

Design and implementation of an edge computing-based GPS tracking system

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Abstract. This paper presents a comprehensive study on the technical aspects of edge-enabled GPS tracking systems, their evolution, and an analysis of existing problem-solving approaches. It introduces mathematical models that simulate the operation of the hardware and software components of these systems. An adaptive user interface has been developed, enabling usage across various platforms such as smartphones and personal computers. The paper also explores innovative methods for visualizing the trajectory of a moving object on an electronic map. Specialized software for the Atmega162-16PU microcontroller has been developed to control the GSM module and GPS receiver. A novel method for data transmission from a GPS tracker to a web server is proposed. The paper concludes with the successful testing of two experimental GPS-tracker prototypes under uncertain conditions. The developed edge-enabled GPS tracking software and hardware show potential for monitoring moving objects within the coverage of GSM cellular networks¹.

Keywords: GPS tracking systems, mathematical modeling, adaptive user interface, Atmega162-16PU microcontroller, GSM module, GPS receiver, data transmission, edge computing, real-world testing

1. Introduction

In today's fast-paced world, enterprises across various sectors heavily rely on vehicles for their day-to-day operations. This includes, but is not limited to, police units, municipal services, healthcare services, taxi services, rental agencies, delivery services, public transport, fire departments, and agricultural sectors. These vehicles, often numbering in hundreds for a single enterprise, are valuable assets that necessitate efficient management and supervision for successful business operations.

For an enterprise leader, real-time location tracking of these vehicles is crucial for effective work schedule management and timely goods delivery. Additionally, historical data of vehicle movements can prevent misuse of the company's fleet, thereby avoiding unnecessary expenses.

However, the need for location tracking extends beyond enterprise leaders. Individuals also seek to monitor their movable assets, especially in light of frequent vehicle thefts where prompt action is critical.

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This paper proposes the development of GPS tracking software and hardware systems to address these challenges. These systems leverage data from satellite navigation systems like GPS (Global Positioning System) or GLONASS (Global Navigation Satellite System).

The proposed GPS tracking systems can be employed across various economic sectors to monitor a wide range of mobile objects in real-time within GSM-cellular network coverage. These objects include vehicles, enterprise employees, tourist groups in unfamiliar territories, children, animals, and mobile equipment.

To accomplish this, the paper sets forth the following objectives:

- Analyze the current applications of GPS tracking.
- Evaluate existing GPS tracking devices.
- Develop a functional diagram of the GPS tracking software and hardware complex.
- Formulate mathematical models for this complex.
- Design an electrical circuit for the hardware of this complex.
- Construct a database structure.
- Develop a user interface for the software and hardware complex.
- Implement and test the hardware and software complex.

2. Imperative need for mobile object monitoring and potential solutions

2.1. Examination of contemporary GPS tracking applications in industry and society

A standard GPS tracking system is typically composed of three key components:

1. Terminals: These are installed on the vehicles and are specialized GPS trackers containing a GPS receiver and cellular tools.
2. Server: This is where the movement data of the vehicle is stored. The server can range from a regular personal computer with installed server software for simpler GPS tracking systems, to a large distributed system equipped with specialized software for more complex, specialized GPS tracking systems.
3. Client Workstations: These are equipped with appropriate software for monitoring transport.

In certain instances, the client software can be integrated with the server part into a single program. However, it is often feasible to connect multiple workstations to the server. Some GPS tracking systems, through the installation of special software on client computers, enable rapid information retrieval via web feeds.

The operation of the GPS tracking system can be broken down into the following stages:

- The GPS-tracker computes the geographical coordinates of the vehicle.
- The GPS-tracker transmits the acquired coordinates and other data to the server via cellular or satellite communication channels.
- The server receives the data from the GPS tracker, analyzes it, and stores it in the database.
- The customer receives information about the vehicle's movement on a smartphone or personal computer.

