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Alternative land elevation assessment through mobile GPS-based rover for small-scale rice farm field preparation

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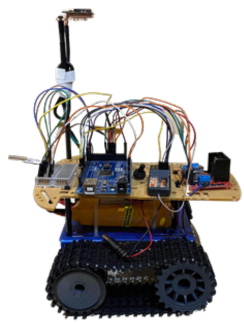
Graphical Abstract



Abstract

One of the many factors that influence rice crop productivity is the field preparation, which includes proper land elevation. Uneven paddy fields cause an uneven distribution of resources, such as irrigation water and fertilizers, lowering crop yields. To remedy the problem, land leveling methods are used to level the crop fields. They involve the use of tools and equipment created specifically for this purpose. These methods are used to determine the difference in field elevations and where the soil should be cut and filled. Small-scale farms, on the other hand, do not employ the specified land leveling method due to a lack of funding and essential equipment, the practicality of usage in large-scale areas, and the time-consuming and labor-intensive operation. This study describes a GPS-based system that is integrated into a rover and controlled remotely to calculate the high and low areas of the ground to determine where to cut and fill the field. The Arduino Microcontroller, Radio Frequency Modules, and Global Positioning System (GPS) module will be the main components of the GPS-based system. The GPS module is utilized to provide the prototype rover's exact location, including latitude, longitude, and altitude. These coordinates are used to derive the rover's elevation data in its current location. This knowledge is used to decide where to cut or fill in the ground of small-scale farms. In comparison to Laser Topographic Surveying, the GPS-based system developed provided reasonable vertical precision with elevation errors of 0 to 10 cm. The findings suggest that a GPS-based system is adequate for land-level assessment tasks and that it may be utilized as a substitute for Cut-and-Fill mapping.

Keywords: land elevation; small-scale farms; GPS-based system; cut-and-fill map

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Introduction

Agriculture is a major contributor to the Philippines' economy. The Philippines has established itself as a major distributor of agricultural products [1]. Rice is the most significant crop in the country. In terms of crop yield, it contributes to 20% of Gross Value Added (GVA) in the Philippines. However, the Philippines, like many other neighboring countries, has seen a surge in demand for agricultural goods due to population growth. With this, the country's agricultural productivity is currently falling. In 2019 and 2020, the overall yield percentage for rice grain or palay declined by about 1.3 and 1.4 percent, respectively. This is produced in irrigated lands, which account for approximately 76 percent of the palay, with rainfed areas accounting for the remaining 23.1 percent. For production to rise, small farmer efficiencies must be increased as a goal [2].

Several farming machines that have been already put into practice, such as hand tractors, rice threshers, etc., are used to improve the ways of the traditional method in increasing yield production. However, the use of manpower is still present in these types of operations [3]. As of today's technology, advances, so as the agricultural equipment that is used in agriculture sectors, this pushes the development of farming robots which when utilized reduces the manpower needed in farming and produces faster and more efficient work to increase the yield production [4]. The majority of produced agricultural robots are primarily focused on enhancing harvest, improving soil or plant health, and better utilizing these robots to improve precision and crop productivity. However, these are not the only options for crop management. Several rovers have been designed to aid precision farming, but land elevation assessment is not a feature that is prioritized in commercialized rovers, even though it is an important aspect in crop management and production. Crop management relies heavily on land leveling as well. This is a requirement for rice farmland preparation, which is a key component of increased yields [5].

An effective land leveling system is critical for improving water coverage, crop development, and weed control. With this in place, water is used efficiently, and a healthy crop is uniformly grown. As a result, crop management workload is decreased and yields are increased [6,7]. A method called topographic surveying is conducted. It is a technique for determining land elevation that is simply the recording of coordinates and height data for a particular survey area. This information can be used to build detailed terrain models of the area that was surveyed [8]. Tractor-drawn levelers are one of the most regularly utilized methods for land leveling techniques. It uses information from the irrigation period to calculate the land areas to be leveled, while the uneven distribution of water determines the land areas to be leveled [9]. The laser land leveling system is a resource-conservation approach for agriculture that has already been utilized for precision field leveling. It is one of the most established methods for using technology for land leveling. This regulates the amount of soil to cut or fill in the case of laser land leveling. On the other hand, this technique is said to be suitable for large-scale farming. The effectiveness and precision of the laser leveling system are also directly influenced by the location of the attached laser transmitter. Furthermore, this is a complicated system that relies largely on labor [10].

