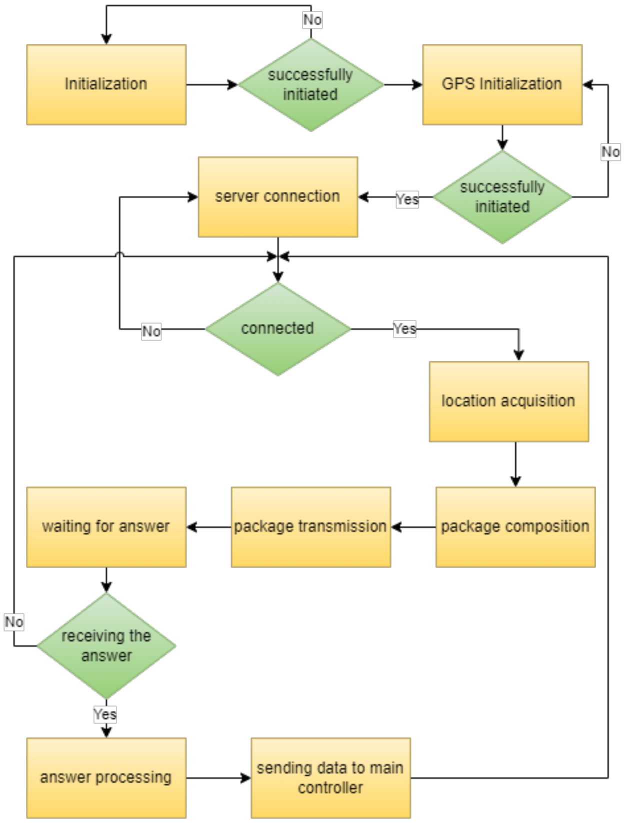


Fig. 7 The microcontroller software diagram

The first part of the program initializes the module, which consists of the following steps(for each step the AT commands used will be specified):

- checking if the module responds to AT commands (AT),
- checking the connectivity of the SIM card and the availability of the GSM network (AT+CGREG?),
- setting the APN (AT+CSTT="APN"),
- configuring the server's IP address and communication port (AT+CIICR, AT+CIFSR, AT+CIPSTART="TCP","server_address","port")
- starting the GPS module (AT +CGNSPWR=1),
- setting the format in which to transmit the positioning data (AT+CGNSSEQ="RMC").

The data provided by the GPS module follows the NMEA GPRMC format and it is obtained by command: AT+CGNSINF.

The GPRMC sentences are the most common sentences transmitted by the Global Positioning System (GPS) devices.

That data contains UTC time, positioning status(effective positioning or invalid positioning), latitude, latitude hemisphere, longitude, longitude hemisphere, ground speed, ground heading, UTC date, magnetic declination, magnetic declination direction, mode indication(autonomous positioning, differential, estimation, invalid data)[4].

The NMEA format for longitude and latitude is (d)ddmm.mmmm. In order to use the data on the Google Maps map, it is necessary to convert these data into decimal degrees.

To get to decimal degrees from degrees and minutes, we can use the following formula:

$$(d)dd + (mm.mmmm/60)\ (* \text{-}1 \text{ for W and S}) \quad (1)$$

Based on these transformations, Haversine's formula [5][6] is used to calculate the ground distance between two coordinate points.

$$a=\sin^2((\Delta lat)/2)+\cos(lat1).\cos(lat2).\sin^2((\Delta lon)/2) \quad (2)$$