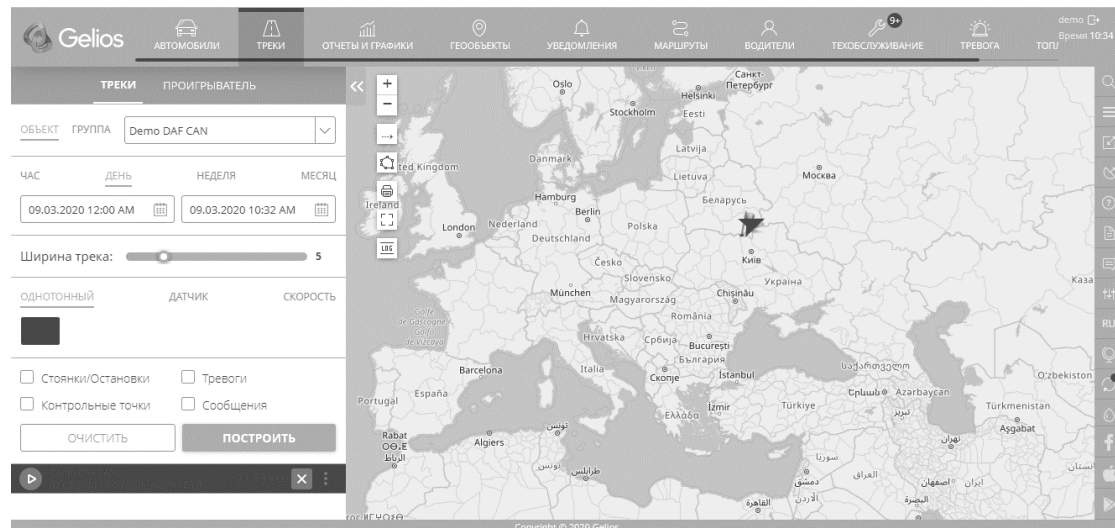


Figure 1: “Gelios” user interface.

2.2. Examination of current GPS tracking solutions

In the contemporary landscape, the GPS tracking system market is saturated with a plethora of hardware and software solutions for vehicle monitoring. One such solution is the “Gelios” GPS tracking software-hardware complex, developed by “GeliosSoft” (<https://tinyurl.com/mw8h3us5>), the user interface of which is depicted in figure 1. The system is accessible to users via a web browser.

The Gelios system facilitates real-time transport monitoring, thereby enhancing vehicle operation efficiency, optimizing financial expenditure, elevating transport safety levels, and improving the work discipline of the company’s personnel. The Gelios GPS tracking system employs third-party GPS trackers, one of which is illustrated in figure 2.

This tracker is engineered to pinpoint the precise location of the object and other parameters, and subsequently transmit them to the server through GSM networks. The device is equipped with two analog and four digital inputs, enabling the connection of various sensors such as fuel level sensors, axle pressure sensor, temperature sensors, and more. This adaptability underscores the potential of edge computing in enhancing the functionality and versatility of GPS tracking tools.

2.3. Fundamentals of satellite navigation

Satellite navigation systems are primarily composed of three key components [3]:

- Space-based equipment;
- Ground-based equipment;
- User equipment.

The space-based equipment encompasses navigation satellites, which are primarily responsible for transmitting requisite information via their radio signals to ascertain the location of



Figure 2: “Ruptela” GPS-tracker.

terrestrial objects.

The ground-based equipment comprises a control center, a spaceport, and measuring equipment. The control center orchestrates the operations of all components of the satellite navigation system.

The user equipment includes satellite receivers utilized by consumers. These receivers are engineered to intercept signals from navigation satellites, compute navigation parameters, and process these computations.

The integration of these components underscores the potential of edge computing in enhancing the efficiency and accuracy of satellite navigation systems.

2.4. Underpinnings of GSM cellular networks

Cellular communication, a form of mobile radio communication, is predicated on a cellular network [9]. A distinguishing characteristic of cellular communication is the division of the coverage area into discrete cells, corresponding to the service areas of the base stations (BS). These cellular zones intersect at certain points, collectively forming a cellular network. The service area of a base station, on a flat surface, assumes a circular shape, resulting in a cellular network composed of hexagons when viewed collectively.

