Topographic data collection system for the construction of contour lines using Global Positioning System

Sistema de recolección de datos topográficos para la construcción de curvas de nivel utilizando sistema de posicionamiento global

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Abstract

Introduction— The construction of contour lines is a daily activity for topography, civil engineering and architecture, with these plans a survey of the information of the earth's surface is carried out. For this process, theodolites are used, which manually go through a determined surface and take the different heights against a reference point. The introduction of electronic systems for data collection would allow this process to be carried out more quickly and efficiently.

Objective— For this reason, the development of a topographic data collection system that allows the construction of contour lines from a GPS receiver module is proposed.

Methodology— To achieve this goal, an experimental investigation was carried out that includes the theoretical review, followed by the design, the construction of the model, and the construction of the prototype with a validation of the results using descriptive statistics.

Results— In this way, a device capable of carrying out the survey of the topographic information necessary for the construction of the contour lines was obtained with a fairly low error in the shots.

Conclusions— The information from the global positioning system was obtained in NMEA0183 format from which the specific data necessary to store it was extracted and then delivered to the various software that is normally used for the construction of contour lines.

Keywords— GPS Parallax; Topography; NMES-0183; Level Curves; data collection

Resumen

Introducción— La construcción de curvas de nivel es una actividad diaria y cotidiana para la topografía, la ingeniería civil y la arquitectura, con estos planos se realiza un levantamiento de la información de la superficie terrestre. Para este proceso se usan teodolitos, que de manera manual van recorriendo una superficie determinada y tomando las diferentes alturas contra un punto de referencia. La introducción de sistemas electrónicos para la toma de datos permitiría realizar este proceso de manera más rápida y eficiente.

Objectivo— Por esto se plantea el desarrollo de un sistema de recolección de datos topográficos que permita la construcción de curvas de nivel a partir de un módulo receptor GPS.

Methodología— Para alcanzar esta meta, se realizó una investigación experimental que incluye la revisión teórica, seguida del diseño, la construcción del modelo y construcción del prototipo con una validación de resultados utilizando estadística descriptiva.

Resultados— De esta manera, se obtuvo un dispositivo capaz de realizar el levantamiento de la información topográfica necesaria para la construcción de las curvas de nivel con un error en las tomas, bastante bajo.

Conclusiones— La información del sistema de posicionamiento global se obtuvo en formato NMEA0183 de la cual se extrajo los datos específicos necesarios para almacenarlos y luego entregarlos a los diversos softwares que normalmente se usan para la construcción de las curvas de nivel.

Palabras clave— GPS Parallax; Topografía; NMES-0183; Curvas de Nivel; recolección de datos

I. Introduction

Contour lines are one of the methods used to reflect the three-dimensional shape of the earth's surface on a two-dimensional map, each line belonging to a curve that joins all the points that have equal conditions and height or level, showing the terrain relief; serving as the basis for most engineering works and projects related to the planning and construction of civil works [1].

The tracing of a contour line on the ground is generally carried out using the techniques of leveling and triangulation with geodetic instruments for topographic surveying. The main instruments that topography requires for the creation of contour lines are theodolite with its tripod, topographic sight, tape measure and compass. To proceed with the measurements, a height or reference point must be known, from which the following measurements will be made. These instruments are of coarse dimensions for mobilization and their application causes both systematic and accidental errors in the measurements made. These errors come from the measurements of angles and distances, due to certain physical limitations due to the presence of alternating sun and shadow, visibility of the upper part of the staff and sight of where the sun is; In addition, fatigue generates a source of error, since the constant movement of the instruments is required. Although other systems such as terrestrial laser scanners are useful for topographic studies [2], due to the technology used, it is impractical for the precise construction of contour lines, even with corrective numerical methods.

It is necessary to take into account the limitations that the theodolite presents, being an instrument for collecting the data that is necessary to perform the calculations of the points that form the line of the curve, its price is high, it generates additional costs for those who must use these services; and to be able to use it, the existence of a reference level is necessary, which is nothing more than a geographical point with a known altitude.

On the other hand, the systems GNSS (Global Navigation Satellite System) systems that are capable of obtaining the necessary data with a squared error ranging from 1 cm to 4 cm, which represents a very small error [3]. Sensitizing occupation times, day times, uncorrected coordinates subjected to a differential correction procedure and type of coordinates obtained. This facilitated an evaluation of precision and accuracy for the GNSS system with the static method, which gave a global RMS (root mean square. It has a very high cost given the recent technology.

The design of a topographic data collection system through a GPS receiver (Global Positioning System), reduces costs and errors for the construction of contour lines, facilitating the mobilization of the measuring instrument, no without the need for the existence of a point of reference, thus delivering great advances to engineers and technicians who develop in work areas where the existence of topographic plans is essential.

The foregoing allows us to formulate the problem in the following way: How to facilitate the topographic data acquisition process for the realization of contour lines without the need to mobilize the robust measuring instruments previously exposed, nor the existence of a point of reference, in order to achieve a simpler, more efficient and automatic way of acquiring the data for the realization of the contour lines?

For the development of the following investigation, the following objectives are had: Design and implementation of a topographic data collection system for the construction of contour lines from the Parallax GPS receiver module. To achieve this, it is proposed to design the algorithm with the communication protocol to establish communications between the Parallax GPS receiver module and the PIC, to develop the program based on the communications protocol algorithm, to implement it with the PIC18F458, with a data visualization system using an LCD, establish serial communication with the computer to download the data and design a system for storing the database and design the PCB circuit of the topographic data acquisition system with the Parallax GPS Receiver Module.

The importance of this research lies in the fact that it allows improving efficiency in the form of acquisition and creation of contour lines, making it easier for users of this device to take measurements at any place and point on the globe, since it works under the global positioning system; reducing in turn the cost for taking the measurements and the errors produced in them, in addition to being a device of easy mobility and access to any place. In the same way, the creation of the contour lines is done by connecting the device to the computer through serial communication in a very simple way, allowing the data obtained to be graphed through a topographic program for the formation of the maps of the terrain studied.

The research carried out is aimed at the design and implementation of a topographic data collection system, where the data obtained can be displayed first on an LCD screen, and then be communicated via serial with a computer that has a program with the ability to generate and display the contour lines, in order to achieve the construction of said maps in a simpler and more efficient way, from the Parallax GPS Receiver Module.

II Literary Review

In order to locate the reader in the subject of this research, a brief literary review is made below.

A. *Global Positioning System*

The Global Positioning System is a positioning and navigation method based on the signals transmitted by the constellation of 24 NAVSTAR (Navigation Satellite Timing) satellites that are received by portable receivers on Earth. The multiple signals that are received simultaneously from the successive positions of the satellites are used to resolve the ambiguities and thus allow the determination of the three-dimensional position of the point to be known [1].

The basis of its operation is triangulation, which consists of finding out the angle of each of the signals, obtaining the absolute position or real coordinates of the measurement point, that is, the satellites. Once the position is known, the GPS receiver measures distances using the travel time of radio signals, multiplying said time by the speed of light to obtain the distance to the satellite. Because of the importance of time accuracy for positioning calculations, satellites carry incredibly accurate atomic clocks on board; the receiver does not have an atomic clock (it would increase their cost), and therefore it performs a fourth measurement, carried out as a cross control, which intercepts with the first three looking for a single correction factor that, being applied to its time measurements, will that the ranges coincide at a single point [1].

B. *Topographic Map*

The topographic map is a graphic and scale representation of all or part of the earth's surface on a plane. In these maps you can study the following elements:

1) *Scale*: Relationship between the dimensions of the earth's surface and those of the map that represents them.
2) *Planimetry*: Precise location of points on the earth's surface by means of a set of imaginary lines drawn from north to south (meridians) and others drawn from east to west parallel to the equator (parallels). Thus, the geographical longitude and latitude of these points are defined.
3) *Altimetry*: Representation of the altitude above sea level through the so-called contour system. Each contour line can be defined as a closed line that joins relief points located at the same height above sea level.

On a topographic map, the contour lines increase inversely with the topographic slope; that is, curves that are far apart mean very little slope and curves that are very close together mean slope [4].

C. *Level curves*

Contour lines are called imaginary lines that marked on the ground develop a trajectory that is horizontal, where a level line represents the intersection of a level surface with the ground, which represent intervals of height that are equidistant on a plane. on a reference plane. The contour lines allow the interpretation of the relief that is studied because the lines that make up the curve are separated by altimetric intervals.

From the above definitions we can cite the following characteristics:

1) Contour lines do not cross each other.
2) They must be closed lines, although this does not happen within the lines of the drawing.
3) When they get closer to each other they indicate a steeper decline and vice versa.
4) The direction of maximum slope of the terrain is at right angles to the contour line [4].

In relation to the geographical network formed by the parallels and meridians, the geographical coordinates are defined that allow the precise location of any point on the earth's surface. These two coordinates are measured as the distance from the point in question to the baselines of the system and are called: latitude and longitude, expressed in sexagesimal degrees, indicating the location of any point on the Earth's surface. The equator is an important element of this coordinate system; represents the zero of the angles of latitude and the midpoint between the poles, it is the fundamental plane of the geographic coordinate system [1].

D. *Parallel technologies*

There are different technologies that have been developed for the study of the terrestrial surface, these being very precise for the acquisition of data of the terrestrial surface and the subsoil, however, these turn out to be technologically viable solutions but that are not compared with the reduced costs manual survey of topographical information carried out with the theodolite.