$$c = 2.\mathrm{atan2}(\sqrt{a}, \sqrt{(1-a)}) \quad (3)$$

$$d = R.c \quad (4)$$

where,

$\Delta lat = lat1 - lat2$

$\Delta lon = lon1 - lon2$

R is radius of earth i.e 6371 KM or 3961 miles and d is the distance computed between two points.

```
distanceInM (lat1, lon1, lat2, lon2) {
    var earthRadiusKm = 6371000;
    var dLat = degreesToRadians(lat2-lat1);
    var dLon = degreesToRadians(lon2-lon1);
    lat1 = degreesToRadians(lat1);
    lat2 = degreesToRadians(lat2);
    var a = Math.sin(dLat/2) * Math.sin(dLat/2) +
            Math.sin(dLon/2) * Math.sin(dLon/2) *
            Math.cos(lat1) * Math.cos(lat2);
    var c = 2 * Math.atan2(Math.sqrt(a), Math.sqrt(1-a));
    return earthRadiusKm * c;
  }

degreesToRadians(degrees) {
    return degrees * Math.PI / 180;
  }
```

Fig.8 The code sequence for calculating the distance based on the GPS coordinates of two points

The API server runs a software package under Linux Debian distribution on a VPS. A virtual private server was created at DigitalOcean in the San Francisco datacenter to test the performance of the system when the communication is over long distances.

This software package is developed in Php and JavaScript using Laravel framework served by Apache2 web server and MySQL database server. All APIs served by this are authenticated with tokens and protected by Laravel Passport module.

It has two components: one responsible for receiving and storing messages from the devices located on the vehicles and providing them with the commands that must be executed (On, Off, Lock), as well as one that performs the entire authentication part, processing the data stored in MySQL database.

The first component uses web socket technology that makes it possible to open a two-way interactive communication session between the scooter and the server. The way this part works is described in the following image.

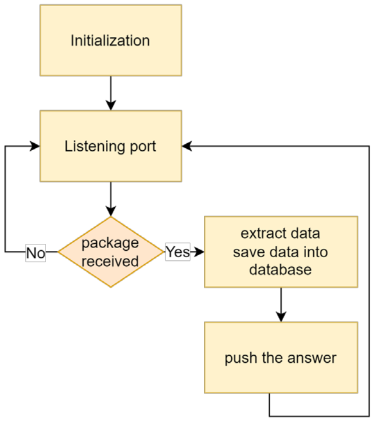


Fig.9 Websocket package

Data processing is done with the aim of providing the user with information about the position, the route traveled, and the condition of the vehicle.

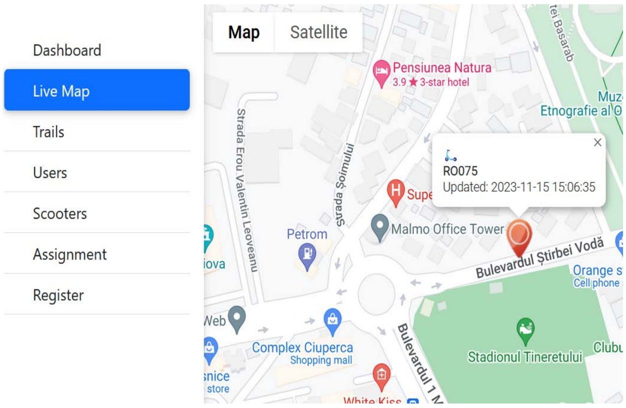


Fig.10 Live Map

Various operations can be performed in the administration interface available in the browser, such as: the positions of the scooters can be viewed in real time, their routes can be viewed in a selected time range, user administration and the allocation of scooters, viewing their status.

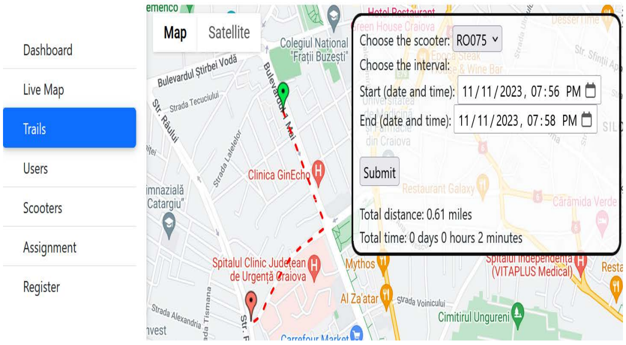


Fig.11 Viewing a route in a selected time interval

The mobile application for smart devices was developed using JavaScript language and React-Native framework, which allowed the creation of a version for Android devices as well as for iOS using the same base code.

