A remote-controlled global navigation satellite system based rover for accurate video-assisted cadastral surveys

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ABSTRACT

One of the main tasks of a cadastral surveyor is to accurately determine property boundaries by measuring control points and calculating their coordinates. This paper proposes the development of a remotely-controlled tracking system to perform cadastral measurements. A Bluetooth-controlled rover was developed, including a Raspberry Pi Zero W module that acquires position data from a VBOX 3iSR global navigation satellite system (GNSS) receiver, equipped with a specific modem to download real-time kinematic (RTK) corrections from the internet. Besides, the Raspberry board measures the rover speed with a hall sensor mounted on a track, adjusting the acquisition rate to collect data at a fixed distance. Position and inertial data are shared with a cloud platform, enabling their remote monitoring and storing. Besides, the power supply section was designed to power the different components included in the acquisition section, ensuring 2 hours of energy autonomy. Finally, a mobile application was developed to drive the rover and real-time monitor the travelled path. The tests indicated a good agreement between rover measurements and those obtained by a Trimble R10 GNSS receiver (+0.25% mean error) and proved the superiority of the presented system over a traditional metric wheel.

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1. INTRODUCTION

In the work of engineers and architects, it is required to perform distance and surface measurements over large areas to position fundamental markers during cadastral surveyings. These measurements are commonly executed within construction sites using hand tools such as metric wheels or optical gauges, which are inaccurate and time-consuming. However, in the last decade, numerous devices based on satellite positioning systems have been developed (e.g. global positioning system-GPS, global navigation satellite system-GLONASS, Galileo, and BeiDou navigation satellite system-BDS) which allow us to obtain high accuracy, positioning speed, manageability, and portability, regardless of the application scenario (e.g. construction sites, agricultural lands, or far from inhabited places) [1]–[4]. Generally, cadastral surveyors determine terrain boundaries by measuring some control points, obtained using a pole-shaped device integrating a global navigation satellite system (GNSS) real-time kinematic (RTK) receiver [5]–[7]. However, this pole-shaped device, which must be hand-carried by the user, usually has a considerable weight, and, more often than not, the necessity to work with particularly extended terrains with irregular outlines arises. In these conditions, measuring a high number of control points with extreme accuracy can be very uncomfortable for the operator.

Therefore, to make this preparatory phase more efficient and immune from possible human errors, the proposed work aims to develop a portable sensors-based stake-out system that allows the localization of specific points over long distances. Its main element is a GNSS receiver which enables positioning measurements with a centimeter-level accuracy when operating in RTK mode [8]–[10]. Specifically, the proposed paper describes an RTK GNSS-based measuring system for carrying out cadastral measurements; the system relies on a Bluetooth-controlled rover, based on a tracked platform, managed by the cadastral surveyor, who drives the device by following the area’s perimeter. The rover acquires real-time data related to its position, travelled distance, and the enclosed area within the traced perimeter using a GNSS-RTK receiver (VBOX 3iSR, manufactured by Racelogic) and downloading RTK corrections through network transport of radio technical commission for maritime services (RTCM) through the internet protocol (NTRIP). Furthermore, the rover streams in real-time the pictures captured by a camera mounted on the front section of the mobile robot. Also, it fully exploits the great potentialities of the internet of things (IoT), cloud computing, programmable electronics, and mobile software [11]–[13]. In fact, the acquired information is shared by the internet network generated by the mobile hotspot with a cloud platform that stores the gathered data in a remote database, displays them on a suitable online dashboard, and processes them with a cloud application. Also, a mobile application was developed to display in real-time the data related to the measured land and the pictures acquired by the rover, aiding the user in driving operations.

Therefore, the main contributions of the proposed scientific work are:

- A Bluetooth-controlled rover for performing cadastral measurements, equipped with a high-accuracy GNSS RTK receiver (VBOX 3iSR) supported by corrections provided by an onboard NTRIP modem. A Raspberry Pi Zero W board manages the acquisition of inertial and positioning data, forwarding them toward a cloud platform. Also, the device includes a camera module to stream the captured pictures toward the Internet network.
- A cloud platform that receives the position and inertial data gathered by the rover system, enabling their remote monitoring, processing, and storage.
- A mobile application to display in real-time the data related to the measured land and the pictures acquired by the rover, aiding the user in driving operations.
- Onfield tests of developed rover system, comparing it with a traditional metric wheel and using the data provided by a Trimble R10 GNSS RTK receiver as reference.

The remainder of the paper is arranged: the following section reports an overview of GNSS-based survey vehicles; section 2 describes the architecture of the proposed GNSS-RTK-enabled measurement system and the rover’s structure. In section 3, the operating modalities for collecting position and inertial data are discussed, as well as the power consumption analysis of the acquisition section. Also, the power supply section is designed for feeding the different components and modulus included in the rover. Finally, the development of the mobile application is described for supporting the rover operation.