Traditionally, land surveying is done with a theodolite or electronic total station. This method is performed using contact lifting, which can result in deformation and destruction of the model. It is a point measurement method whose efficiency is low. 3D laser scanning technology is presented as one of the alternatives to the traditional way. They are highly accurate, very fast, simple to use and easy to handle data are some of the advantages of the technology. On the other hand, one of the main disadvantages is the high cost of used equipment [5].

Another technology developed for topographic surveying is GPR (Ground Penetrating Radar), it is a wide-spectrum electromagnetic technology (1MHz - 1GHz) used to detect reflections from subsurface features. It is a relatively new method, it plays an important role in surface layer detection, due to its easy operation, high automation, high resolution images and reliable interpretation results. It has been successfully used in various fields such as landmine detection, municipal pipeline mapping, non-destructive road testing, archaeological detectors, etc. The GPR uses high-frequency electromagnetic waves to perform underground exploration. For dielectric constant differences of different media, underground media can be detected using their reflection image. Currently, dual-antenna GPR typically uses the profile measurement method [6]. The elevated GPR scans the measurement area along the horizontal survey line at a non-negligible elevation. Therefore, there is always a layer of air between the GPR and the ground surface. The EM wave (Electromagnetic waves) always propagates through the air layer [7]. One of the advantages of this technology is that best-fit surface topographies and deviations have been obtained from a pair of nominally identical samples, allowing the measurement of significant submicron surface differences between them. The usefulness of the technique in the quality control of reflective concave surfaces has become evident [8]. Although this technology turns out to be very useful and precise, it is not designed for work on the earth's surface, but rather in the subsoil.

Photographic technologies have also been developed that allow the calculation of the surface to be measured, the SfM (Structure from Motion) technology performs the calculation, the photogrammetry measurement with a small unmanned aerial vehicle (UAV) to quantify the geometry, the volume and rate of topographic change using the difference between the 3D topographic data [9]. This represents an example of how alternative technologies can be applied for the altimetric survey of a surface.

SAR satellites are another technology developed for calculating altimetry of the earth's surface and have gained acceptance as a measurement technique for its precision in geodesy and mines surveying. The measurement errors of this technology are mainly caused by spatial and temporal influences [10].

LIDAR technology has multiple applications in different fields of study, altimetry does not escape the use of this versatile technology. Topographic lidar can record the complex waveform of the backscattered signal echo. Traditionally, narrow beam laser pulses with a pulse repetition rate were fired and echoes from targets were measured by a sensor to calculate round trip time, full waveform surveying LIDAR has a large footprint, high pulse energy and low PRF (pulse repetition frequency). The laser transmitted pulse and the echo pulse were often considered to be a Gaussian function or a mixture of various Gaussian distributions [11].

III. Methodology

The basic principles present in this research for the development of a topographic data collection system that allows the construction of contour lines from a GPS receiver, were compiled and evaluated in order to achieve its development, achieving its implementation. running for reliable measurement results; this study corresponds to an experimental design, projective type [12], since it gives a feasible solution to the problem posed in obtaining the topographic data necessary for the elaboration of said graphic representations. Next, the phases that make up the investigative process are outlined (Fig. 1):

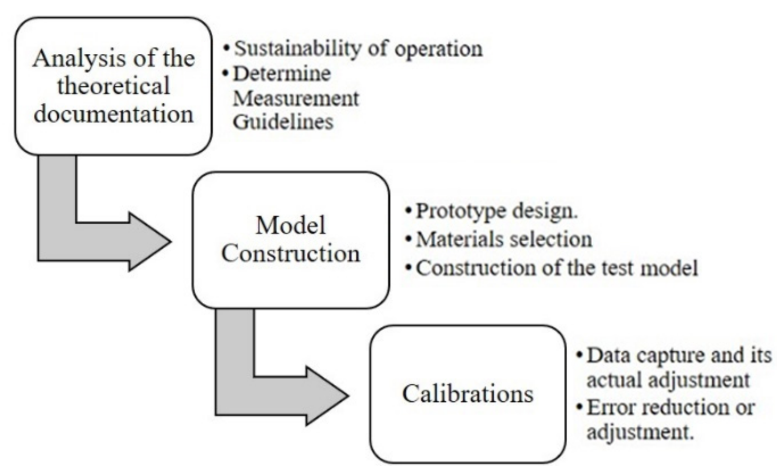


Fig. 1. Methodological phases of the research.
Source: Authors.

To ensure the reliability of the data provided by the system, the calibration phase is divided into two parts. In the first, a direct comparison of the measurements is made using a reference device with a standard error. For this, simultaneous measurements will be taken at the same point, using a Garmin GPS with high reliability among the devices available on the market as a reference. The results of this measurement will be verified with a T Student distribution, for samples smaller than n 30 and a confidence level of 99%.

In the second part, 10 static altitude measurements will be made, in an area with validated elevations. Again, checking the fit of the data to reality and reducing the error to a minimum.

IV. Design

To continue, the operation of the topographic data collection system for the construction of contour lines with the use of the Parallax GPS receiver module is explained in detail. The description of each of the phases that were followed to carry out the module is collected, up to the presentation of the results of the tests and their analysis.

For the realization of the system, five (5) phases were followed:

- Study and realization of the conceptual block diagram for the system,
- Description of the hardware and components required for the design of the topographic data acquisition system.
- Microcontroller programming,
- Electronic design for the data acquisition system
- Programming of a graphical interface for visualizing the data on the computer and storing them in a database

A. *Study and realization of the conceptual block diagram for the system*

This phase consisted of modeling the requirements to establish communication between the GPS Microcontroller and the PC, taking as a basis for the design the Parallax GPS receiver module from which a microcontroller receives the signals emitted by the satellites, processes the received data and sends them to the computer.

The satellites constantly send signals which are received by the GPS receiver module, and it decodes and processes them, then sends them to the microcontroller which, together with a code converter, allows the interface to the computer (Fig. 2).

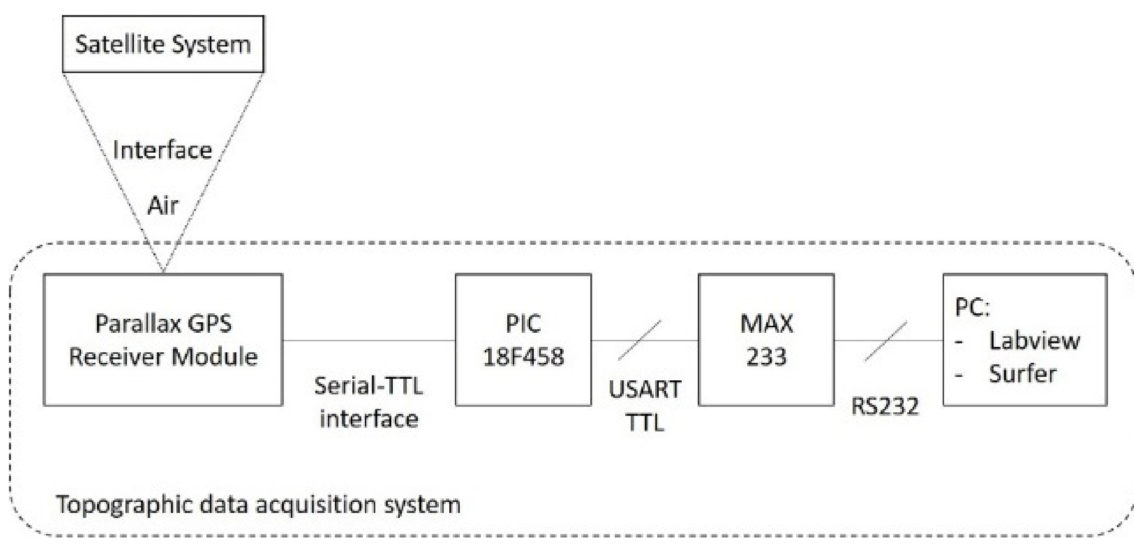


Fig. 2. General system for the construction of contour lines.
Source: Authors.

This process requires several stages so that the contour lines can be generated, and they are the following:

1) *Acquisition*: The GPS receives the signals from the satellites, and they are sent to the microcontroller every time it is indicated by means of a button, where the received data strings are processed, displayed on an LCD screen, and stored in the internal memory of the device. microcontroller.
2) *Transmission*: By means of a button, the microcontroller is told to send the data to the computer via the serial port.
3) *Storage*: The data in the computer is stored in a database (Excel).
4) *Construction of contour lines*: The data that has been stored in the PC is loaded into a topographic software for the generation of the curves.

The fundamental structure of operation can be seen in Fig. 3, in which the necessary information is acquired from the satellites so that the acquisition device can triangulate their location, the data in NMEA0183 format is manipulated to obtain the altitude and stored as so that later the construction of the curve can be carried out. To reduce the error in GPS altitude measurements, the Least Squares Parameter Estimation technique is used [13].