The network comprises spaced cellular base stations, which facilitate the determination of the location of moving objects, albeit with a significant margin of error that can extend to several hundred meters. These base stations ensure seamless communication as a network subscriber transitions from one cell area to another.

When a cell phone exits the coverage area of a base station (approximately 35 kilometers in radius), it establishes a connection with the base station using the base station. The phone simultaneously measures the signal level of the thirty-two nearest base stations. Data on the top six signal levels are relayed by the phone through the service channel to the switching

center. Subsequently, the communication control is transferred from one station to another. The maximum distance between the phone and the nearest base station for communication is 120 kilometers, which can be extended with the use of GSM amplifiers and directional antennas.

Base stations of the cellular network are centrally located within the cell, typically atop iron towers or on the roofs of multi-story residential buildings. The cell phone continually scans the radio to detect the base station signal. Upon detection of a base station signal, the phone transmits an ID to that station. The phone and the base station maintain constant radio contact. Different cellular networks are interconnected and linked to a fixed telephone network.

GSM cellular networks represent the second generation (2G) of digital cellular communication. Mobile phones are designed to operate in four frequency bands: 850, 900, 1800, 1900 MHz, as different regions of the world utilize different frequency bands for GSM networks. The GSM network enables the use of a common packet data service, i.e., GPRS. This standard employs a voice line to transmit any information. The service is utilized by mobile devices to access the Internet. GPRS classes range from the first to the twelfth. As the class increases, so does the data rate. The average GPRS data rate ranges from 20 to 40 kilobits per second.

This examination of GSM cellular networks underscores the potential of edge computing in enhancing the efficiency and accuracy of these networks.

3. Design of edge-enabled GPS tracking software and hardware complex

3.1. Architectural design of the edge-enabled GPS tracking software and hardware complex

The operation of the GPS tracking software and hardware complex is segmented into the following stages:

- The GPS-tracker receiver computes the geographical coordinates of its location;
- The tracker's microcontroller receives geographical coordinates from the GPS receiver;
- The tracker's GSM-modem receives geographical coordinates from the microcontroller and transmits them to the web server via the GSM network;
- The web server receives the geographical coordinates from the GPS receiver, verifies their integrity, and stores them in the database;
- The user software displays the newly received geographical coordinates of the tracker on an electronic map in the web browser window.

The functional scheme of this complex necessitates two domains on the web server. The domain `mygps.pp.ua` must have an installed SSL certificate to utilize the HTTPS protocol for data exchange between the user and the web server [11]. The second domain will be employed to receive geographical coordinates from the tracker via the HTTP protocol [10] using PHP scripts [6]. Trackers must transmit geographical coordinates in the parameters of the GET request [6]. Both domains must share a common database.

Two types of GPS trackers are planned for development. The first type of trackers will transmit the coordinates of its position approximately every 15 seconds, operating continuously.

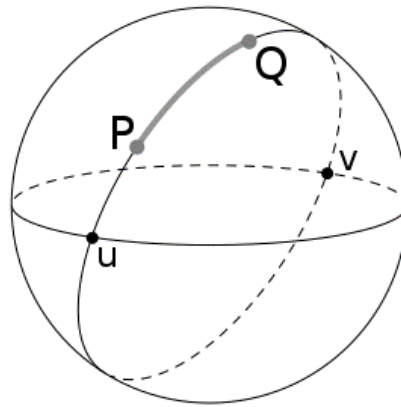


Figure 3: Two points on the sphere.

The data rate of such a tracker will enable the display of the vehicle's movement with sufficient precision.

The second type of trackers will transmit the coordinates of their position approximately every 5 minutes. Following each successful transfer of coordinates, the tracker will enter sleep mode, designed to conserve battery power and significantly extend the device's battery life.