Several scientific works deal with autonomous ground vehicles (AGV) equipped with GNSS receivers, applied to different application scenarios [14]–[16]. For instance, Moeller *et al.* [17] proposed an autonomous navigation system for precision farming applications. The proposed system uses the combination of an unmanned air vehicle (UAV), equipped with a hyperspectral camera for detecting potato plants affected by Potato Virus Y (PVY), and a low-cost unnamed ground vehicle (UGV) for removing the infected plants. This last comprises an RTK-based GPS receiver (Piksi multi evaluation kit), based on the Pixhawk microcontroller, for coordinating its movements to reach the established position with high accuracy (error <0.1 m). Similarly, Iqbal *et al.* [18] proposed a Multipurpose Autonomous Robot for Intelligent Agriculture (MARIA) to conduct plant morphological trait phenotyping and soil sensing indoors and outdoors. The proposed system was equipped with a GNSS receiver (Novatel RTK GPS), allowing autonomous navigation. For the phenotyping, the robot employed an actuated light detection and ranging (LiDAR) unit, various phenotyping sensors, a three degree of freedom (3DoF) robotic arm and a depth camera to estimate plant morphological characteristics. A final example of an AGV using GNSS technology for precision agriculture can be found in [19]. The proposed system tracks the performance of a robot mower within a turfgrass, using a framework consisting of a remote sensing system to collect position and time data and custom-designed software to compute, display, and extract this data. The remote sensing unit consisted of two Emlid Reach RTK devices mounted in custom-built cases, one serving as the base station and the other as the rover [20]. The Reach RTK is a small device equipped with an RTK-GNSS receiver (Ublox NEO-M8T series) and an Intel® Edison module. The case containing the GNSS rover was mounted on the robot mower, and the enclosure containing the base station was installed at the edge of the turfgrass. The rover was powered by a lithium battery (i.e. 9,000 mAh power bank), ensuring 24 h runtime. Sudevan *et al.* [21] presented a complete autonomous non-contact inspection system (ANCIS) to detect, locate, navigate, and geo-tag buried pipelines. The robot has two primary components: non-contact sensors (NCS) and an AGV to carry the sensors. Since the AGV needs to inspect the buried pipelines regardless of the terrain, the Segway RMP 440LE, a rugged, all-terrain mobile robot with four wheels and a 200 lb payload, is used as the ground vehicle. A pipe locator that identifies the buried pipeline is attached to the front, whereas any non-contact magnetic sensor that collects data from the buried pipeline could be attached to the vehicle rear; the module GPS is also placed at the vehicle's top. All the sensors are connected to an onboard computer acting as the master controller for the entire system. A simple proportional integral derivative (PID) controller is designed to generate the yaw rate and velocity so that the AGV tracks the buried pipeline structure smoothly.

Jilek [22] presented an RTK GNSS-based UGV for autonomous field measurements in outdoor areas. The robot used in this work is the Orpheus-X3 mobile robot, a multifunctional robotic platform usable for different exploration and measurement tasks in harsh and unreachable places. A Trimble BD982 receiver operates as a stationary base station, while a second GNSS receiver module acts as a rover on the mobile robot. The latter has two separate GNSS receivers, and each of them has its GNSS antenna and a different RTK engine. The first one receives the corrections from the stationary base station, whereas the second engine uses corrections calculated by the measurements related to the vector antenna position. Fundamental for the cooperation of AGV systems is the used communication strategy; specifically, several scientific works pointed out the potentialities of local strategies [23] over the centralized ones [24] in terms of task throughput and communication overhead. Nor *et al.* [24] proposed a modified broadcast controller able to obtain a convergence probability 1. They derived a new local controller, reducing the deterministic information about the robot's position. The simulation demonstrated the reduction of the instability and convergence time. Similarly, Vasiljevic *et al.* [25] exploited a local communication between neighboring underwater robots to track the median value of each parameter from measurements of multiple entities. Fanti *et al.* [26] introduced a complex algorithm for managing and coordinating multiple AGVs using a decentralized strategy. The proposed algorithm requires that each AGV choose its path based on solutions of integer linear programming problems; additionally, each AGV coordinates its motion with the neighboring by a decentralized protocol for avoiding deadlocks and collisions. Also, local/distributed communications between autonomous devices can be exploited for implementing localization systems where GNSS are not applicable. Ultra wide band (UWB)-based localization systems represent an optimal solution for positioning tasks in heterogeneous multi-autonomous systems [27]; these systems rely on measuring the time-of-flight (ToF) of electromagnetic signals, knowing their propagation speed. Multimodal sensor fusion techniques can be used to improve the positioning accuracy of each robot.

2. THE PROPOSED METHOD

2.1. Architecture of the proposed RTK GNSS-based measuring system

The developed RTK GNSS-based measuring system uses a radio-controlled (RC) rover to acquire real-time position and inertial data directly on the field and forward them to a cloud platform where they are automatically stored and processed. Particularly, the user drives the Bluetooth-controlled rover by means of the mobile application along the perimeter of monitored land, acquiring real-time position and inertial data using an onboard GNSS receiver (VBOX 3iSR sensor), corrected using the RTK NTRIP corrections downloaded from the internet network. The gathered data was used to determine the travelled distance and the enclosed area within the traced perimeter, fundamental for the cadastral measurements. As detailed below, the rover includes a microcontroller section (Raspberry Pi Zero W) that manages the acquisition of the position and inertial data from the VBOX 3iSR sensor, formatted in National Marine Electronics Association (NMEA) messages and their transmission toward a cloud platform. Specifically, the acquired data are stored inside the rover's local memory (SD card) and forwarded using message queue telemetry transport (MQTT) protocol, arranging them in JavaScript object notation (JSON) packets [28]. It is a communication protocol adhering to the publish/subscriber paradigm ideal for the considered application given its low overhead and high efficiency, allowing edge devices to send data toward the broker. In this way, the technical staff can remotely consult and monitor the measurements performed in the field, making the filing phase faster and more efficient. In addition, the operator can also view on a tablet the data captured by a camera mounted on the front section of the rover, allowing the operator to follow the terrain boundaries precisely. Specifically, the acquired images are streamed using the UV4L software installed on the Raspberry board, offering a generic purpose streaming server, suitably made for IoT devices and leveraging different built-in services for real-time communication. The advantages of the developed device lay in the possibility of accurately measuring the boundaries of large lands and locating in difficult places easily, avoiding the operator's continuous transport by hand. Also, the rover shares the acquired information using the internet network generated by the mobile hotspot with a cloud platform (i.e. IBM Cloud). This last stores the acquired data in a remote database, displays them on a suitable online dashboard, and processes them with a cloud application as shown in Figure 1. Besides, the rover is driven by the commands sent from the mobile application using the Bluetooth connection as shown in Figure 1. The control board that manages the RC platform is equipped with a Bluetooth module (model HC-06, manufactured by Kuongshun Electronic Inc.) to receive commands from a paired host device.