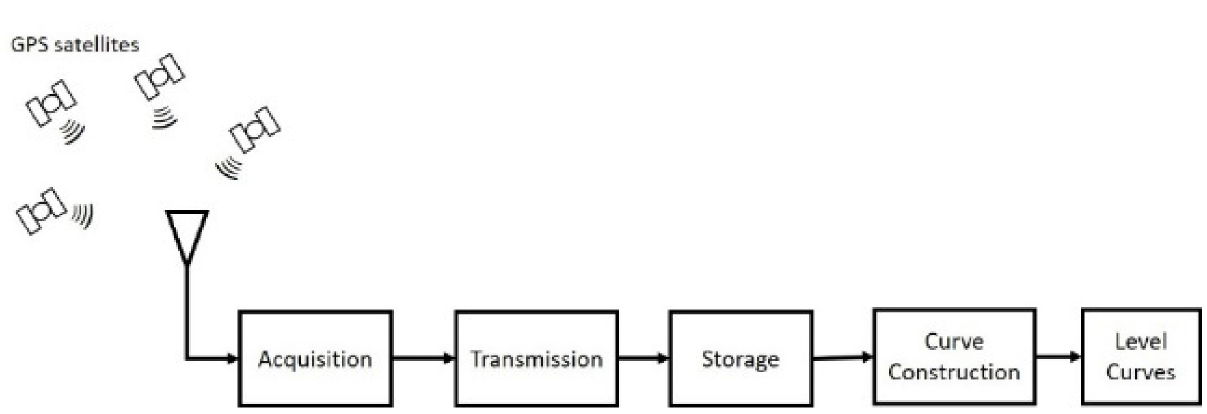


Fig. 3. Stages of the data acquisition system.
Source: Authors.

B. *Description of the hardware and components required for the design of the topographic data acquisition system*

The data collection system is made up of different blocks (Fig. 4), which fulfill a defined function for its perfect operation, which will be described in the following sections.

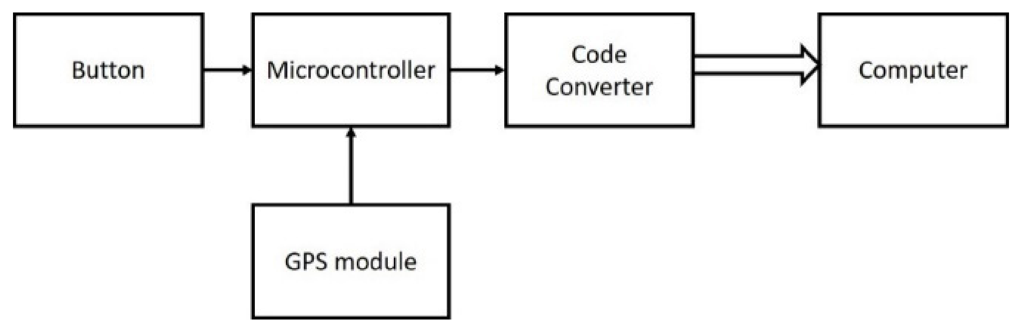


Fig. 4. General hardware diagram for the data acquisition system.
Source: Authors.

It is necessary to define in a general way the connections made to the microprocessor of the peripheral devices [14], as well as making clear the signals with which they work, their addressing, speed and communication protocol for both reception and transmission (Fig. 5).

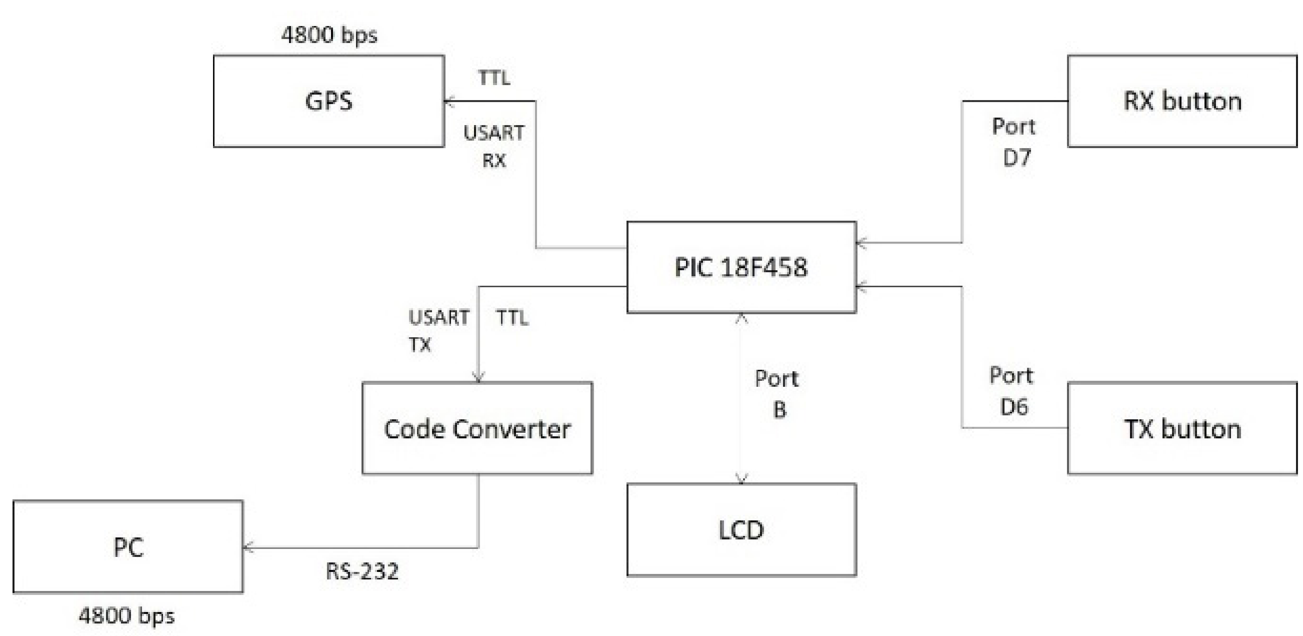


Fig. 5. System hardware block diagram.
Source: Authors.

1) *Communication with the Global Positioning System (GPS)*

The data acquisition system starts working with the global positioning system the moment it is turned on. The GPS begins to link with the satellites with which it has a direct view from the sky with it [15]. The GPS receiver module has a single red LED to indicate system status. When it is blinking it is searching for satellites or it was not able to link with any satellite, when it is fixed it is because it found a link with satellites.

Once linked to the satellites, the GPS performs the necessary calculations to obtain the geographic coordinates in GPS coordinate format. For research purposes, GPS was used in raw mode, which provides data such as date and time, latitude, longitude, altitude, speed, direction of movement, among others, from standard NMEA0183 data strings and communicates via serial port via Serial I/O pin, data is transmitted at 4800 bps, 8 stop bits, no parity, non-inverted, at TTL levels [16]; this signal reaches the PIC through the RC7/TX port (Fig. 6).

