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LOW-COST REMOTELY-OPERATED VEHICLE NAVIGATION WITH GPS AND RF LORA INTEGRATION

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SUMMARY

In recent decades, remote-controlled vehicles (ROVs) have attracted significant attention because of their potential applications in healthcare, medicine, agriculture, and civilian information. In this article, we investigate the development of low-cost mobile robots equipped with a global positioning system (GPS). GPS-assisted robot is used to provide geographical information and navigation for vehicle control via radiofrequency (RF) long-range (LoRa) wave communication signals. Micro-processing units, including a GPS U-blox NEO M8N integrated antenna, an RF LoRa circuit, and moving actuators, are deployed. Additionally, the U-center 18.06 software acts as a monitoring station. Outdoor experiments proved our design performed well, with reduced latency errors and increased location accuracy.

Key words: *global positioning system, navigation robot, radio frequency long-range, remotely-operated vehicle.*

INTRODUCTION

The Global Positioning Systems (GPS) is a worldwide navigation system, which was initially designed and operated by the United States Department of Defense. It incorporated a constellation of 24 satellites orbiting the Earth in 6 orbital planes and associated earth stations [1], [3]. Vehicle localization methods using GPS have been widely investigated, and improvements in accuracy and reliability have been achieved by employing four satellite constellations. Using information transmitted by satellites, GPS estimates distance using a simple technique known as "time of arrival." Compared with other technologies, GPS is more accurate, widely available on the Earth, weather-proof, and simple. Navigation systems are nowadays used for monitoring vehicles/crafts or moving objects, enabling them to move in different terrains such as on/off-road areas, sea, and space.

However, vehicles in vehicular ad-hoc networks (VANETs) exhibit high-mobility and location-aware characteristics. Location-aware applications require accurate and reliable position information. Several methods, such as GPS, dead reckoning (DR), differential global positioning system (DGPS), roadside unit (RSU), map matching (MM), distance-based, angle-and filter-based systems, cellular localization, etc., have been proposed for vehicle location [4-9]. For example, the operation of DGPS is based on determining the difference between satellite and actual pseudoranges. DR estimates the current position of a vehicle using a known position before a certain period. By combining MM with DR, vehicle position can be estimated using GPS and matched to a real-world map, thus improving the accuracy of position estimation.

In VANETs, scalability, low-cost, long-range coverage, and low power consumption are important factors. The long-range (LoRa) wide-area network has been widely employed in VANETs because of its following advantages:

- It provides a coverage range of up to 3 km in sub-urban areas with dense residential dwellings, as evaluated in [10].
- It exhibits low power consumption and low throughput and is used in long-range network applications because it operates in the unlicensed ISM band; additionally, it features a physical layer protocol [11].
- It forwards packets collected from network nodes to the network server via gateways.
- It achieves localization using time-difference-of-arrival and time-of-flight measurements because of its high bandwidth [12].
- It monitors the network nodes and contributes to accurate traffic decisions [13].

Nowadays, most vehicles are equipped with GPS devices that track or monitor vehicle position. However, vehicle localization is a difficult task because of the vehicle's high speed [14]. GPS signal interference i.e., fading, radio emissions, and space weather affect the accurate vehicle position estimation. The RSU reported in [15] is a fixed infrastructure that estimates fixed or reference positions. Using vehicle-to-RSU communication, vehicle position can be measured by evaluating the position information obtained from at least two RSUs. In [16], a low-cost real-time automated vehicle location system using GPS technology was reported. This system requires three primary components: a microcontroller, a GPRS wireless modem, and a differential-capable GPS receiver. It achieves real-time accuracy of up to 2–3 m at road lane level. Additionally, it is suitable for most applications, achieving an approximate delay of 5–10 s. Xiao-hui *et al.* [17] proposed a method for creating traffic-flow maps using data received from GPS mobile terminals installed in vehicles. The objective of our study is to design a GPS-based system incorporating LoRa technology and test it in real-time. Hence, we propose a mobile robot capable of autonomously navigating using GPS combined with a LoRa module.