Each tracker will possess a unique number for accessing the web server. To access the Internet, the tracker will use SIM cards of the cellular operator "lifecell".

This design of the GPS tracking software and hardware complex underscores the potential of edge computing in enhancing the efficiency and accuracy of these systems.

3.2. Formulation of mathematical model for edge-enabled GPS tracking system

Let's delve into a mathematical model that calculates the distance between two points on the Earth's surface using geographical coordinates. The Earth's shape can be approximated as a sphere. In Euclidean geometry, the shortest distance between two points is a straight line. However, on a sphere, straight lines are not feasible. Instead, these lines on the sphere are segments of great circles [5], the centers of which align with the sphere's center (as depicted in figure 3).

Figure 4 presents a sphere as a model of the Earth. Points Q and P are located on the sphere's surface, and the distance between them needs to be calculated.

Consequently, the distance L between points Q and P is computed using the following formula:

$$L = \Delta\sigma R,$$

where $\Delta\sigma$ is the angular distance between the points Q and P , rad; R – radius of the Earth, m.

The angular distance $\Delta\sigma$ between the points Q and P is calculated by the modified formula

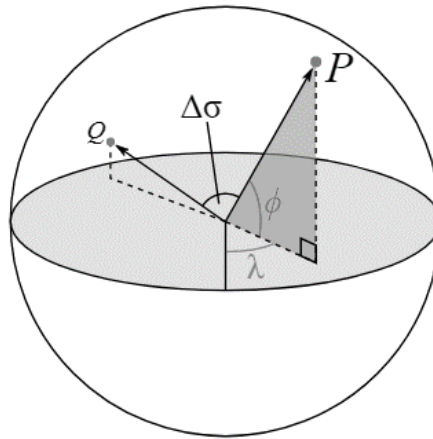


Figure 4: Model of the globe with two points on the surface.

of haversine [5, 16]:

$$\Delta\sigma = \arctan \frac{\sqrt{(\cos \phi_2 \sin(\lambda_2 - \lambda_1))^2 + (\cos \phi_1 \sin \phi_2 - \sin \phi_1 \cos \phi_2 \cos(\lambda_2 - \lambda_1))^2}}{\sin \phi_1 \sin \phi_2 + \cos \phi_1 \cos \phi_2 \cos(\lambda_2 - \lambda_1)},$$

where ϕ_1, ϕ_2 – latitudes of two points, rad; λ_1, λ_2 – longitudes of two points.

Consider a computational model for determining the data rate of the Atmega162-16PU USART microcontroller. The USART (Universal Synchronous and Asynchronous serial Receiver and Transmitter) is a versatile synchronous-asynchronous serial transceiver. This peripheral device is an integral part of the Atmega162-16PU microcontroller [2] from Microchip. The data rate of the USART is defined as the number of bits transmitted or received per unit of time.

The data transmission rate via USART is computed using the following formula:

$$BAUD = \frac{f_{osc}}{16(UBRR0 + 1)},$$

where f_{osc} is the clock frequency of the microcontroller, Hz; $UBRR0$ – the contents of the register pair UBRR0 in decimal form.

Consider a mathematical model for calculating the overflow time of 16-bit timers-counters of the microcontroller Atmega162-16PU. Numbers from 0 to $2^{16} - 1$ can be written in 16-bit case.

Overflow time of 16-bit timers-counters is calculated by the formula:

$$t = T(2^{16} - 1),$$

where T is the increment time of the 16-bit register.

The increment time of the 16-bit register is calculated by the formula:

$$T = \frac{d}{f_{osc}},$$

where d is the clock divider of the microcontroller; f_{osc} – clock speed of the microcontroller, Hz.