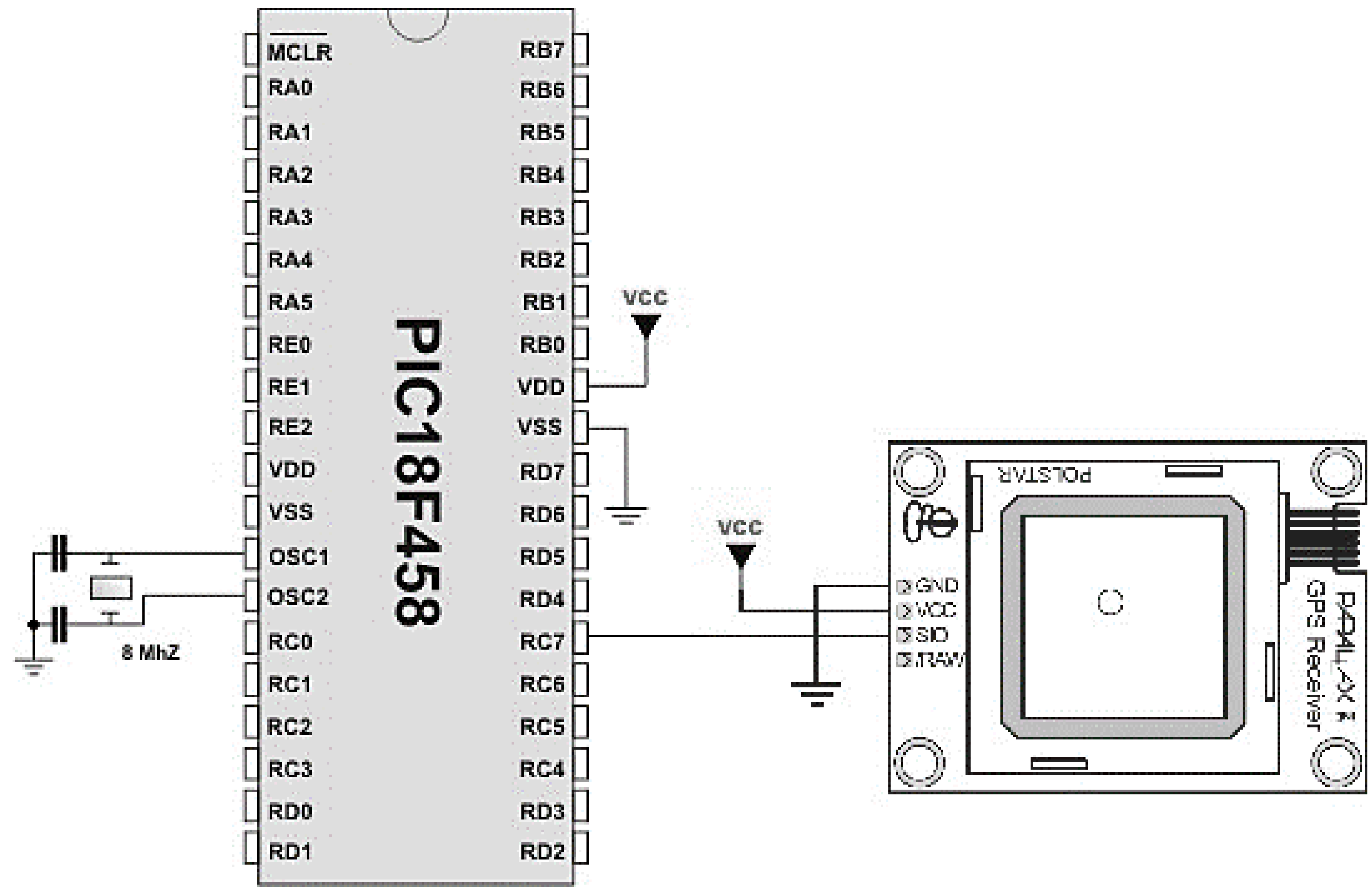


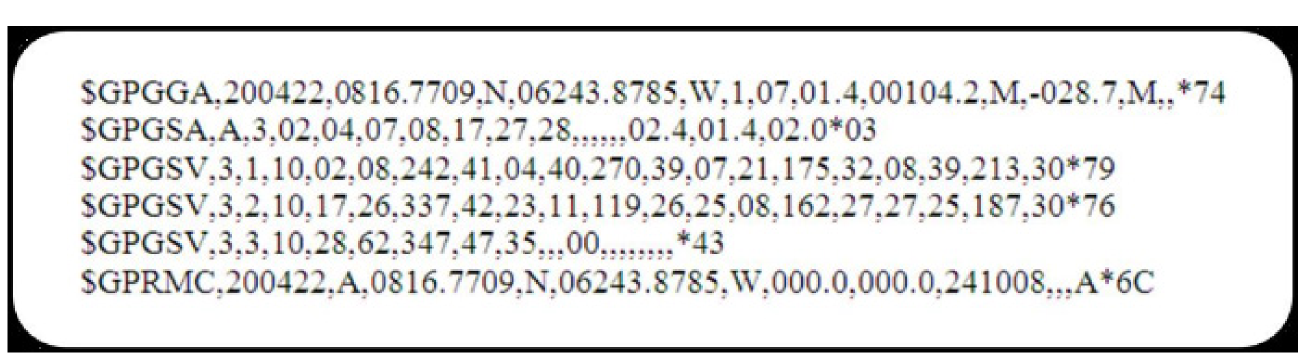
Fig. 6. Connection of the Parallax Receiver Module to the PIC18F458.
Source: [22].

To carry out the GPS link and data transmission tests, the Parallax receiver module was connected to a max233 code converter and data was continuously transmitted through the channel.

The SIO pin of the GPS was connected to the input of the max233 and its output to the computer, through a serial cable; the visualization of the data was carried out using the RCOM Serial software [18], obtaining the following strings:

- *GPS linked*

This test was carried out at (Polytechnic Experimental University Antonio Jose de Sucre) UNEXPO in the rear parking lot of the Electrical Engineering Building, obtaining (as indicated in the receiver module manual) a string of data in standard NMEA0183 format as follows (Fig. 7):



```
$GPGGA,200422,0816.7709,N,06243.8785,W,1,07,01.4,00104.2,M,-028.7,M,,*74
$GPGSA,A,3,02,04,07,08,17,27,28,,,,,,02.4,01.4,02.0*03
$GPGSV,3,1,10,02,08,242,41,04,40,270,39,07,21,175,32,08,39,213,30*79
$GPGSV,3,2,10,17,26,337,42,23,11,119,26,25,08,162,27,27,25,187,30*76
$GPGSV,3,3,10,28,62,347,47,35,,,00,,,,,,,*43
$GPRMC,200422,A,0816.7709,N,06243.8785,W,000.0,000.0,241008,,,A*6C
```

Fig. 7. Data string sent by the GPS module in “linked” condition.
Source: Authors.

It was verified that the GPS needs to be facing a clear sky and it was observed that the string $GPGGA (Global Positioning System Fix Data) sends the data required for this project in the form $GPGGA,hhmmss.ss,ddmm.mmm,a,dddmm.mmm,b,q,xx,pp,ab,M,cd,M,xx,nnnn; where the data correspond to the shown in Table 1.

Table 1.
Classification of data in NMEA format.

Data	Reference
hhmmss.ss	position UTC
ddmm.mmm	position latitude
A	N or S, latitude hemisphere
dddmm.mmm	position length
B	E or W, hemisphere longitude.
Q	0 = not linked, 1 =GPS, 2 = DGPS
Xx	Number of linked satellites
p.p	Precision horizontal dilution
a.b	Height above sea level (altitude)
M	Altitude measurement unit (meters)
c.d	geoid height
M	Geoid height unit of measure (meters)
x.x	DGPS Data Age
Nnnn	Differential reference station

Source: Authors.

This served to know the position of the necessary data in the chain given by the GPS, for the manipulation of them by the microprocessor.

- *GPS not linked*

This test was carried out at the UNEXPO university (Venezuela) in the rear parking lot of the Electrical Engineering Building, obtaining a data string in standard NMEA0183 format as follows (Fig. 8):

```
$GPGGA,214051,,N,,E,0,00,,,M,,M,,*6E
$GPGSA,A,1,,,,,,,,,,,,,,,*1E
$GPGSV,3,1,09,29,,,37,28,,,37,12,,,37,31,,,38*7D
$GPGSV,3,2,09,15,,,39,02,,,36,25,,,40,30,,,38*73
$GPGSV,3,3,09,22,,,39,,,,,,,,,,,,*7A
$GPRMC,214051,V,,N,,E,,,231008,,,N*53
```

Fig. 8. Data chain sent by the GPS module in "not linked" condition.
Source: Authors.

Where the data chain was observed when the positioning system is not linked to the minimum number of satellites necessary to perform the calculations, which served to verify that the system is not linked, therefore it cannot perform the data processing by the microprocessor.

2) *Communication with the Computer*

The microcontroller communicates with the computer via a serial port, for this it is required to condition the levels of the signal that contains the data, for this it complies with the RS-232 standard corresponding to communications through the serial port, at TTL levels, which is used by PIC 18F458. This action is carried out by MAXIM's MAX233 integrated circuit whose function is the conversion from RS-232 to TTL as well as from TTL to RS-232.

The USART module of the microcontroller was configured as a 4800 baud serial interface, 8 data bits, one start bit and one stop bit. In this mode, the RC7 pins are used as a transmitter (TX) and RC6 as a receiver (RX), to adapt the signals from these ports to the electrical specifications of the RS-232 standard, a MAX-233 integrated circuit was used, as shown. explained above. Fig. 9 shows the connection of the PIC 18F458 microcontroller with the MAX233 device for code conversion.

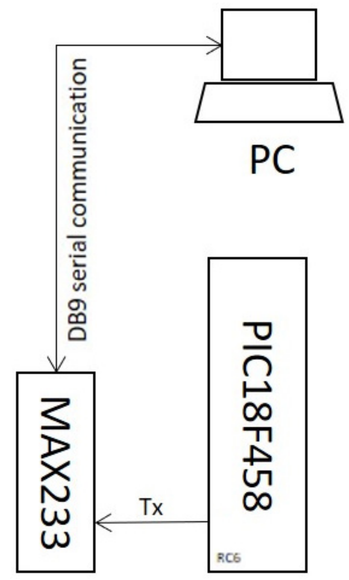


Fig. 9. Connection of the PIC18F458 to the MAX233.
Source: Authors.

As can be seen in the Fig. 9, the communication between the signal converter and the computer is carried out through the RS232 protocol.

3) *Display*

The display used for data visualization is 4 lines x 16 display characters. It has eight data bus lines and three control bus lines. As it is an output device, messages and instructions are displayed to the user through it.

The pins connections for the LCD screen. The LCD CONTROL bus (2 pins) and the LCD DATA bus (4 pins) are connected to the corresponding pins of port B of the 16F458 microcontroller (Fig. 10).

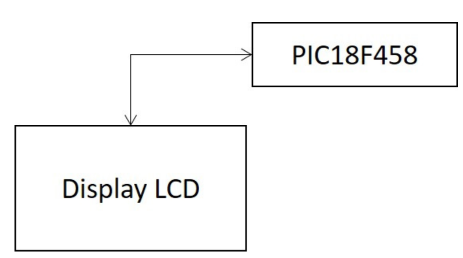


Fig. 10. Connection of the display to the PIC18F458.
Source: Authors.

In addition, there is a potentiometer in the circuit, through which the Contrast value is modified, which is adjusted to optimally observe the text displayed on the LCD Screen.

4) *Power supply*

As it is a mobile device, it requires that the system be powered from a battery. For this, a circuit was designed (Fig. 11), that delivers 5V from a 9V battery through the 7805 integrated circuit. The circuit has a led which lights up when the On/Off switch is placed on.

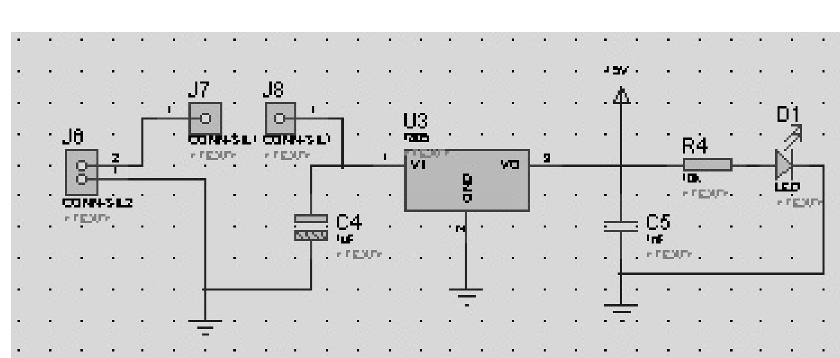


Fig. 11. Power circuit.
Source: Authors.