There are digital topographic surveys using various sensors and systems, although these approaches are said to be best employed on large-scale maps. Most of the studies use a contour method to create topographic maps, which isn't suitable for assessing small farm fields because it can obscure some characteristics. Moreover, the data processing carried out by the approaches is time-consuming because it necessitates complex execution that is largely reliant on expert field operators, making it impractical for farmers [11,12,13].

Introducing different alternatives that function in the same way as laser land leveling but with less complexity and cost could be a huge help in speeding up the agricultural process. Agriculture in the Philippines might benefit from developments like these that make farming easier and help increase crop yield. Furthermore, because the components utilized can be integrated with other emerging technologies and modified in terms of specifications depending on their kind, these technologies have the potential to improve even further.

Materials and methods

Development of Prototype. Figure 1 shows the overall circuit design of the GPS-based remote-controlled rover. A rechargeable 11.1-volt lithium-ion polymer battery was employed in this design. The L298N motor driver was linked to the positive and negative terminals, with a toggle switch in between. The Arduino Mega 2560 microcontroller, which can accept a voltage between 7 and 12 volts, was connected to the battery via a tapped connection. The Arduino Mega microcontroller's ground pin was connected to the motor driver's ground terminal. The motor driver's output terminals were connected to the input terminals of the left and right DC geared motors. The motor driver's signal pins can be linked to the input and output terminals of Arduino Mega using the connections. The receiver and transmitter are the sensors that were used to give radio or remote control of the rover. The steering, and throttle, channels on the receiver were programmed to fulfill their specialized tasks. For the GPS and Radio Frequency Modules, the transmitter and receiver pins were connected to the serial connection pins of the Arduino Mega, while the ground and enable pins were connected to the power pins of the Arduino Mega Microcontroller. Initially, the latitude, longitude, and altitude data gathered by the GPS receiver was extracted using the TinyGPS++ library. The GPS raw data were gathered using an Arduino program where the data produced by the GPS receiver over a serial interface are National Marine Electronics Association (NMEA) sentences, which is the standard message format of GPS receivers. The data gathered are acquired using its default baud rate which is 9600. Several sentences were produced in the NMEA standard, however, in this study, coordinates were extracted in the $GPGGA sentence as it provides essential fixed data providing 3D locations including latitude, longitude, and altitude.

The rover designed will only be subjected to the assessment of the field in terms of topographic elevation measures and not in field leveling applications directly. Moreover, this will only provide elevation data, that is measured in meters, with respect to a particular reference level, and will not calculate the amount of soil to be cut or filled. With regards to actual field deployments, the study focuses primarily on elevation data where the collection will only be conducted on a clear weather conditions and dry terrain only.

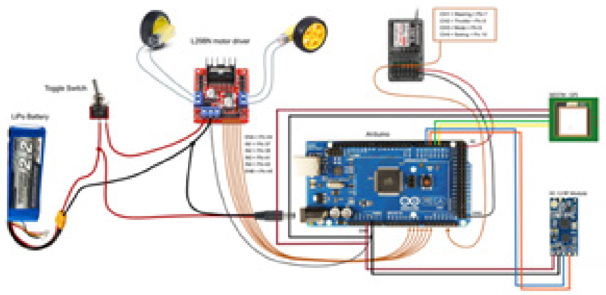

Figure 1. Circuit Diagram of Remote-Controlled System.

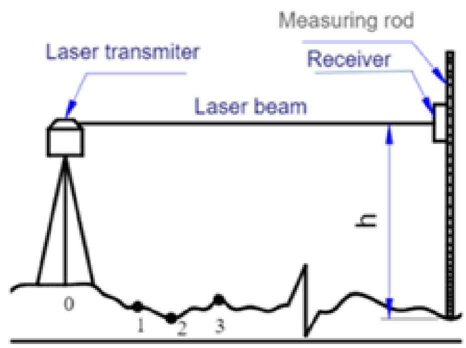

Figure 2. Sample setup of Laser Topographic Survey Method [14]

Vertical Height Acquisition. Initially, a plan of the field to be surveyed was conducted. The vertical data of the GPS and Laser Topographic Survey were tested in 12 pre-determined data points situated in the area to be surveyed.

Laser Topographic Survey is the most established method of land level assessment conventionally. This equipment was utilized to determine differences in field elevations and an initial operation before the laser land leveling operation. It was done by setting up the tripod on the side of the field attached with a laser transmitter; the sample of the setup can be seen in Figure 2. The laser beam pointed at the measuring rod, which is located at the center of each cell in the grid, determines the height of the ground in uniform grid points of the field [14].