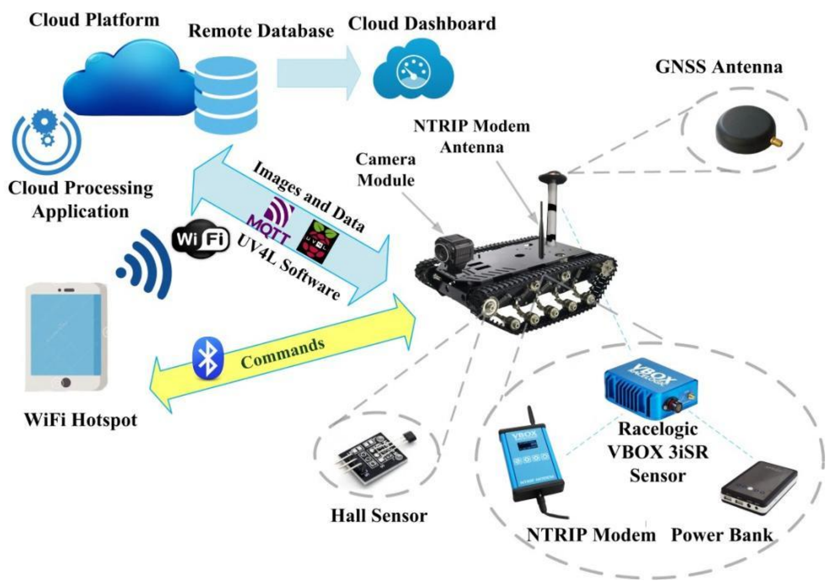


Figure 1. Architecture of the developed RTK GNSS-based measuring system

The main component of the rover is the VBOX 3iSR, which can provide, through a GPS/GLONASS integrated receiver, measurements of the antenna's position in real-time and with centimeter accuracy thanks to the RTK technology. The VBOX 3iSR sensor receives correction data through a standard transmission protocol called NTRIP. In this protocol, corrections are transmitted in real-time from reference stations working as NTRIP servers, making them accessible through the internet network. Access to the corrections offered by these reference stations is free for the regional GNSS network, whereas national networks like HxGN SmartNet, NetGEO, and RING require a paid subscription. The positioning data of the path travelled by the rover, measured by the VBOX 3iSR sensor, are processed by a microcontroller board, capturing the position data at a fixed distance (i.e. 5 cm) so that the outline of the terrain can be accurately defined. In particular, if the robot's speed, measured through a Hall effect sensor, varies, the microcontroller board automatically adjusts the acquisition rate of the positioning measures so that the system can still capture one point every 5 cm. As described above, the acquired data are wirelessly transmitted through a mobile hotspot towards a cloud platform. The acquired data are securely stored and processed by a cloud application to reconstruct the entire path traced by the rover, monitorable on a satellite map.

A further advantage of the implemented system is that it provides information about the altitude of the terrain monitored by the rover, thus giving a 3D perimeter and showing eventual slopes. All of this is possible since the VBOX 3iSR sensor can also measure the altitude with centimeter accuracy. Because the measurements refer to the center of the GNSS antenna, it is fundamental to subtract from the detected altitude value the antenna's elevation with respect to the ground. The acquired data, including the 3D profile, can be sent to a cloud server through a Wi-Fi connection and downloaded later. The developed rover could be used for inspection and maintenance tasks in the oil and gas industry, detecting the path of buried pipelines. Other prospective uses include applications related to the design and inspection of electrical energy distribution plants, such as the accurate detection of faults and damages in cable ducts. Besides, the developed device could be used in precision farming scenarios to characterize plants and terrains more efficiently, given its portability and easy manageability; in this case, the processing unit could be equipped with visual recognition algorithms for identifying plants or recognizing and localizing the infected ones [29].

Furthermore, the developed device can be employed for centimeter-level inspection tasks in energy production facilities to better coordinate and manage the repair technical team, i.e., in very large photovoltaic plants, to precisely determine the position of damaged components. Also, the localization of abnormal gas leaks could be another possible application of the proposed rover for remotely inspecting harsh environments where human intervention would be too dangerous. This application implies that the rover is equipped with proper low-power gas sensors, thus correlating the high level of a gas species with the detected position [30].