C. *Microcontroller programming*

The data processing core is the PIC18F458. This component requires programming for its operation, which was done in C language for PIC using the MikroC development program [19].

At the beginning, the PIC's own configurations are made, such as the configuration of the ports, USART, LCD, among others, then it is in a cycle where the states of the ports to which the reception buttons are connected are surveyed. and data transmission; if any of these is active, it jumps to a subroutine that is responsible for carrying out its function and then returns to this initial routine.

Next, the functions of the buttons are defined: if the Rx button is pressed (receive data from the GPS), the program enters a subroutine that is responsible for receiving the data from the GPS to be processed by the microcontroller. If the Tx button (transmit data to the computer) is pressed, the program enters the subroutine that is responsible for transmitting the received data to the computer. The program always returns to the button survey, to then execute actions, being an infinite cycle, as shown by the operating algorithm in Fig. 12.

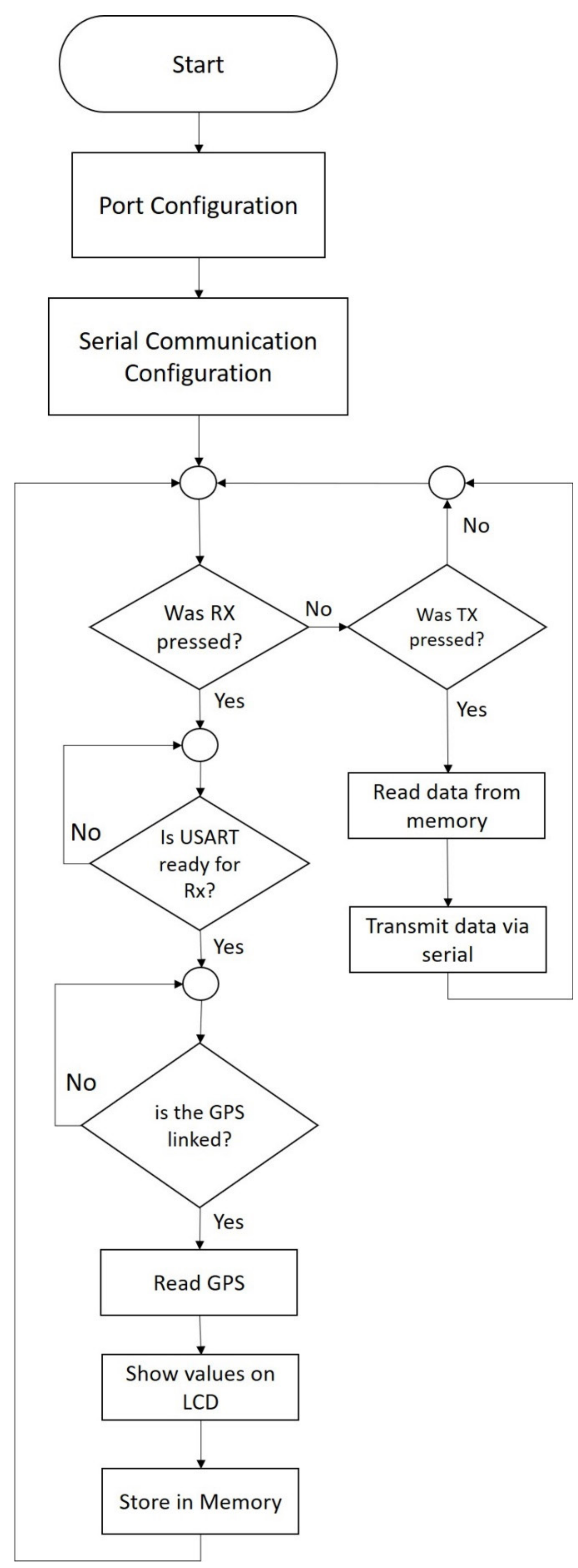


Fig. 12. Main Algorithm of the MikroC Software.
Source: Authors.

The data reception subroutine, first, checks that the USART reception port is ready for a receive, then it checks that the GPS is linked through the string that has been received by analyzing the position of the commas in the NMEA string. If it is linked, it checks that the first data received is $GPGGA, then it searches the string for the data: time, latitude, longitude and altitude, storing them in the PIC's EEPROM memory, displaying them on an LCD screen and then polling again the state of the buttons.

The data transmission to the computer subroutine reads the data stored in the PIC's EEPROM, sends it to the computer via the PIC's USART transmission, and polls the button states again.

D. *Electronic design for the data acquisition system*

Fig. 13 shows the circuit designed for the acquisition of topographic data from the Parallax GPS receiver module, with its respective connection port via serial port to the computer.

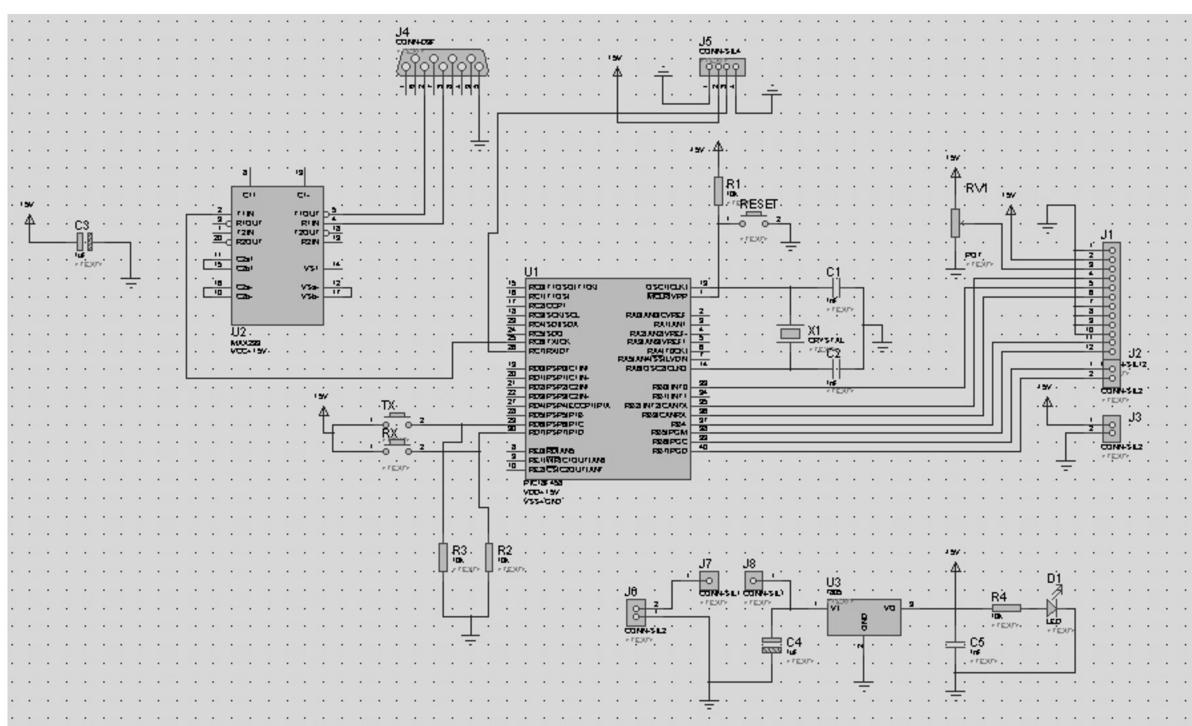


Fig. 13. Electronic circuit for the topographic data acquisition system.
Source: Authors.

Fig. 14 shows the operation of the system in the tests carried out before the implementation of the prototype in printed circuit design.

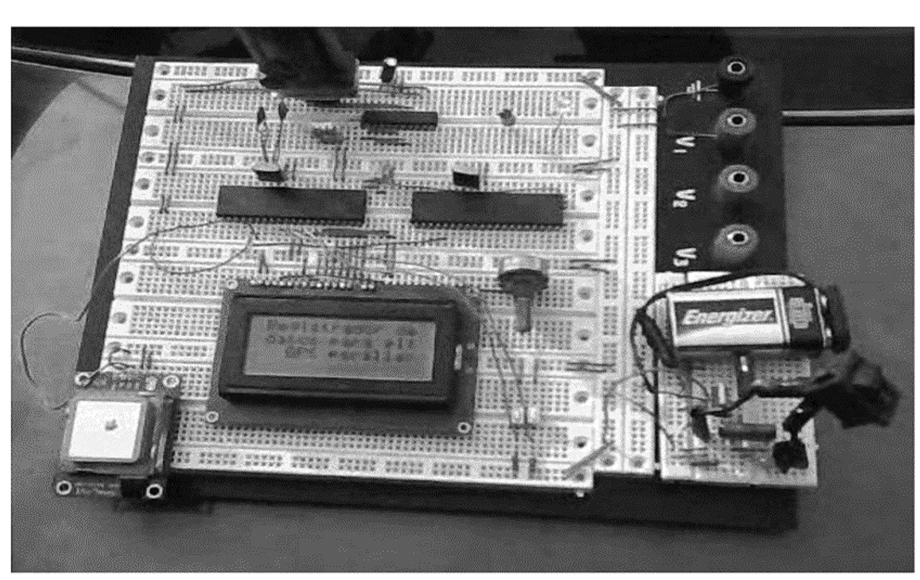


Fig. 14. Photo of the data acquisition system in operation.
Source: Authors.