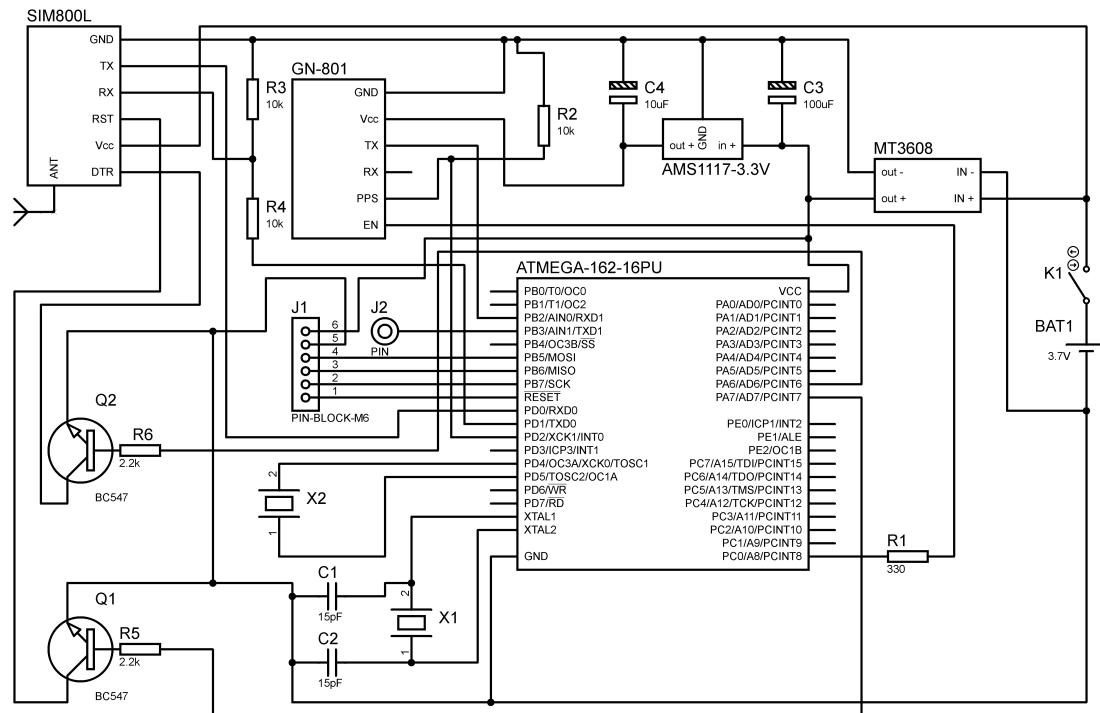


Figure 5: Electronic circuit of the GPS tracker.

3.3. Designing the electrical circuit diagram for edge computing hardware

The electrical circuit of the GPS-tracker, depicted in figure 5, was developed using the specialized software package “Proteus 8 Professional”. Let’s delve into the unique design features of this scheme.

The tracker’s power supply is a lithium-ion battery with a voltage of 3.7 volts, equipped with an integrated short circuit protection circuit. The tracker’s operation is controlled by switch K1.

The MT3608 module [1], illustrated in figure 6, is engineered to boost the voltage from 3.7 to 5 volts. On the other hand, the AMS1117-3.3 circuit is designed to step down the voltage from 5 to 3.3 volts.

Polar electrolytic capacitors, labeled as C3 and C4, have capacities of 100 μF and 10 μF , respectively. The Atmega162-16PU microcontroller [2], shown in figure 7, is powered by the MT3608 module.

The programming of this microcontroller is facilitated through the J1 contact group using the USBASP programmer [15], as depicted in figure 8. The quartz resonators X1 and X2 operate at frequencies of 4 MHz and 32768 Hz, respectively. Resonator X1 serves as the clock for the microcontroller, while Resonator X2 assists in time measurements. As per reference, the capacitances of capacitors C1 and C2 can range from 12 to 22 pF [2].