2.2. Structure of the developed RC rover for carrying out cadastral measurements

The developed Bluetooth-controlled rover is based on a commercial tracked platform, managed by the cadastral surveyor, who drives the device for measuring the land parameters. The platform, equipped with rubber tracks, allows better grip and stability over rough terrains and smooth surfaces since they have a greater support surface. Moreover, elastic structures that support the tracks allow for cushioning the robot's passage over obstacles or depressions of the ground. The main elements of the developed system are the VBOX 3iSR sensor and the Raspberry Pi Zero W board, which integrates a Wi-Fi module. VBOX 3iSR sensor is an industry-standard data logger used for automotive applications, equipped with a 100 Hz GPS and GLONASS receiver and an inertial measurements unit (IMU) [31]. In particular, it is typically used to accurately track the position of a moving vehicle or measure roll, yaw, and pitch angles during vehicle tests. Connected to the VBOX 3iSR sensor, a GNSS antenna (model RLACS156, produced by Racelogic Company) receives the satellite signals, locating the vehicle position, and an NTRIP Modem (model RLVBNTRIPMDM, manufactured by Racelogic) acquires positional corrections from the RTK network without using a VBOX base station, enabling position measurements with centimeter-level accuracy. In addition, the Raspberry Pi Zero microcontroller board acquires the positioning and inertial data from the VBOX 3iSR sensor and the images for the onboard camera, manages the sampling rate according to the rover speed, and transmits the acquired data towards a cloud platform using a mobile gateway. Based on the OV5647 image sensor, the onboard camera is connected to the Raspberry board with a camera serial interface type 2 (CSI-2). This interface supports up to four data lines, with each a 1 Gbps maximum bandwidth, providing a total bandwidth of 4 Gbps. Figure 2 shows the mobile robot's 3D model, highlighting its main external components and size; the GNSS antenna was mounted on a pole with 30 cm height, extendible up to 40-80 cm so that any obstacles don't interfere with the antenna's reception.

Figure 2. 3D model of the proposed device mounted on an RC tracked platform highlighted the main external components and its size

The VBOX 3iSR sensor can provide positioning data by working autonomously (in standalone mode) or receiving corrections from a GNSS base station via radio communication (RTK and DGNSS working modes supported). The VBOX 3iSR's positioning accuracy values reported in the sensor datasheet are shown in Table 1. The accuracy is expressed using the circle of error probable (CEP), defined as the radius of a circle centered on the target that contains a defined percentage (95% in Table 1) of the positioning measurements [32], [33].

Table 1. Positioning accuracy of the VBOX 3iSR sensor

Accuracy	3 m (95% CEP)
Accuracy wih SBAS DGPS	< 1.8 m (95% CEP)
Accuracy with RTCM DGNSS base station	40 cm (95% CEP)
Accuracy with RTK base station	2 cm (95% CEP)
Update rate	100 Hz
Height accuracy	6 m (95% CEP)
Height accuracy with DGNSS	2 m (95% CEP)

The system is also equipped with a 49E analog hall sensor (manufactured by Yangzhou Positioning Tech. Co.), typically used for proximity sensing, speed detection, and positioning. Therefore, the motherboard must be equipped with a 16-bit analog-to-digital converter (ADC) (model ADS1115, manufactured by Analog Devices Co.) interfaced using a digital communication interface, as shown in Figure 3. The developed system can also take pictures and stream data in real-time, thanks to the OV5647 camera module (manufactured by OmniVision Technologies, Inc.) mounted on the device. Finally, the developed electronic system includes the power supply section used to obtain the different voltage values from the battery voltage to power the components described above. In particular, it provides the 12 volts of direct current (VDC) used to supply the VBOX 3iSR sensor and 5 VDC for the Raspberry Pi board, which in turn feed the camera and the Hall module. Instead, the NTRIP modem is powered by the VBOX RS-232 interface, used to exchange the RTK corrections. Also, the system comprises the VBOX 3iSR sensor, connected to the motherboard through a UART (universal asynchronous receiver-transmitter) interface. The NTRIP modem and GNSS Antenna (RLACS156) are connected to the VBOX via RLCAB170 cable, using a UART interface (115200 baud) for sending RTCM (radio technical commission for maritime services) corrections. Correction messages received via the RTK network can be advantageous if testing is conducted tens of kilometers away from the base station, over significant elevation changes, or where topographical obstacles could get in the way. The modem can be configured for using either the internal 4G receiver or an external Wi-Fi hotspot to connect it to the chosen RTK network. Figures 4(a) and 4(b) show two typical application scenarios of the developed Bluetooth-controlled rover engaged in measuring the boundaries and surface of agricultural land and a cycle track, respectively.