To run, the application requires at least iOS 13.0 or Android 8. Its role is to allow the user to interact with the system and implicitly with the equipment[7].

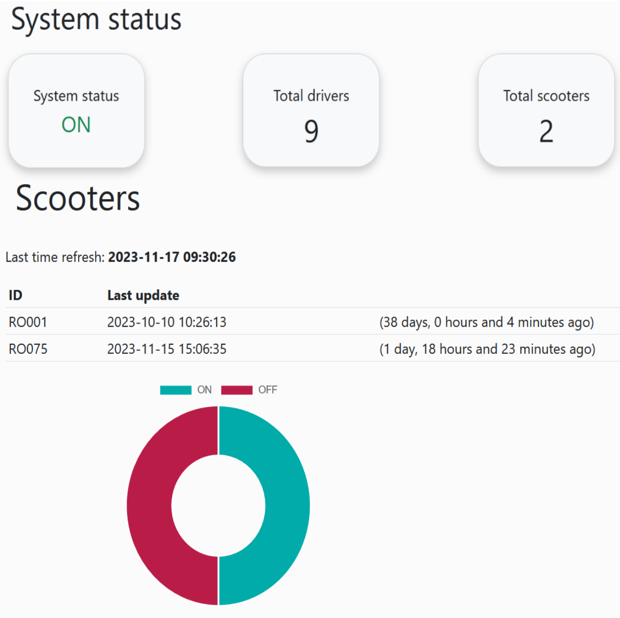


Fig.12 System status dashboard

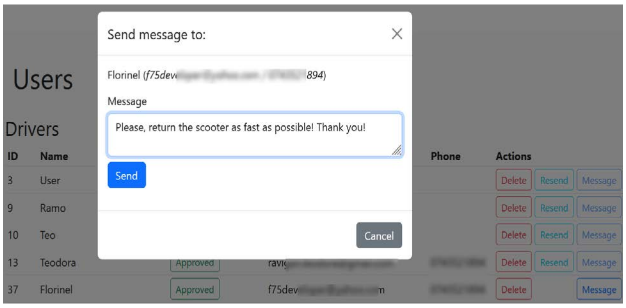


Fig.13 Sending messages from the admin panel via OneSignal

The application needs permission to access the location of the device, as well as to receive notifications. The system has implemented the possibility of sending push notifications using the OneSignal platform.

The application allows the following operations:

- the authentication procedure(Accounts are created by the system administrator in the backend and approved after confirming the email address, but the account creation from the application can be easily implemented),
- viewing the position of the equipment as well as that of the user on the map,
- the state of the vehicle,
- the analysis of the distances covered,
- the time of use,
- the history of trips on the map.

The act of pressing the start button will lead to starting the vehicle, and it can be used. The interface also offers a button with which the scooter can be locked. Through this blocking, the scooter will not be able to be used by other people because its wheel will be blocked (the BLDC motor will instantly enter dynamic braking mode), and when the wheel is moved the horn will sound an alarm and the brake light will also flash very fast[8].

Also, the interface allows searching and identifying the scooter when it is not visible, by triggering the horn that will emit three short sounds.