E. *Circuit design for the data acquisition system*

Fig. 15 shows the printed circuit designed for the acquisition of topographic data from the Parallax GPS receiver module, with its respective connection port via serial port to the computer.

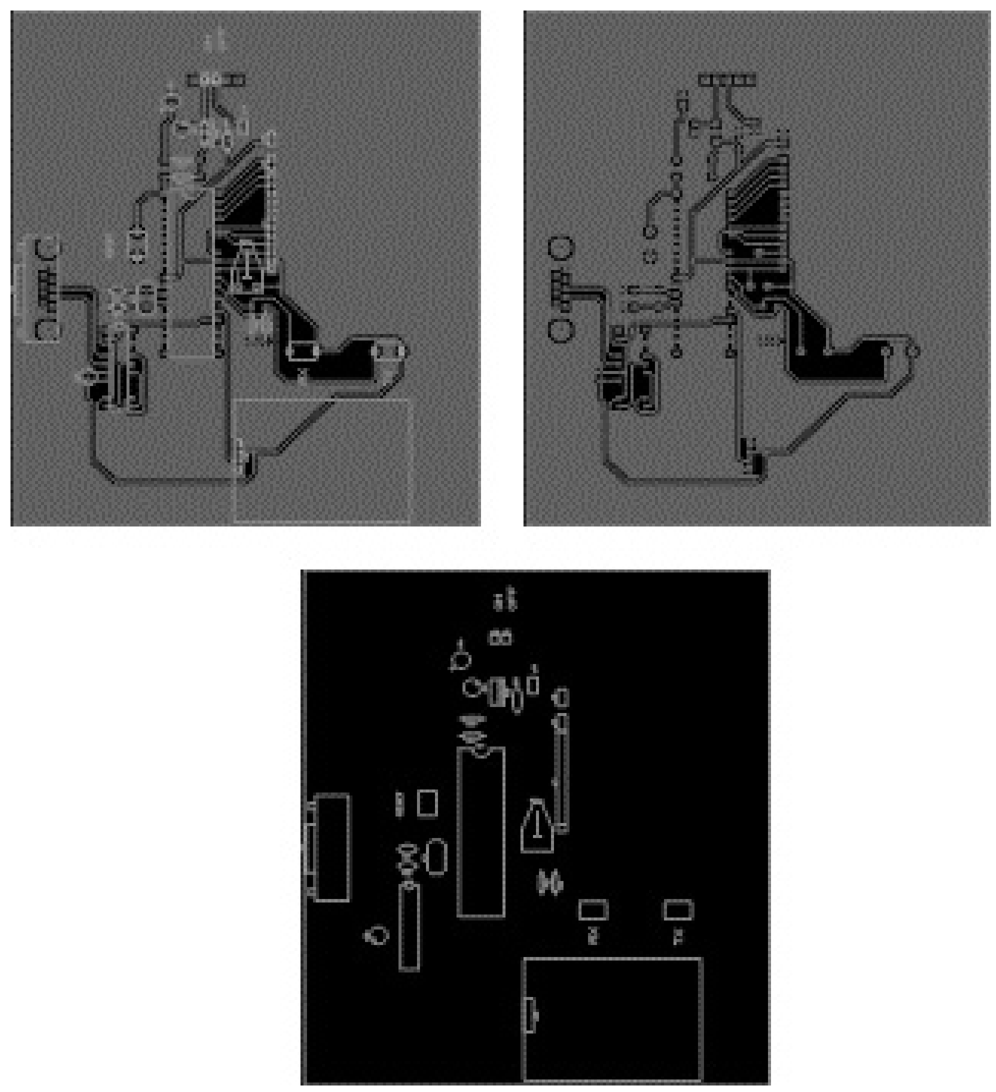


Fig. 15. Printed circuit design for the data acquisition system.
Source: Authors.

Fig. 16 shows the 3D design, which simulates the PCB card designed for this study.

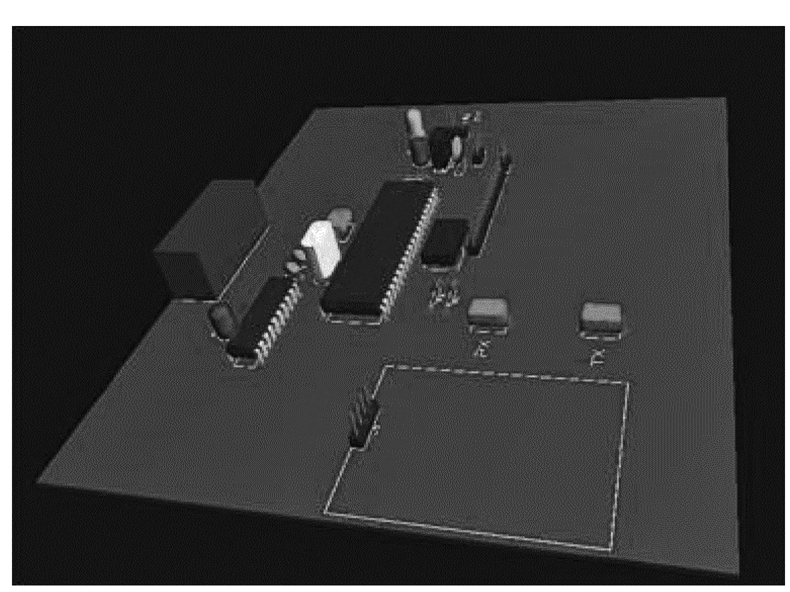


Fig. 16. PCB design in 3D.
Source: Authors.

Fig. 17 shows the design of the topographic data acquisition system from the Parallax GPS receiver module with all the components that it requires, as well as its perfect operation.

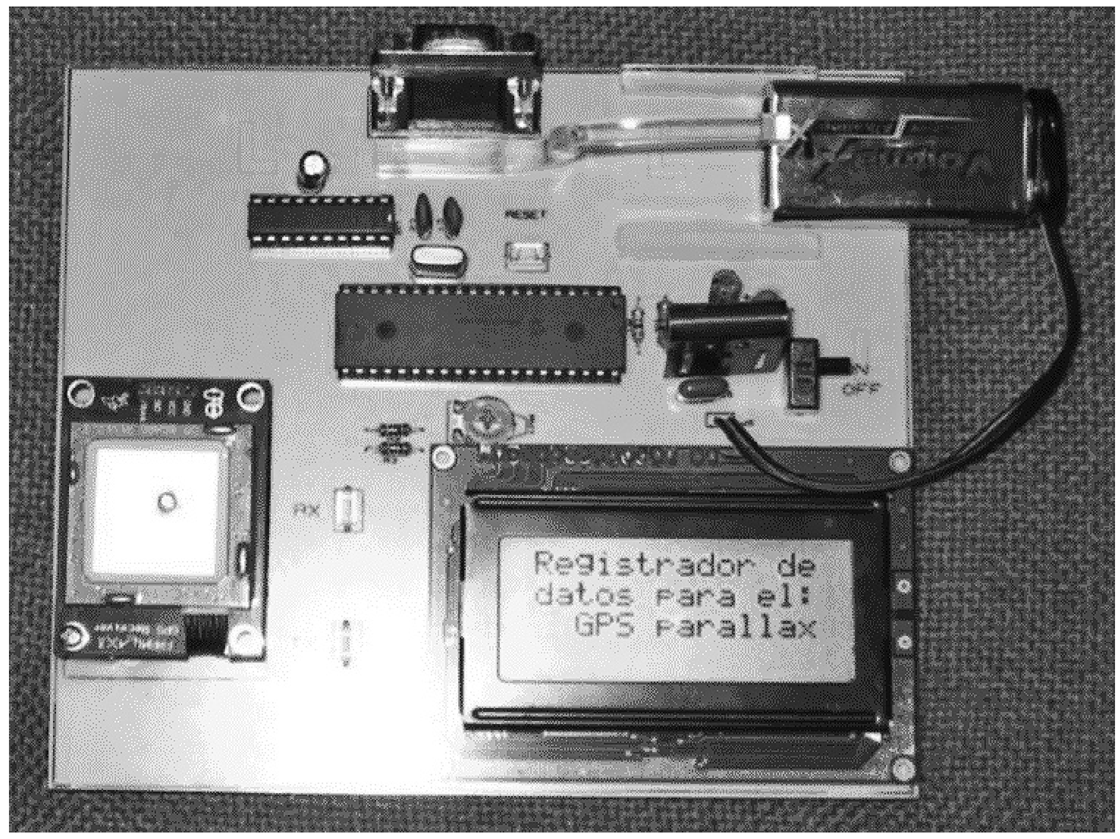


Fig. 17. Printed circuit data acquisition system.
Source: Authors.

For data acquisition it is necessary to know the buttons contained in the module, and these are: reception and transmission:

- *Reception button*: This button is responsible for collecting data from the GPS. Once the data acquisition system is turned on and located in the position in which you want to know the topographic coordinates, you must check the GPS status by viewing the LED of the receiver module that is located in the lower right corner of the module, indicating two states of the module:
  - *Blinking*: Searching for satellites or not linked to any satellite.
  - *Stable*: Successful link with satellites (a minimum of three satellites is required before the module proceeds to transmit valid GPS information).