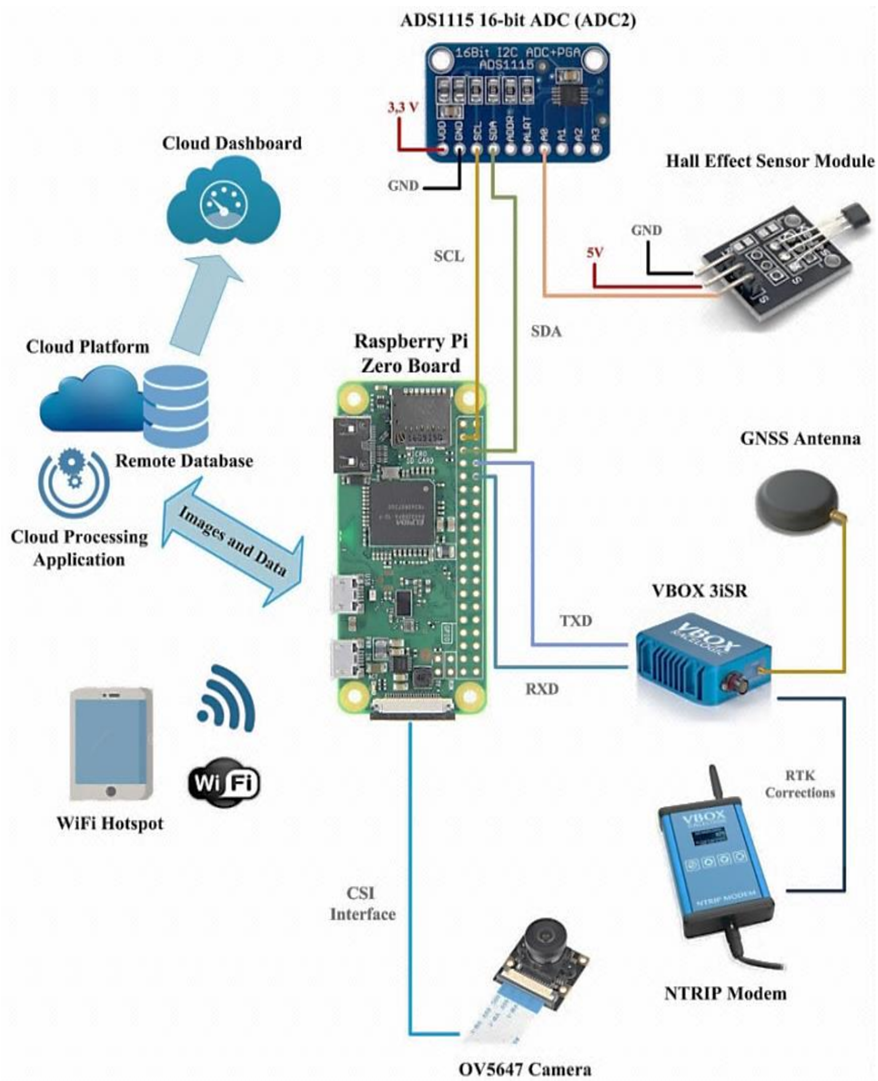


Figure 3. Physical connections of the system components

(a) (b)

Figure 4. Images related to the rover application scenarios in (a) an agricultural land and (b) a cycle track

3. RESULTS AND DISCUSSION

3.1. Description of the firmware for positioning data acquisition

This section describes the flowchart of the firmware implemented by the Raspberry Pi Zero board to manage the acquisition of the rover position at a fixed length (every 5 cm). In particular, the rover manages the acquisitions using the information provided by a hall sensor (i.e. 49E sensor) installed on the tracked platform's body and a magnet placed under the crawler. Whenever the crawler does a complete lap, the sensor provides a peak in the output signal by intercepting the magnetic field generated by the permanent magnet. The temporal distance between two peaks will be called Δt, as shown in Figure 5.