We employ GPS as a low-cost geographical information and navigational system for a remotely-operated vehicle (ROV), namely, an autonomous mobile vehicle [18-25]. Several wireless systems are nowadays available for various innovative vehicle applications including location, communication, tracking, intralogistics, and security. We conducted experiments using a testbed mobile robot, both in automatic and manual motion modes, using an integrated GPS U-blox NEO M8N antenna and a radiofrequency (RF) LoRa receiver. These two devices were connected via a UART/TTL interface to an Arduino controller, which was operated as the vehicle's electronic control unit (ECU). In addition, DC servo motors, batteries, power banks, motor controllers, and other components were integrated to operate a tank-chassis ROV. ROVs are used in many practical applications; they can move around autonomously and independently without relying on external intervention. The proposed design can be adapted to indoor commercial markets such as malls, hotels, banks, nursing homes, hospitals, offices, stores, schools, museums, and many others.

The contributions of this paper are the following:

- Investigate a low-cost mobile robot navigation system using an integrated GPS U-blox NEO M8N antenna and an RF LoRa receiver.
- Design, configure, implemente, test, and evaluate a digital motion-control system equipped with a GPS module.
- Use the low-cost Arduino-based equipment and low-cost hardware for deployment in the real-time environment.
- Perform an verify the proposed mobile robot navigation control system.

VEHICLE HARDWARE SETUP

Our proposed system architecture includes devices, gateway, cloud, and user application, as shown in Figure 1. The key characteristic is the integration of GPS and LoRa networks. It guarantees that the ROV is accurate in mapping and retracking. GPS acts as a navigation system to track and monitor vehicle position. Besides, the user applications communicate and control ROV via LoRa networks. Table 1 shows a comparison of the different communication technologies. In ROV, its application does not have big data to transfer, LoRa is the best option. Moreover, in the field of robots, low power consumption is required. Thus, LoRa is ideal for our system.

Table 1. Comparison table [26, 27]

Transmission technology	**ZigBee**	**Global System for Mobile (GSM)/General Packet Radio Service (GPRS)**	**LoRa**
Standard	Alliance IEEE 802.15.4	N/A	Lora Alliance IEEE 802.15.4
Communication range	100 m (open spaces)	1–10 km	20 km (rural)
Power consumption	Low	Medium	Very Low
Processing board	Arduino, Raspberry Pi	Arduino, ESP8266	Raspberry Pi, Atmega setup
Data rate	20, 40, and 250 kbps	Up to 170 kbps	50 kbps