When you turn on the GPS Receiver Module at a new location, it takes a maximum of 5 minutes for the module to link your location to the minimum of 4 satellites. During this period, the red LED will flash. Once the module makes contact with the minimum number of satellites to work properly, the LED will become solid. The number of satellites may vary depending on various factors.

Once the link with the satellites is established, the data receiving system is ready to be used. If the status of the link LED with the satellites is not observed or if the button to receive data was pressed by mistake and the GPS is not linked, the acquisition system will not take the data, since it has been designed to capture data when it is linked, so this does not represent a problem or a source of error.

- *Transmission button*: This button is responsible for transmitting the data received and stored in the PIC to the computer. For this, it is required that the device is connected to the computer via a serial port and that the user interface software is in operation.

In addition to these buttons, the hardware system for data collection has other switches and buttons:

- *On/Off switch*: For powering all hardware. When the switch is set to On, the power LED should light up, otherwise, check the system power supply (9V battery).
- *Reset*: Button that allows the reset of the microcontroller, in case of any failure. It must be taken into account that when the PIC is restarted, all the collected information is lost.

F. Programming of the graphical interface for the visualization of the data in the computer and storage of these in a database.

The core of data transformation and storage is the software designed in Labview [20]. This component requires programming for its operation through graphical programming.

The core of data transformation and storage is the software designed in Labview [20]. This component requires programming for its operation through graphical programming. At the beginning, the serial port will be configured for the communication of the PIC with the computer for data transmission; this transmission is carried out exclusively when the hardware TX button is pressed. Next, the received string is read and it is verified that it has been received, otherwise an error message is displayed and another data is expected to be sent from the microcontroller. Once the data string is read, it is displayed in a software window, this string continues to a stage of transformation from GPS coordinates to Cartesian coordinates; the program waits to receive a signal to show these value to be saved in the database (Excel) verifying the destination address of the document to receive a new string, observing here its infinite cycle. The programming algorithm made for Labview is shown in Fig. 18 [1].

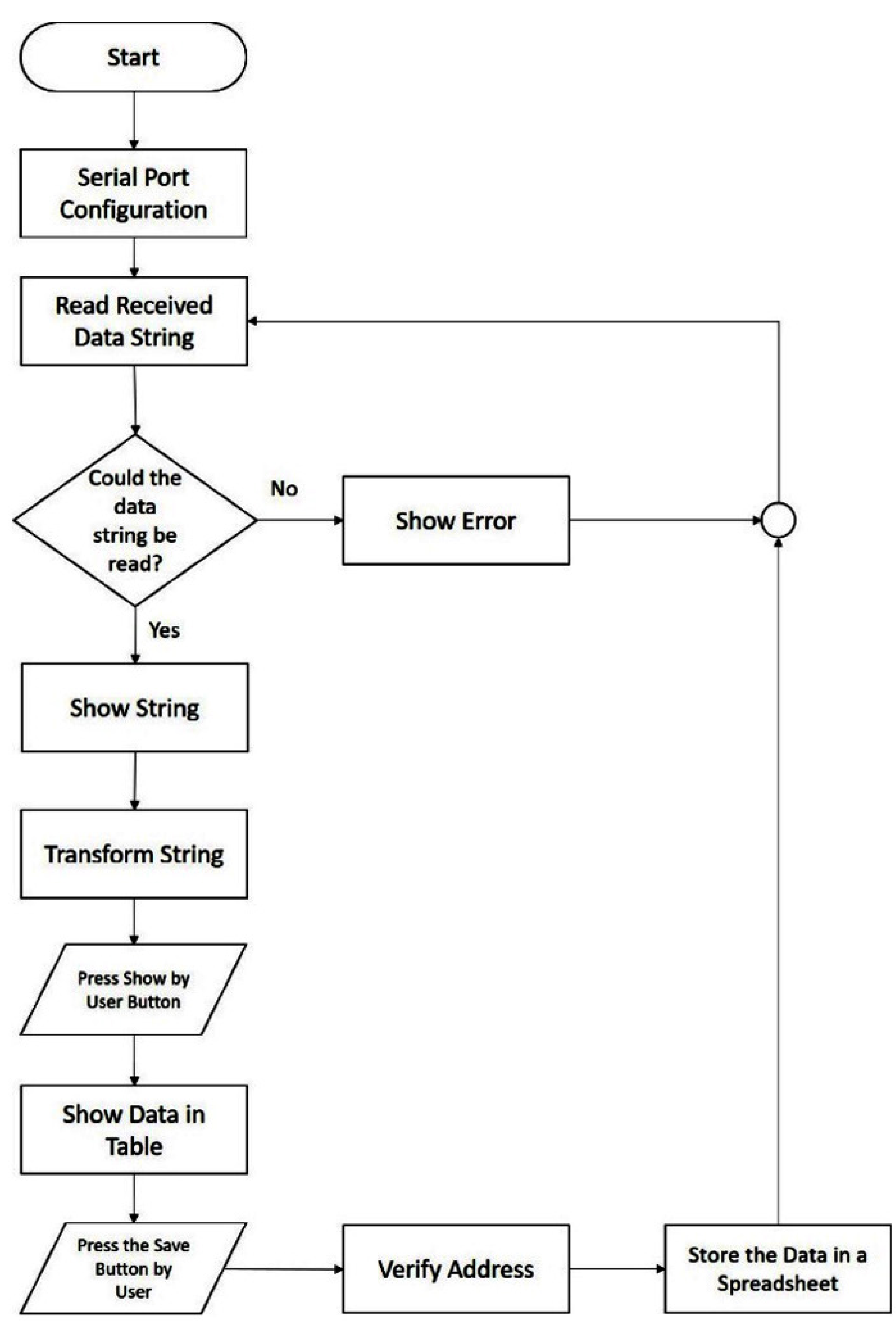


Fig. 18. Labview Software Algorithm.
Source: Authors.

For the transformation of the latitude and longitude data to cartographic coordinates (or decimal degrees), formulas had to be used to achieve said conversion, firstly the GPS delivers fractional degrees, minutes and seconds (ddmm, mmmm), which must be converted into seconds by applying (1):

$$s = (mm,mmmm - mm) \times 60 \tag{1}$$

Once the value of degrees (*d*), minutes (*m*) and seconds (*s*) is known, the cartographic coordinates are obtained using (2):

$$d.dd = d + \left(\frac{m}{60}\right) + \left(\frac{s}{3600}\right) \tag{2}$$

The cartographic coordinate (*d.dd*), already has its magnitude, but in addition to the magnitude it is represented with a (+) plus or minus (–) sign to indicate its orientation, the negative (–) represents the west and east directions. South, while the positive (+) represents east and north.

Following the logic of the algorithm presented in Fig. 18, the software must be able to: Configure the serial communication, Show the data acquired by the receiving system, Show the data transformed to Cartesian coordinates, Visualize the data as it will be shown on the database, Choose the file in which you want to save the topographic data, Store the data in an Excel database.

The software allows the data received via the serial port and the data transformed to cartographic coordinates by the program that is being executed to be observed, as shown in Fig. 19. It is comprised of the following elements:

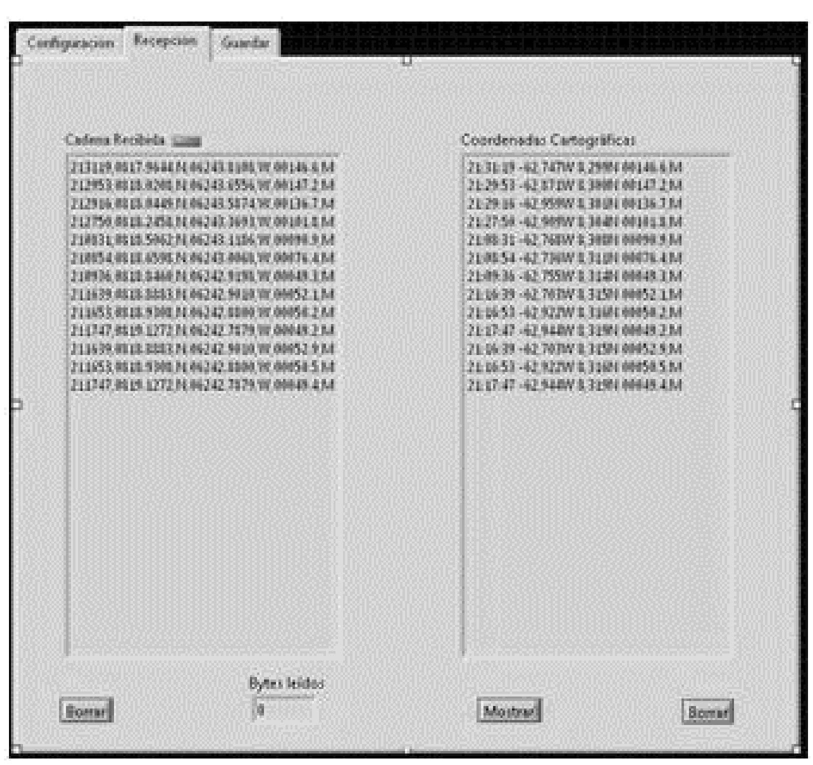


Fig. 19. Reception Window.
Source: Authors.