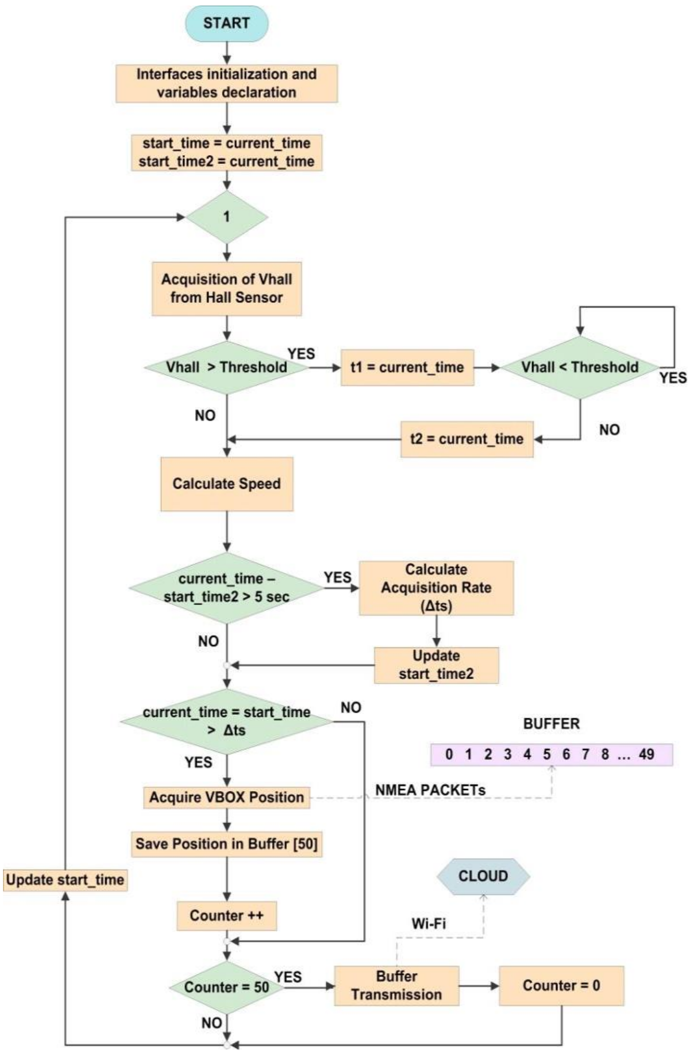


Figure 5. Flowchart of the firmware to acquire the positioning data

The first step in the firmware implementation is the declaration and initialization of all the useful variables, such as *start_time* and *start_time2*, and communication interfaces (i.e. I^2C and UART) used to interface the Raspberry Pi board with the peripheral devices. Specifically, the two variables are used to store the instant of the last acquisition and the last update of the data rate, respectively in Figure 5. Afterwards, the firmware enters into the loop and, at first, the V_{hall} voltage is acquired from the Hall sensor; if V_{hall} is above a certain threshold, the instant t_1 stores the *current_time*, then, a while cycle waits till V_{hall} is above the threshold once again, storing the second instant into the t_2 variable. Later, the robot's speed is calculated as in (1):

$$v = \frac{L}{\Delta t} \tag{1}$$

where v is the robot's speed, L the crawler's length and Δt the difference between t_1 and t_2. The acquisition rate Δt_s is then calculated:

$$\Delta t_s = v \cdot L_{ref} \tag{2}$$

where L_{ref} is the reference length, equal to 5 cm. To avoid continuously updating the acquisition rate (Δt_s), this last is periodically refreshed every 5 seconds. Indeed, the Δt_s updating is conditioned by the expiration of a timer based on the last acquisition instant, stored in the *start_time2* variable. If *current_time – start_time2 > 5 seconds*, the acquisition rate and *start_time2* are updated; otherwise, the last calculated Δt_s is used to acquire the positioning data as shown in Figure 5.

The position acquisition is temporally controlled by a second timer, based on the *start_time* instant and the Δt_s acquisition rate. If *current_time – start_time* > Δt_s, the firmware acquires the positioning data from the VBOX sensor and saves it in a buffer; then, a counting variable is incremented to keep track of the number of the acquisition. When the counter reaches 50, the entire buffer is transmitted over Wi-Fi to the cloud server updating the rover position, and the counter is reset. Finally, *start_time* will be updated to begin a new acquisition cycle in Figure 5.

3.2. Power consumption calculation and definition of the rover supply section

In the following section, a consumption analysis is carried out to optimally size the battery and determine the rover's autonomy. The current consumption of all the sensors and modules included in the developed system is summarized in Table 2. There are two or more reported values for almost all components, depending on the operating mode (i.e. active mode or sleep/rest mode) and the operation performed. However, the operation modality of the rover system requires the continuous acquisition of its current position and the streaming of images acquired from the onboard camera, compelling all the components to operate in active mode, with higher power consumption. Based on the current consumption of each component, the power consumption (P_{tot}) for the worst-case scenario was determined as in (3):

$$P_{tot} = P_{Raspberry+camera} + P_{ADC} + P_{VBOX} + P_{NTRIP} + P_{49E} + P_{Antenna} = 1150\,mW + 0.66\,mW + 7500\,mW + 4992\,mW + 21.45\,mW + 110\,mW = 13774\,mW = 13.774\,W \tag{3}$$

where $P_{Raspberry+camera}$, P_{ADC}, P_{VBOX}, P_{NTRIP}, P_{49E} and $P_{Antenna}$ represent the power consumed by the respective components, obtained by multiplying the absorbed current times the operative voltage. In particular, $P_{Raspberry+camera}$ was calculated by using data found in [34].

Therefore, the energy required by the system (E_{DUT}) to ensure an autonomy (Δt) of 2 hours:

$$E_{DUT} = P_{tot} \times \Delta t = 13.77\,W \times 2h = 27.54\,Wh \tag{4}$$

Imposing the battery energy (E_{Batt}) equal to the energy required by the system (E_{DUT}), the following relation is obtained:

$$E_{Batt}\,[Wh] = V_n\,[V] \times C\,[mAh] = E_{DUT} = 27.54\,Wh \tag{5}$$

where V_n is the nominal voltage and C the battery capacity. A 4 Li-ion cell (Lithium-ion) battery was selected to power the developed system. Imposing a 30% discharge margin (M) over the complete battery discharge for avoiding its rapid degradation, the minimum battery capacity (C_{batt}) can be calculated [35]:

$$C = \frac{E_{DUT}}{V_n \times (1-M)} = \frac{27.54Wh}{14.8V \times 0.7} = 2657\ mAh \quad (6)$$

Therefore, a four-cell Li-Po battery is selected, featured by a 3,000 mAh capacity and 14.8 V nominal voltage (model ZO622502, manufactured by *ZOP Power Co*.). The battery is connected to two adjustable buck DC-DC converters (i.e. MP2307, manufactured by *Monolithic Power Systems Co., Ltd.*). The first one is used to step down the battery voltage from 14.8-5 V to power supply the Raspberry Pi Zero board, to which the OV5647 camera is connected via the CSI interface as shown in Figure 6. The ADS1115 16-bit ADC and the 49E Hall sensor are connected to the 3.3 V supply voltage through the Raspberry board [36]. The second buck DC-DC converter steps down the battery voltage from 14.8-12 V to power the VBOX through which the NTRIP Modem and the GNSS Antenna are powered to 12 V and 5 V, respectively, as shown in Figure 6. Furthermore, a protection board is added to protect the battery against short-circuits, overcharge, over-discharge, and overcurrent, as shown in Figure 6. The protection module is based on the S-8254A IC manufactured by the *Ablic Semiconductor*, used for 3-serial- or 4-serial-cell lithium-ion/lithium polymer rechargeable batteries and featured by 4.25÷4.35 V±0.05 V overcharge voltage, 2.3÷3.0 V±0.05 V over-discharge voltage, and 10 A maximum working current.