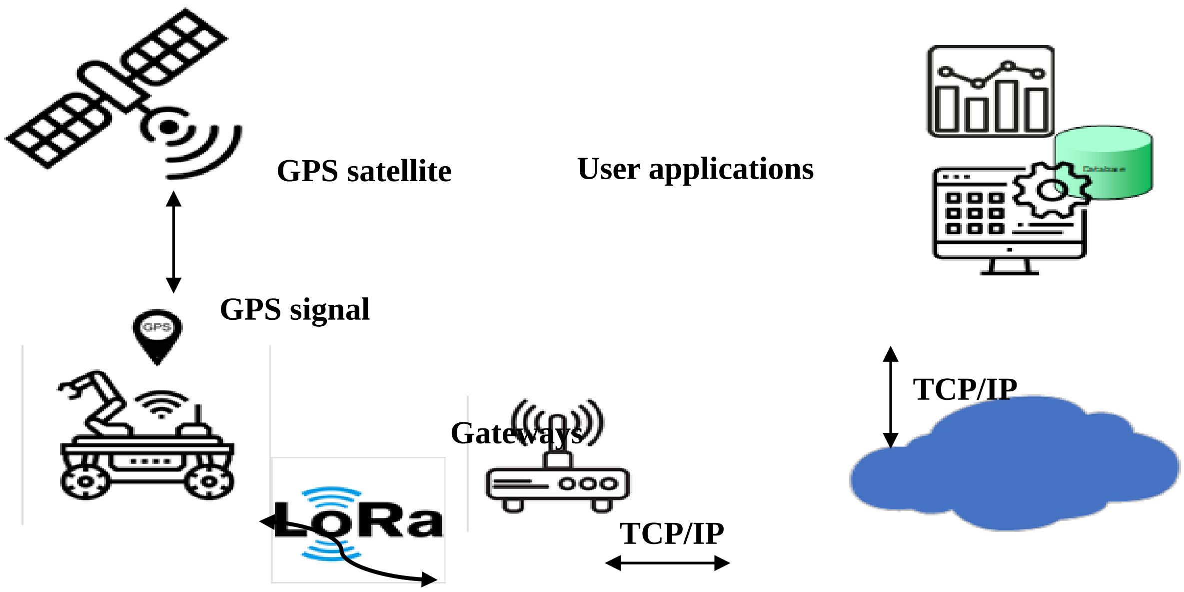

Figure 1. Proposed system architecture

The vehicle studied is an ROV, which performs mapping and moves in an environment; additionally, it performs a set of tasks within the boundaries of the mapped environment. A prototype system incorporating GPS and RF LoRa modules was built, and its navigation and control performance was tested. The results showed that the system performs accurate mapping and retracking.

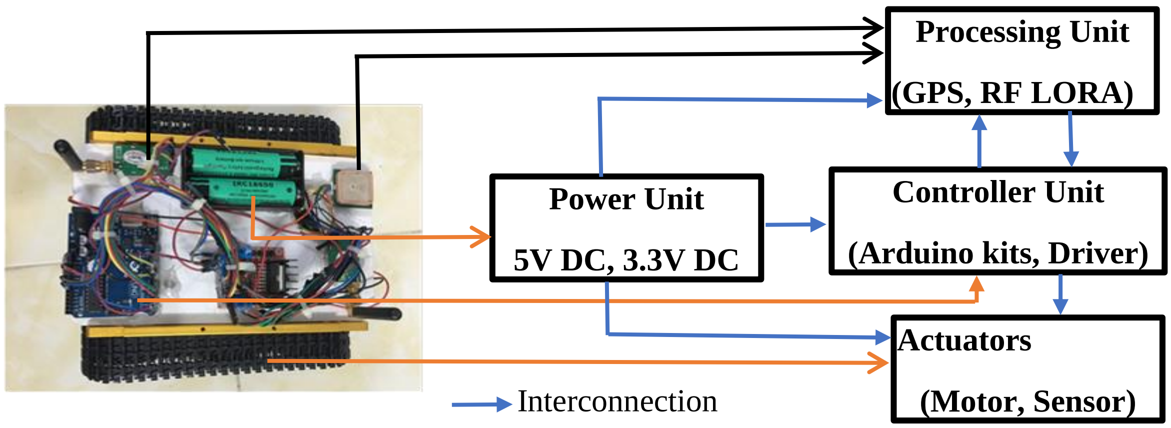

Figure 2. ROV testbed including GPS and LoRa modules

The proposed ROV testbed consists of an RF LoRa module, which transmits and receives communication signals, and a GPS module, which tracks the ROV position data. These two modules are connected via a UART/TTL interface to an Arduino controller, which operates as the vehicle's ECU. Power banks and batteries are used to drive the DC servo motors, motor controllers, and other components. ROV requires a current supply of more than 3 A to operate properly. To achieve smooth operation in all-terrain or off-road environments, the vehicle chassis-tank model was equipped with two DC servo motors connected to chains. The motors can be controlled in both clockwise and counterclockwise directions. As shown in Figure 2, the ROV is fully equipped with GPS and RF LoRa modules [31].

CONTROLLER SETUP

Considering the cost, connection and program coding requirements for the proposed GPS navigational system, an Arduino microprocessor kit was selected as the ROV's microcontroller.

Table 2. Arduino uno versus arduino nano specification

Specification	Arduino Uno	Arduino Nano
Voltage	5 V	5 V
I/O max current	20 mA	40 mA
Clock frequency	16 MHz	16MHz
Microcontroller	ATmega328	ATmega168 or 328
Flash memory		16 KB/32 KB
SRAM	2 KB	1 KB/2 KB
EEPROM	1 KB	512 Bytes/1 KB
USB	Yes	Yes, mini
GPIO	14	14
Analog I/O	6	8
UART	Yes	Yes
PWM	6	6
FCC approved	Yes	Yes
SPI/I2C	Yes	Yes
Size	2.7" × 2.1"	1.7" × 0.73"
Price	~$ 20	~$ 7
Picture		