The GN-801 GPS receiver, illustrated on both sides in figure 9, features a UART interface with RX and TX contacts [13, 14]. The RX contact is designated for data reception, while the

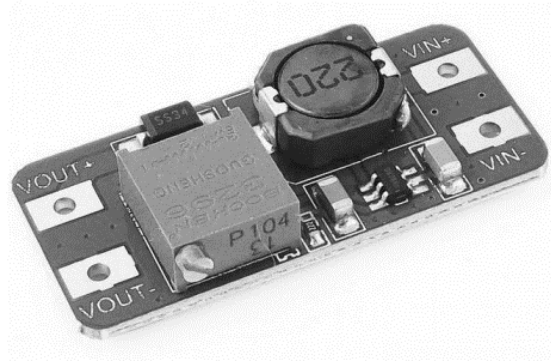


Figure 6: Appearance of the MT3608 module.

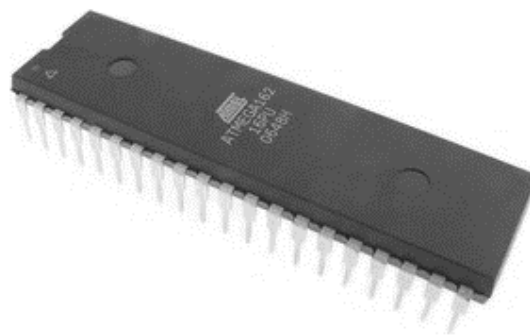


Figure 7: Atmega162-16PU microcontroller.

TX contact is for data transmission. The PPS contact alerts the microcontroller about data transmission when its signal level is high. The GPS receiver can be turned on or off depending on the voltage at the EN contact. To activate the EN contact, it is necessary to remove a resistor from the surface of the GPS receiver as shown in [13].

Resistors R3 and R4, which form a voltage divider, each have a resistance of 10 k ohms.

The SIM800L GSM module [4], depicted in figure 10, is engineered to transmit data to a web server over the internet. This module utilizes micro-SIM phone cards.

This GSM module features a UART interface [2] with RX and TX contacts for data reception and transmission, respectively. The RST contact is used for device rebooting, while the DTR contact is designed to bring the GSM module out of sleep mode. The ANT contact is used for connecting a GSM antenna.

The circuit diagram includes bipolar transistors BC547, denoted as Q1 and Q2, which are designed to reboot the GSM module and wake it from sleep mode, respectively. Activating transistor Q1 changes the voltage level at the RST contact from high to low, and similarly, activating transistor Q2 changes the voltage level at the DTR contact from high to low. Resistors R5 and R6, each with a resistance of 2.2 k ohms, are incorporated to limit the current through the bases of transistors Q1 and Q2. This design ensures efficient power management and data



Figure 8: USBASP programmer.



Figure 9: GN-801 GPS receiver.

transmission for edge computing applications.

4. Results

4.1. Hardware implementation

The software for the Atmega162-16PU microcontroller was developed using the Atmel Studio 7 development environment [8]. This integrated platform is designed for developing and debugging AVR and SAM (Smart ARM-based Microcontroller) programs. It provides a user-



Figure 10: GSM module SIM800L.

friendly environment for writing, building, and debugging applications written in C/C++ or assembly code. This environment supports interaction with debuggers, programmers, and development kits that are compatible with AVR or SAM devices.