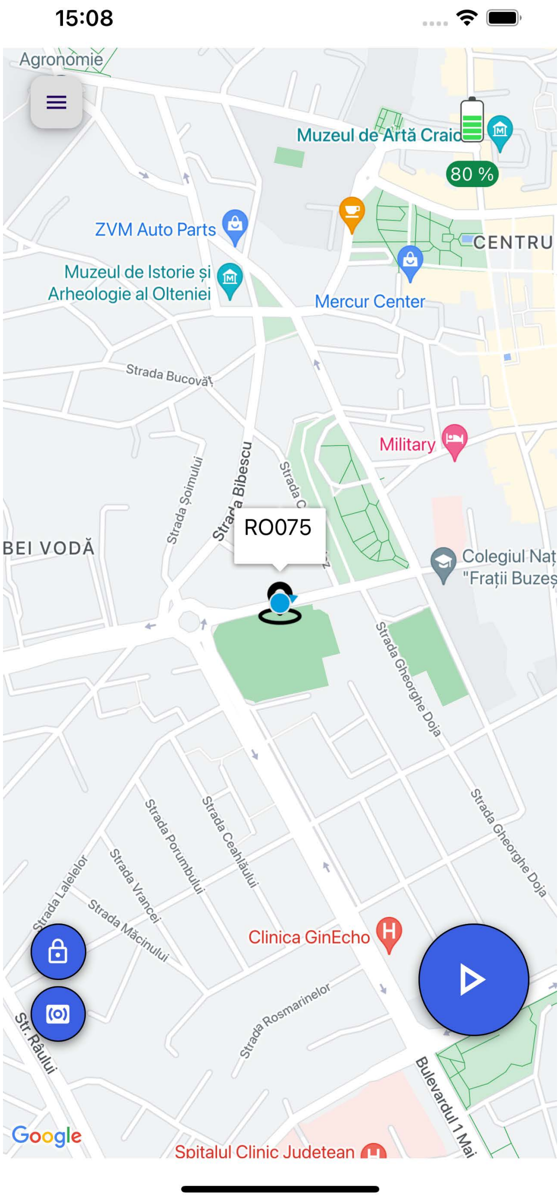


Fig.14 The main user interface of the mobile app

In the upper right part of the mobile application interface, the scooter's battery level can be monitored in real-time.

On the map in the application, you can see both the position of the scooter (black marker) and the position and orientation of the user (blue marker).

Also, in the upper part, there is a button that allows access to a menu through which the online account can be accessed, a history can be viewed as well as statistics related to the duration and distance of trips.

All statistics calculations are done in the backend to reduce the processing effort of the application and to provide a better user experience.

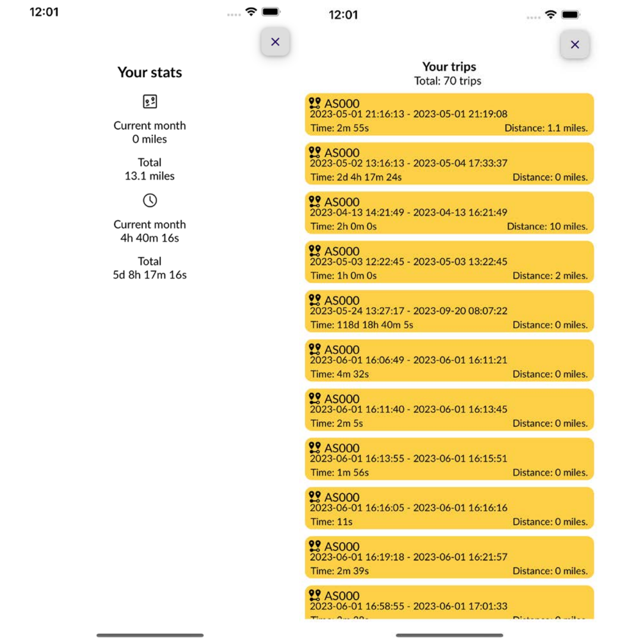


Fig.15 Viewing statistics and travel history

## V.CONCLUSIONS

Starting from the described system, it can be developed and used in a variety of applications that require the location management of some devices.

This system can be used to monitor fleets of electric scooters or bicycles, cars, boats, and industrial equipment.

During system testing, the designed hardware proved to be very reliable, providing stable connectivity even in conditions with weak GSM signal, as well as location information with small errors.


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Second coauthor – 20%

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