The values are placed in order of arrival, that is, in the order in which they were acquired by the module, placing the first value received in the first free box in descending order, so that the first value received is the one corresponding to the first line, and is divided into four (4) fields: the time the value was taken, the value of latitude, longitude and altitude as shown in Fig. 20.

Hora	Longitud	Latitud	Altitud
21:31:19	-62,747W	8,299N	00146.6,M
21:29:53	-62,871W	8,300N	00147.2,M
21:29:16	-62,959W	8,301N	00136.7,M
21:27:50	-62,909W	8,304N	00101.8,M
21:08:31	-62,768W	8,308N	00090.9,M
21:08:54	-62,736W	8,311N	00076.4,M
21:09:36	-62,755W	8,314N	00049.3,M
21:16:39	-62,703W	8,315N	00052.1,M
21:16:53	-62,922W	8,316N	00050.2,M
21:17:47	-62,944W	8,319N	00049.2,M
21:16:39	-62,703W	8,315N	00052.9,M
21:16:53	-62,922W	8,316N	00050.5,M
21:17:47	-62,944W	8,319N	00049.4,M

Fig. 20. Table to store topographic data.
Source: Authors.

V. Results

The data obtained by the module for the three variables were compared with data delivered by a Garmin GPS (Table 2).

Table 2.
Comparison of results with respect to the standard device.

Latitude		Length		Altitude	
GPS Parallax	GPS Garmin	GPS Parallax	GPS Garmin	GPS Parallax	GPS Garmin
0817.9644,N	0817.9644,N	06243.8108,W	06243.8107,W	146.6	147.1
0818.0208,N	0818.0212,N	06243.6556,W	06243.6550,W	147.2	147.3
0818.0449,N	0818.0446,N	06243.5874,W	06243.5871,W	136.7	136.2
0818.2458,N	0818.2459,N	06243.3693,W	06243.3693,W	101.8	102
0818.5062,N	0818.5062,N	06243.1186,W	06243.1186,W	90.9	90.7
0818.6598,N	0818.6599,N	06243.0068,W	06243.0067,W	76.4	76.4
0818.8460,N	0818.8462,N	06242.9198,W	06242.9198,W	49.3	49.2
0818.8883,N	0818.8882,N	06242.9010,W	06242.9011,W	52.1	52.2
0818.8883,N	0818.8880,N	06242.9010,W	06242.9010,W	52.9	52.8
0818.9308,N	0818.9308,N	06242.8800,W	06242.8800,W	50.2	50.2
0818.9308,N	0818.9309,N	06242.8800,W	06242.8802,W	50.5	50.4
0819.1272,N	0819.1272,N	06242.7879,W	06242.7880,W	49.2	49.3
0819.1272,N	0819.1272,N	06242.7879,W	06242.7878,W	49.4	49.4

Source: Authors.

As a validation tool, a comparison of means is used using a t-test for independent samples. In this way, it is possible to obtain the fit of the data and the error with respect to each data set, with a confidence level of 99% (Table 3; Table 4; Table 5):

TABLE 3.
DESCRIPTIVE STATISTICS FOR THE RESULTS.

Group Statistics						
Device		N	Average	Standard deviation	Mean standard error
Latitude	GPS Parallax	13	818.629269	0.4258108	0.1180987
	GPS Garmin	13	818.629285	0.4257847	0.1180914
Length	GPS Parallax	13	6243.123546	0.3569688	0.0990053
	GPS Garmin	13	6243.123485	0.3568320	0.0989674
Altitude	GPS Parallax	13	81.0154	39.64267	10.99490
	GPS Garmin	13	81.0154	39.67845	11.00482

Source: [21].

TABLE 4.
RESULTS OF COMPARISON OF MEANS, T-TEST FOR INDEPENDENT SAMPLES.

		Levene's test for equality of variance	
		F	Sig.
Latitude	Equal variances are assumed	0.000	1.000
Length	Equal variances are assumed	0.000	0.999
Altitude	Equal variances are assumed	0.000	0.998

Source: [21].

TABLE 5.
RESULTS OF COMPARISON OF MEANS, T-TEST FOR INDEPENDENT SAMPLES.

		t test for equality of means						
		t	gl	Sig. (bilateral)	Differences between measurements	Standard error differences	99% confidence interval of the difference	
							lower	higher
Latitude	Equal variances are assumed	0.000	24	1.000	−0.0000154	0.1670116	−0.4671368	0.4671060
	Equal variances are assumed	0.000	24	1.000	−0.0000154	0.1670116	−0.4671368	0.4671060
Length	Equal variances are assumed	0.000	24	1.000	0.0000615	0.1399879	−0.3914760	0.3915991
	Equal variances are assumed	0.000	24	1.000	0.0000615	0.1399879	−0.3914760	0.3915991
Altitude	Equal variances are assumed	0.000	24	1.000	0.00000	15.55615	−43.50962	43.50962
	Equal variances are assumed	0.000	24	1.000	0.00000	15.55615	−43.50963	43.50963

Source: [21].

According to the results presented in Table 3, Table 4 and Table 5, the mean differences are low, as well as the standard error difference. In this sense, the reliability of the data collected by the model in terms of latitude, longitude and altitude with respect to the reference device can be asserted.

A. *Parallax GPS Receiver Module Accuracy*

In the second phase of verification, given the importance of altitude in the use of data for the construction of contour lines, the real accuracy of the receiver module in the designed system is tested. 10 static altitude measurements were made at the "Simón Bolívar" Hydroelectric Power Plant (Guri, Bolívar state in Venezuela). Due to the fact that in said generating complex the elevations are established with a practically null error taking as reference the height above sea level (Table 6, Table 7, Table 8, Table 9).

Table 6.
Altitude reported by Parallax.

Static measurements	At 148 masl	At 272 masl
1	149.3	273.3
2	149.1	272.9
3	148.3	272.7
4	148.5	273.1
5	150.1	272.9
6	148.4	273.5
7	150.1	273.4
8	149.9	272.8
9	147.4	273.9
10	147.3	273.1

Source: [21].

Table 7.
Central tendency statistics.

		Measurement at 148 masl	Measurement at 272 masl
N	Valid	10	10
	lost	0	0
Average		148.840	273.1600
Standard error in measurements		0.3270	0.11662
Median		148.800	273.1000
Mode		150.1	272.90[a]
Standard deviation		1.0341	0.36878
variance		1.069	0.136
Minimum		147.3	272.70
Maximum		150.1	273.90
a. There are multiple modes. The smallest value is displayed			

Source: [21].

Table 8.
Descriptive statistics for static measurements at different heights.

	N	Minimum	Maximum	Average	
	Statistical	Statistical	Statistical	Statistical	Standard error
Measurement at 148 masl	10	147.3	150.1	148.840	0.3270
Measurement at 272 masl	10	272.70	273.90	273.160	0.11662
Valid N (per list)	10				

Source: [21].

Table 9.
Estadísticos descriptivos para mediciones estáticas a diferentes alturas.

	Standard deviation	Asymmetry		Kurtosis	
	Statistical	Statistical	Standard error	Statistical	Standard error
Measurement at 148 masl	1.0341	–0.203	0.687	–1.207	1.334
Measurement at 272 masl	0.36878	0.780	0.687	0.235	1.334

Fuente: [21].

The use of standardized references makes it possible to compare the accuracy of the measurements not only against other commercial brands, but also against manual measurements with traditional instruments such as theodolites and altimeters.

Standard error per measurement results ranges from 0.1162 to 0.3270. Likewise, a better grouping of the data is observed in the second measurement than in the first, according to the central tendency statistics. The standard error allows establishing the accuracy of the altitude measurement for the GPS Receiver Module, resulting in an approximate of +/– 1.334 meters above sea level.

VI. Conclusions

The topographic data collection system using the Parallax GPS receiver module was achieved by establishing the raw receiver operating mode, allowing the data to be sent instantly and constantly without the need to send commands to the GPS for communication, which allowed the data acquisition, with temporary storage of the information through a graphical interface, sending the data through the PIC18F458 microcontroller, which has an instantaneous data visualization system.

The GPS data exchange protocol supports a transmission speed of 4 800 bps, compatible with that of the PIC18F458 microcontroller and the computer.

Additionally, a voltage regulator was designed that allowed the device to be portable and to be able to take it to any terrestrial surface without the need for the existence of a power supply through the development of the data acquisition module on a printed circuit card.

The developed device allowed data acquisition, with temporary information storage; It has an instant data display system every time the device is turned on, it is necessary to check that the GPS is linked to the satellites before pressing the system reception button.

A topographic data acquisition system was implemented through a global positioning system for the construction of contour lines, and can be used in the field of engineering for the construction of topographic plans [17].

The data collection system can be optimized by incorporating an E-PROM memory for temporary data storage. This system is powered by a battery, which could be discharged before downloading the information in the computer, thus losing the information collected; in addition, the amount of data received by it would increase considerably with the use of E-PROM memories; you could also add an antenna to the GPS receiver to improve its reception; otherwise, make sure to place the data reception module outdoors or with a view of open space so that it can link with the satellites more easily, acquire data from a greater number of satellites and thus reduce the position error.

Every time the device is turned on, it is necessary to check that the GPS is linked to the satellites before pressing the system reception button; additionally, it is necessary to always keep in mind that the transmission speed of 4800 bps must be established so that communication between the PIC and the computer can be carried out effectively, and thus avoid errors in the transfer.

It is highly recommended to carry out device calibration processes with proven altitude sources, to prevent systematic errors that may affect the subsequent use of the data.

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