Table 2. Summarizing table with supply current values of the different components included in the rover

Component	Modality	Measured supply current
Raspberry Pi Zero W	Idling	120 mA
	Loading LXDE	160 mA
	Watch 1080p Video	170 mA
	Shoot 1080p Video (Rapberry + Pi Camera)	230 mA
ADS1115	Supply current operating (@T_A=25°C)	150 µA (TYP)/200 µA (MAX)
	Supply current power-down (@T_A=25°C)	0.5 µA (TYP)/2 µA (MAX)
VBOX	Supply current	625 mA (MAX)
NTRIP Modem	Supply current	416 mA (MAX)
49E Hall sensor	Supply current (@B=0 Gauss)	4 mA (TYP)/6.5 mA (MAX)
RLACS156 Antenna	Supply Current (@85°C)	15 mA (TYP)/22 mA (MAX)
OV5647	Dormancy current	20 µA
	Working current	110 mA

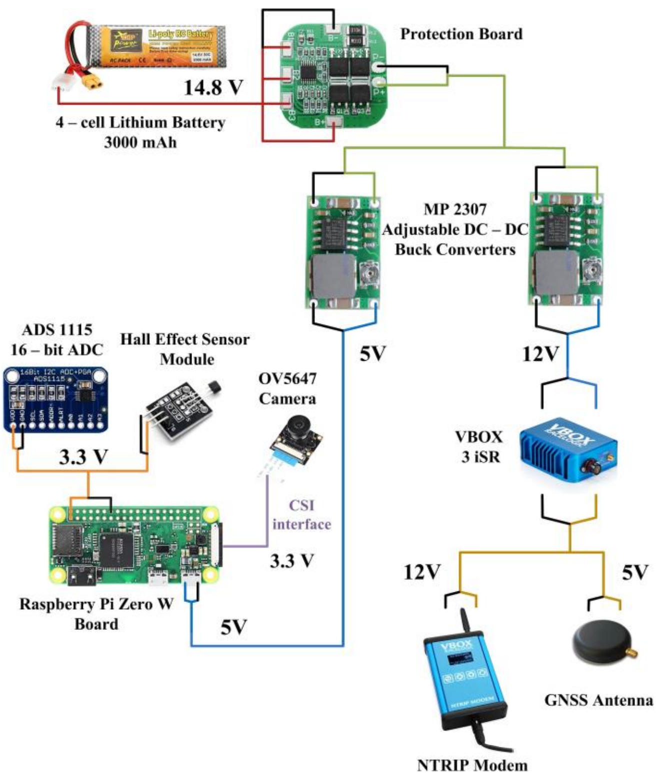


Figure 6. Physical connection scheme for supplying the various peripheral devices included in the developed tracking system

3.3. Test results and mobile application for monitoring the rover's data

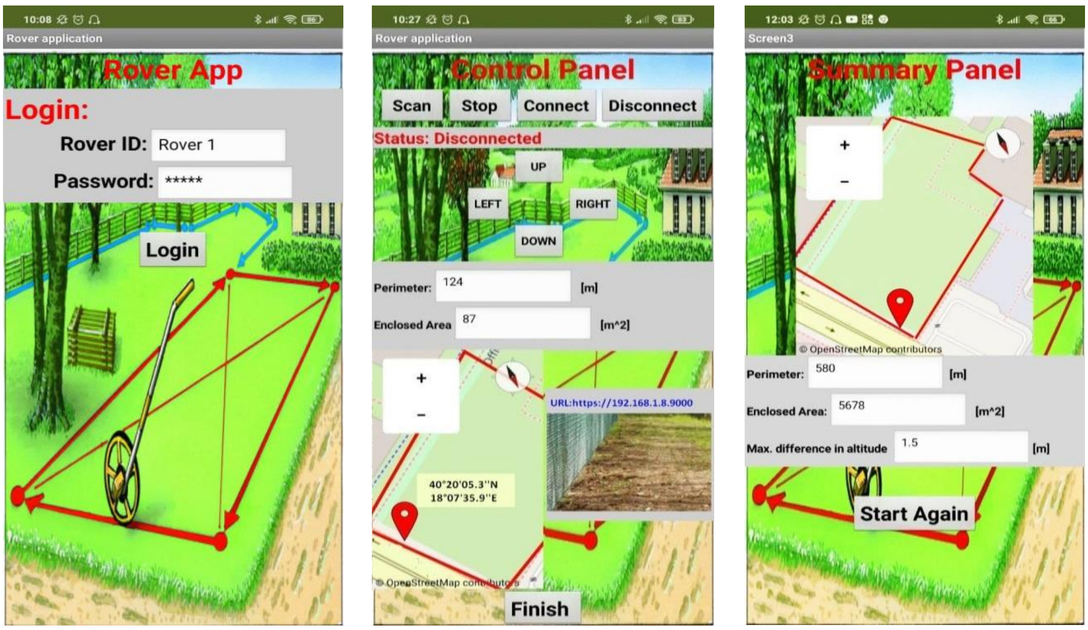
Three test campaigns were carried out to establish the performance of the presented tracking system, comparing the rover's measurements with those obtained by a metric wheel (model 3942, produced by ER-Rancati Inc.) and using as reference value the data provided by a Trimble R10 GNSS RTK receiver, supported Trimble Access® software. Specifically, three land portions inside the Ecotekne Campus (Lecce, Italy, 40.336669N, 18.121888E) were considered, marked by pegs and delimitator tape; for each land, ten perimeter measurements were performed with considered measurement devices. Table 3 compares the mean perimeter measurements obtained by the rover system and those obtained by the metric wheel, calculating the error with respect to the data determined by the pole-based GNSS RTK receiver (3 mm+0.1 ppm RMS accuracy in static condition); also, the time duration of the measurement operations are reported.