Arduino Uno (where "Uno" means "one" in Italian) is an ATmega328P microcontroller board. It features 14 digital inputs/outputs, six of which control pulse width modulation (PWM) devices, and six analog inputs/outputs. It additionally features an ICSP header, a 16-MHz ceramic resonator, a USB connection, a power jack, and a reset button. A USB cable, an AC-to-DC adapter, or a battery can be used for easy connection to a computer or for powering the microcontroller. Uno is easy to tinker with; in the worst-case scenario, it can be replaced for a few dollars. Additionally, it can be programmed using the Arduino software integrated development environment as the reference model platform. As shown in Table 2, Arduino Nano is a good alternative to Arduino Uno because of its small size, which makes it suitable for small working spaces. For simple low-cost and small profile projects, "Nano" is a good option, which can be used for collecting sensor signals in portable electronics. If desktop prototyping with ethernet or mobile shields is required, Uno is the most suitable choice and can be used in Internet of Things (IoT) sensors.

DEVICES AND MONITORING PLATFORM

GPS Module

The GPS module compares in real-time the current position coordinate value of the receiver with the coordinate value that the robot wishes to move. The NEO-M8 series of global navigation satellite system (GNSS) modules has been designed to operate with the highly efficient U-blox M8 GNSS engine, which is an effective system in the trusted NEO form factor. In this study, we employed the GPS U-blox NEO M8N module to simultaneously receive data from GNSS systems (GPS/Galileo, BeiDou, and GLONASS), recognize multiple parallel constellations, and provide high positioning accuracy, even in urban canyons or areas of weak signals. The GPS NEO-M8 module features four connection interfaces, including USB (serial), I2C, SPI, and UART, which can access information concurrently. Its characteristics are presented in Figure 3 and Table 3.

Figure 3. GPS U-blox (UBX-M8030-KT) module connected to Arduino [28]

Table 3. GPS pin definition

Name	Function description
PPS (pulses per second)	Output time pulses
VCC	3.3-5 V DC, power consumption: 50mA/h
Interface type	UART/TTL, default baud rate: 9,600
TX/RX	RS232_TXD/RXD is optional
Distance	Indoor: 30 m; Outdoor: 120 m
Data transmission	40 Kbit/sec
GND	Connected to ground
NC	Not connected

Radio Frequency Long Range Module

When selecting an IoT device, the main factors considered are coverage, bandwidth, range, and power consumption. Based on the type of device, the environment it will be deployed, and the required characteristics, additional factors may be considered. Based on the bandwidth and range of the different IoT technologies shown in Figure 4 [29], we selected the RF LoRa technology to evaluate the ROV operations. The RF UART LoRa SX1278 transmitter/receiver wireless module employs the 433-MHz LoRa SX1278 chip of SEMTECH shown in Figure 5, which covers a 3,000-m range; this chip has two important characteristics: low power consumption and ultimate long-distance wireless coverage. Consequently, it can be used in IoT applications by determining the address, speed, and other parameters.

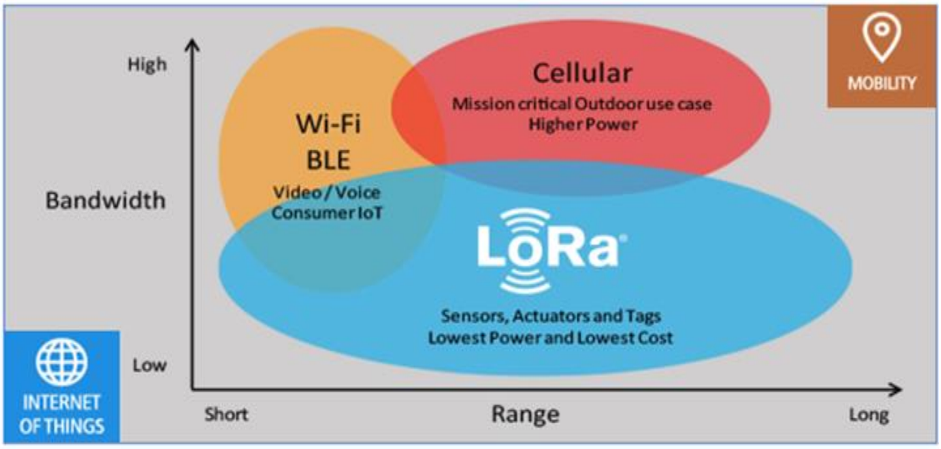

Figure 4. IoT mobility technologies: Wi-Fi, cellular, and LoRa [29]