Let's consider the process of data transfer to a web server. This process is based on the cyclic execution of a constant sequence of AT-commands [12] by the GSM-module, as shown in figure 11. The command in line 62 checks the readiness of the module to execute commands. The command in line 63 verifies the module's registration in the cellular network. Commands in lines 64, 65, and 66 establish a connection to GPRS. The command in line 67 initializes the HTTP session, and the command in line 68 sets the ID for the HTTP session. The command in line 69 sets the GET request, assigning the "id" parameter the value of the tracker number by which the tracker is identified on the web server. If a tracker has a number that is not in the database on the web server, the data of such a tracker is not stored in the database. The "gps-data" parameter is assigned the value of the data packet from the GPS receiver. The command in line 70 sets the "User-agent" header of the HTTP request. The command in line 71 executes a GET request. The command in line 72 terminates the HTTP session. The command on line 73 disconnects the GPRS connection. The command in line 74 puts the GSM module into sleep mode. The command in line 75 wakes the GSM module from sleep mode. To unlock the UART of this module, it is necessary to change the voltage level from high to low at the DTR contact before executing the command in line 75. After each command execution, the GSM module returns an alphanumeric response code that must be received and analyzed. Commands and response codes are exchanged through the USART0 interface of the microcontroller. As a result of the hardware development for the GPS tracking complex, two working prototypes of GPS-trackers were produced, as shown in figure 12. These GPS trackers have identical structures, but they may run different software.

```

62 char* at[] = {"AT\r",
63             "AT+CCALR?\r",
64             "AT+SAPBR=3,1,\"CONTYPE\",\"GPRS\"\r",
65             "AT+SAPBR=3,1,\"APN\",\"internet\"\r",
66             "AT+SAPBR=1,1\r",
67             "AT+HTTINIT\r",
68             "AT+HTTTPARA=\"CID\",1\r",
69             "AT+HTTTPARA=\"URL\",\"http://fxnik7f1.beget.tech/php/addGps.php?id=1234567&gpsdata=
70             "AT+HTTTPARA=\"UA\",\"Mozilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML,
71             "AT+HTTTPACTION=0\r",
72             "AT+HTTPTERM\r",
73             "AT+SAPBR=0,1\r",
74             "AT+CSCLK=1\r",
75             "AT+CSCLK=0\r"};

```

Figure 11: GSM module SIM800L.

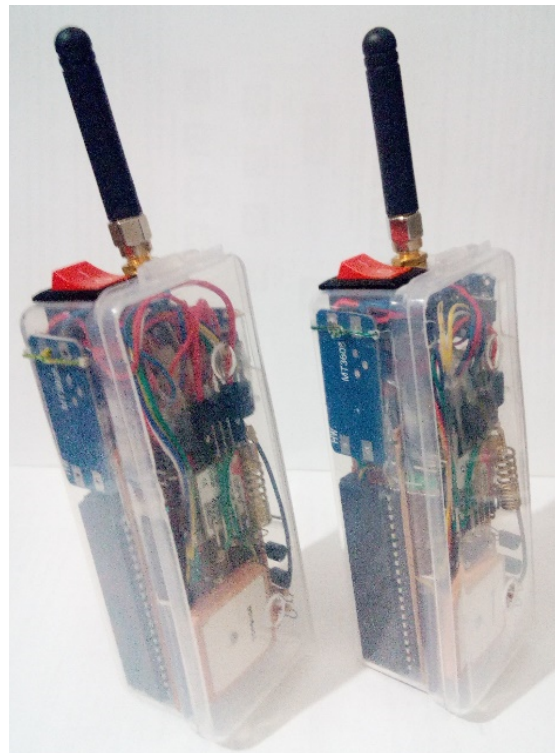


Figure 12: Prototypes of GPS trackers.

4.2. Evaluation of edge-enabled GPS tracking system

The edge computing-based GPS tracking system was put to the test, successfully tracking a vehicle's movement within the urban landscape of Kryvyi Rih, specifically along Kuprina and Petro Kalnyshevsky streets, as depicted in figure 13.

In the said figure, the vehicle's trajectory is represented by interconnected black circles along a gray line. Clicking on any of these circles triggers a pop-up window that provides additional