As evident from the results reported, the perimeter values obtained with the rover are very close to the reference measurements obtained by the GNSS receiver, with a +0.25% mean error. Furthermore, the metric wheel measurements show a higher error (on average -1.56%), probably due to the bumpy ground surface of considered test fields, causing difficulties for the operator and an overestimation of the acquired measurements. Additionally, the three methods are compared, considering the time spent making the measurement. As can be noticed, the rover takes a lower time compared to the metric wheel and the pole-shaped GNSS receiver. Not considered in the previous table is the manageability of the measuring device; indeed, the measuring wheel and pole-shaped receiver require physical effort from the user to maneuver or move the instruments. In contrast, the developed rover enables greater handling and simplicity since the user does not have to carry any load unless the tablet to drive the device.

A mobile application was developed to control the Bluetooth-controlled platform along the perimeter of the measured land and monitor the acquired measurements and statistics. The application was realized using the *MIT App Inventor software*, a simple development environment for Android application, created by Google, but now of the Massachusetts Institute of Technology (MIT) property [37] as shown in Figure 7(a)-(c).

Table 3. Summarizing table reporting the results of the test campaigns on the developed rover system

	Rover		Metric Wheel		Trimble R10		Error [%]	
Land	Perimeter [m]	Meas. Time [min]	Perimeter [m]	Meas. Time [min]	Perimeter [m]	Meas. Time [min]	Rover	Metric Wheel
A	353.9	6.6	360.1	8.5	352.1	10.1	-0.51	-2.27
B	567.1	8.1	574.4	11.1	567.5	14.5	+0.07	-1.21
C	455.1	7.1	461.5	9.3	455.8	12.4	+0.15	-1.25



(a) (b) (c)

Figure 7. Screenshots of the custom mobile application used to control and manage the developed rover (a) login screen, (b) control and monitoring panel, and (c) summary panel

At first, the user must log in to the system, filling the suitable fields related to the rover ID and password as shown in Figure 7(a); consequently, the application accesses to a cloud database where the ensemble of the enabled users are stored, verifying the user's membership. Afterwards, the Control and Monitoring panel was loaded, allowing the user to drive the Bluetooth-controlled rover and control the followed path. Specifically, the user must press the Scan button to establish the Bluetooth connection with the platform's control board. After selecting the Bluetooth module's medium access control (MAC) address, the user must establish the connection by pushing the connect button. Otherwise, to finish the scanning for Bluetooth modules, the user can press the stop button, as well as close the connection by pushing the disconnect button. Once the connection with the platform is established, the user can drive the rover using four buttons to follow the land perimeter; during the navigation, the user can monitor the followed path using a map at the bottom left angle. Particularly, the application accesses the remote database where are stored the acquired measurements, downloaded and displayed on a satellite map to reconstruct the entire path traced by the rover, as shown in Figure 7(b) [38].

Furthermore, by clicking on a generic point of the traced path, the coordinates associated with the travelled path, along with a picture taken by the camera mounted on the robot, are shown on the dashboard main screen. On the right side of the dashboard, the numeric values of the perimeter and enclosed area of the traced path are visualized. Once finished the considered path, the user closes the measurement session by pressing the finish button, opening the summary panel where the statistics of the measured land are reported. Finally, the user can start a new measurement session by pushing the start again button, as shown in Figure 7(c).

4. CONCLUSION

Cadastral surveying is an essential part of the legal creation of properties and calculating properties taxes. One of the main tasks of a cadastral surveyor is to accurately determine property boundaries by positioning control points and determining their coordinates. The proposed work reports the development of a remotely controlled tracking system for making cadastral surveying more efficiently and accurately by integrating a GNSS RTK receiver (VBOX 3iSR). The system is based on a Bluetooth-controlled rover equipped with a Raspberry Pi Zero W motherboard that manages the acquisition rate according to the rover's speed, acquired by a Hall sensor, as well as an NTRIP modem to download RTK corrections from the internet. Position and inertial data are shared with a cloud platform, allowing remote data consultation and storing. The power supply section of the acquisition section has been developed based on its power consumption estimation, sizing the battery to ensure 2 hours of energy autonomy. Onfield tests demonstrated an optimal agreement between the rover measurements and those provided by a commercial Trimble R10 GNSS RTK receiver (+0.25% mean error). Finally, a mobile application was developed for controlling the rover and real-time monitoring of the travelled path.

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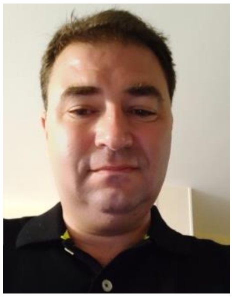

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