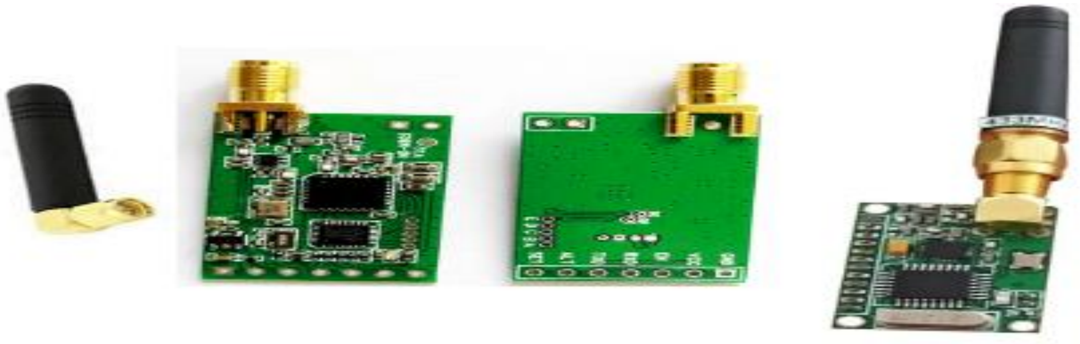

Figure 5. Transmitter/receiver 433-MHz RF LoRa and antennas

U-center GNSS Software

The U-Center software is a free and optimized tool, which is used to monitor and navigate the coordinates of GNSS devices by configuring the U-blox GPS receivers via the Windows OS platform. It features many interfaces [30] and is connected to devices via the COM port, as shown in Figure 6. Its characteristics are presented below:

a. High degree of interaction and easy use.

b. Full support for all GNSS receivers.

c. Control functions and expansion of the configuration system.

d. Coordinate display and real-time operation.