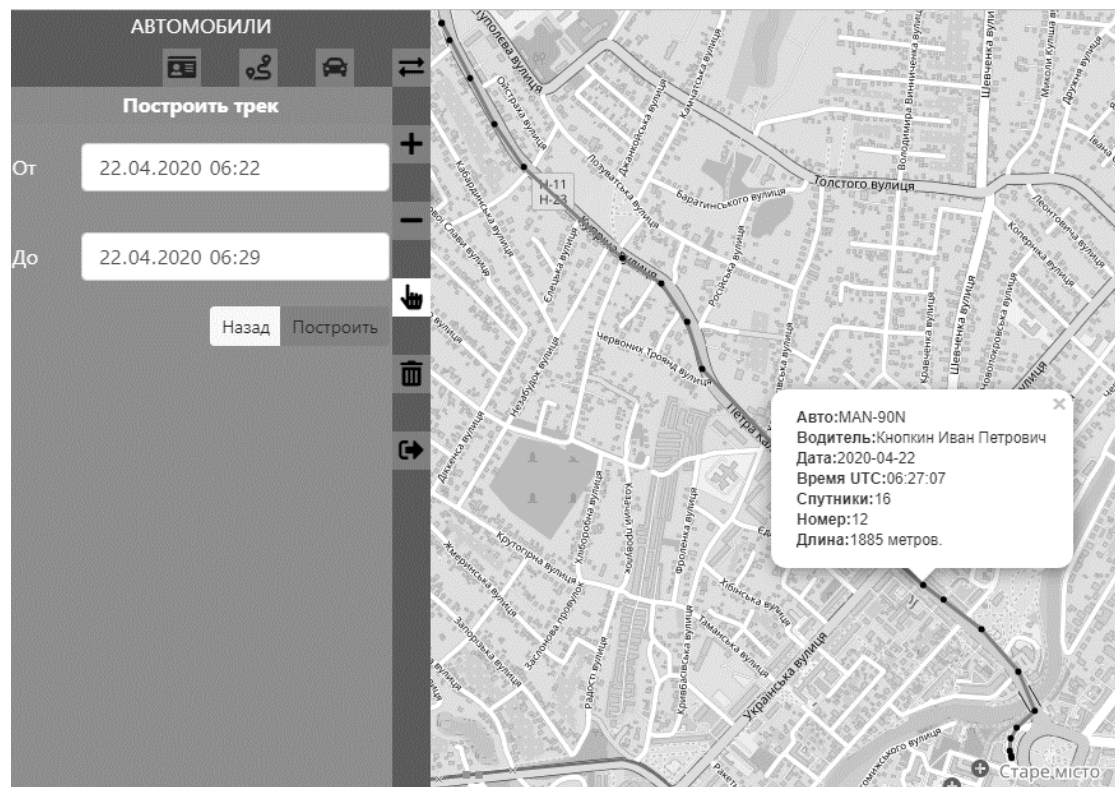


Figure 13: The path of movement of the vehicle.

data, including the cumulative distance covered from the start of the journey to the selected point.

5. Conclusions

In the contemporary era, satellite tracking of mobile entities remains a pertinent field, with the latest scientific and technological advancements playing a crucial role. This study presents the design and implementation of an edge computing-based GPS tracking system, leveraging modern web technologies and electronic components.

An analysis of current applications and existing GPS tracking tools led to the decomposition of these systems. The primary structural elements of the GPS tracking system include GPS-trackers, a web server, and client software. This analysis facilitated the development of a functional diagram and the mathematical software for the GPS tracking system.

The functions of GPS-trackers were analyzed to select the necessary electronic components, such as a microcontroller, GPS-receiver, and GSM-module. It was observed that all these components share a common serial UART data interface. Based on this research, an electrical circuit for the edge-enabled GPS tracker was developed.

A web-based user interface for the edge-enabled GPS tracking system was also developed,

enabling access via a computer or smartphone using popular web browsers. The design results led to the development of software for the Atmega162-16PU microcontroller and user software with a web interface.

The edge-enabled GPS tracking system was tested by tracking the real-time movement of a vehicle. The test results indicated that the tracker's measurement accuracy of a moving object's coordinates is influenced by the surrounding environment. Specifically, the fewer high-rise buildings around the tracker, the more accurate the coordinates.

The edge-enabled GPS tracking system can be utilized to monitor the movement of objects within the coverage of GSM cellular networks. These objects can range from vehicles to enterprise employees, tourist groups in unfamiliar countries, children, animals, and mobile equipment.

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