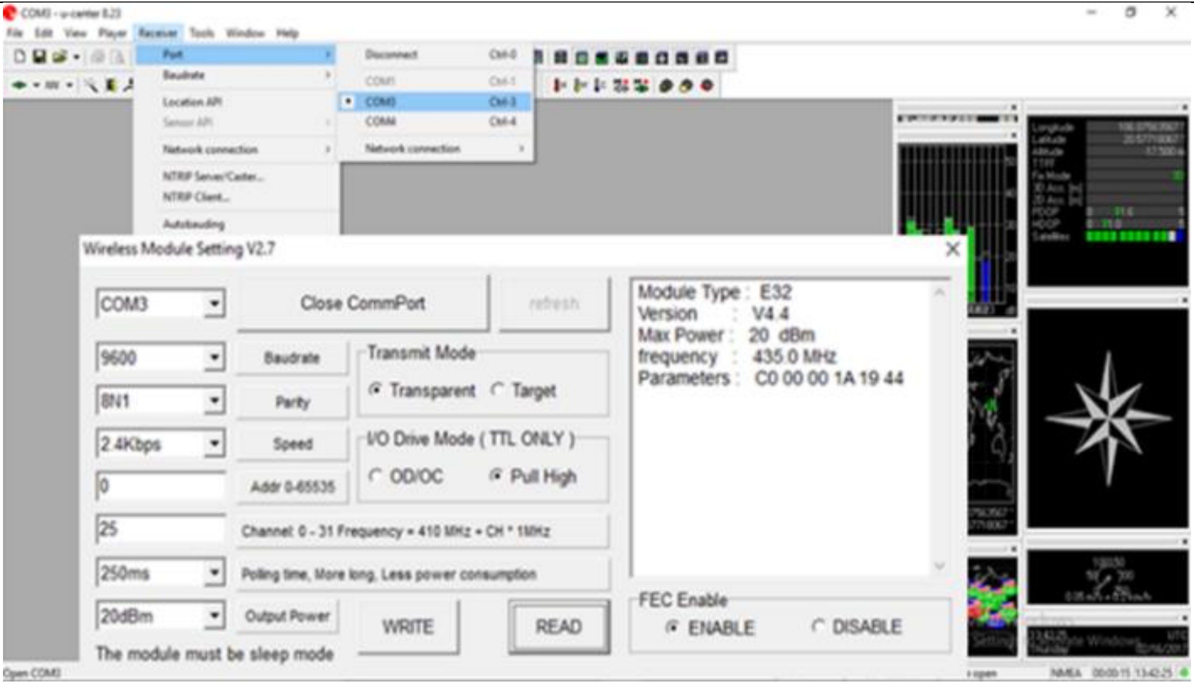

Figure 6. U-Center setup and COM port popup window

EXPERIMENT AND ANALYSIS

The ROV model's dimensions are 22 cm × 20 cm × 15 cm. The testbed ROV experiment was performed on a road lane. The GPS and RF LoRa modules were used for the control and communication of the ROV. A was used to control the ROV's motion. The ROV's left and right turns were controlled by the x-axis, whereas its back and forward movements were controlled by the y-axis. A block diagram of the proposed navigation and control system is shown in Figure 7, and a demonstration of the testbed operation via the U-Center software platform is shown in Figure 8. The GPS raw data are collected and displayed in Figure 9.

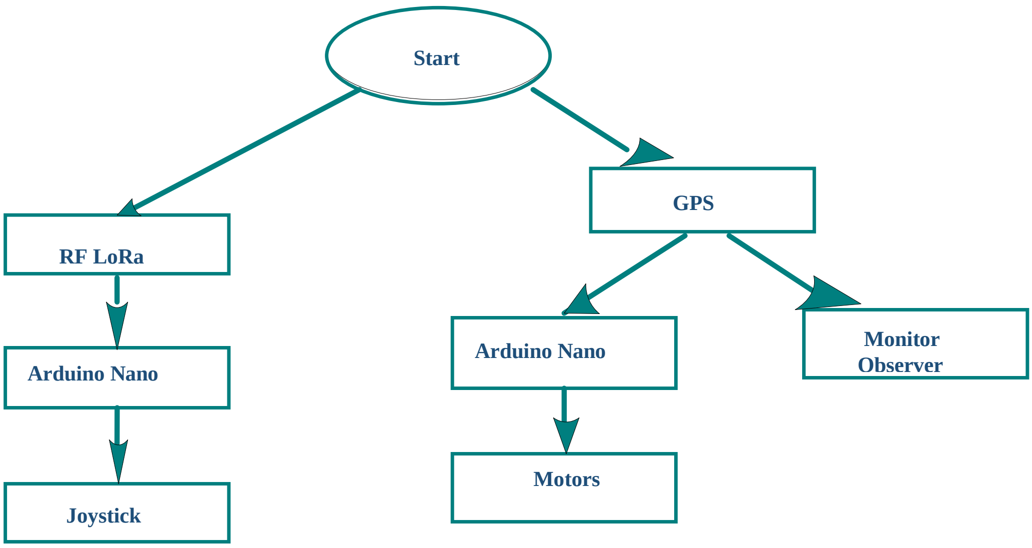

Figure 7. Control block diagram

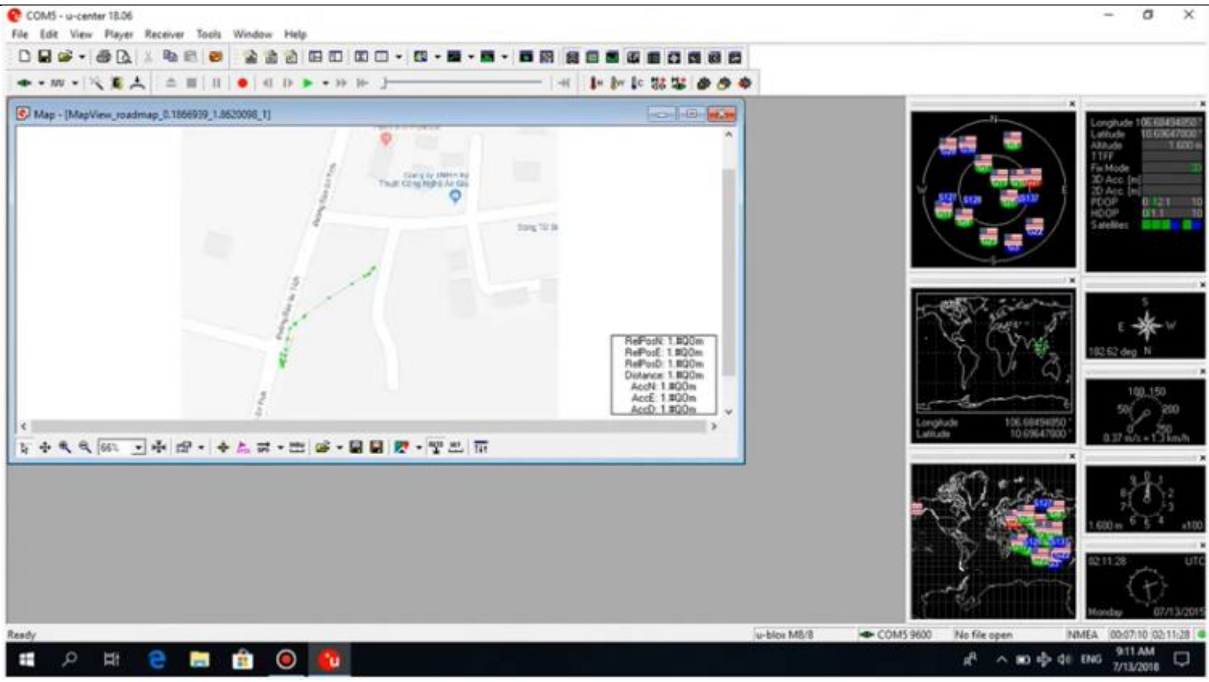

Figure 8. ROV operation test [31]

A controlled self-regulating ROV was developed using low-cost GPS and RF-communication modules to achieve stable navigation in land surveying operations. The GPS receiver was used to locate and navigate vehicles, transmit their location using LoRa RF signals, and transfer data among vehicles. Due to the fluctuation of the GPS signal and data, the ROV could not reach its destination with high precision; the average error was less than 0.2 m, and the time delay was 2 to 3 seconds. Compared with other reported systems [16, 17, 22, 23], the proposed ROV achieves better accuracy with a low-cost design [32, 33, 34, 35, 36].

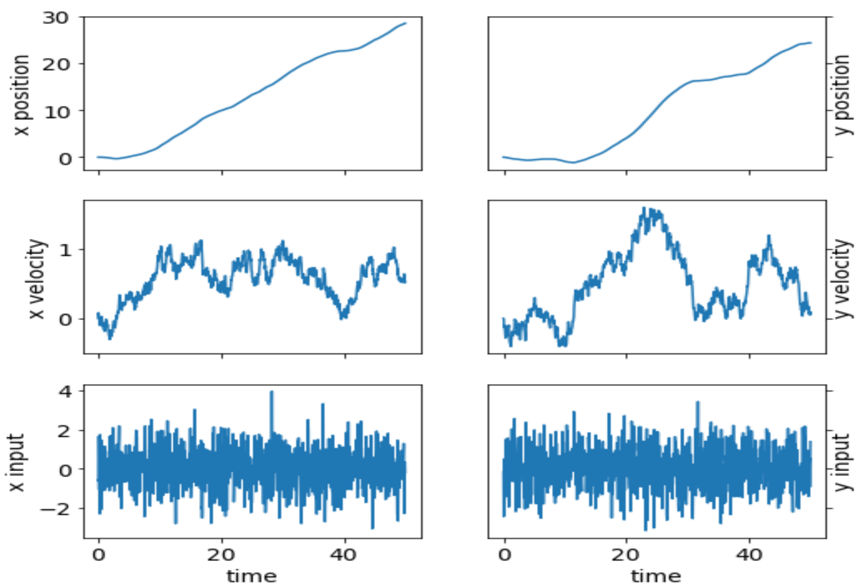

Figure 9. GPS data collection

CONCLUSION

Employing GPS in an autonomous mobile robot, such as an ROV, is a promising solution because GPS is a practical and advantageous positioning system, which improves the robot's navigation ability. Mobile robots require a powerful and reliable motion-control system to perform accurate actions, which is a challenging task. In the proposed low-cost system, a GPS-enabled digital motion-control system was designed, implemented, tested, and evaluated. In a future study, vision and laser scanner signals will be added to the system to allow automatic and improved accuracy movement over long distances as well as obstacle avoidance.

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