As observed in Figure 3, the elevation data of the Laser Topographic Survey were tested initially following pre-determined points within five (5) meters distance from each other, making the grid, in the field as the distance between the points were referenced to the size of the field to be surveyed. With that, the GPS-based system also utilized the said pre-determined points for comparison. The twelve (12) height data points gathered from both methods, which were located at the center of each cell in the grid, represent the height of the ground within each respective cell. The specified number of data points was selected to maximize the whole area to be surveyed.

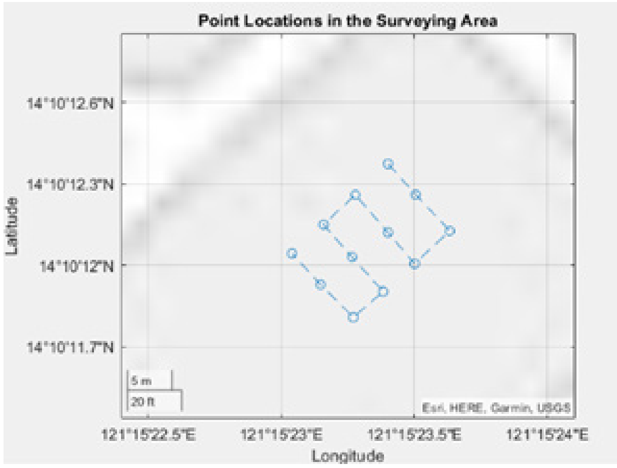

Figure 3. Point Locations in the Area to be Surveyed.

Moreover, to compare the two methods, the behavior of each data was obtained through a line graph. This will serve as the initial data points for determining the cut or fill areas while calculating the error between two sets of data.

Computation of Cut and Fill Information. Cut and fill information was utilized to provide precise ground elevation. This outputs a vertical data of each grid that will identify areas of high and low points based on a reference level. With the data collected, a computation of cut and fill information was conducted to test the GPS-based prototype's capability to what is conventionally practiced in determining land level information.

The mean was obtained using the elevation values of the 12 data points gathered from each method. This will be the reference height to obtain the cut or fill data of each point to calculate the difference between the identified points and the reference level applied in the two methods.

$$Mean = \frac{A+B+C+\cdots.+L}{12} \tag{1}$$

With the elevation data provided, as well as the mean or the reference level for the two methods, the cut or fill data between the identified points were acquired using the said variables. The gathered mean from the 12 elevation data points was subtracted from each of the elevation values as seen in the equation below, which will identify areas of cut and fill. This was done for both methods.

$$H = h_m - h_i \tag{2}$$

Where:
h_m = average height of measured points
h_i = heights of all measured points

Data Analysis. To further obtain the accuracy of the GPS-based system in cut and fill applications, the two methods were compared, and the error was calculated at each point.

$$Error\ (m) = \ |Theoretical\ (m) - Experimental\ (m)| \qquad (3)$$

Where:
Theoretical (m) = Elevation value of Laser Topographic Survey
Experimental (m) = Elevation value of GPS-based System

The error, in meters, was computed by getting the absolute difference between the theoretical and experimental values.

Results and Discussion

Overall Design of the Prototype. Figure 4 shows the overall design of the rover. The whole robotic system was divided into four parts, that is; drive system, control system, power supply system, and sensor system. The drive system is the one that runs the rover. Moreover, the control system is responsible for receiving and processing signals from the sensors and giving signals to the actuators. Also, the one that gives voltage and current to the rover is the power supply system. Lastly, the sensor system is done by connecting the GPS module to the Microcontroller and through RF modules for data transmission.

Elevation of Data Points. The study utilized a grid system method that divides the area to be surveyed in pre-determined number of grids. Thus, the points were assigned at the center of each grid. The center of each grid was assumed to be the height of that grid. A single measured value for each grid is sufficient to represent the height of the grid, as it was based on the process of the conventional technique of surveying.

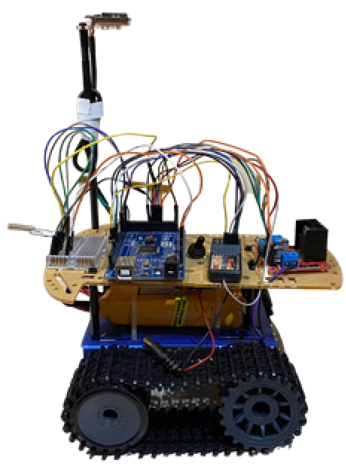

Figure 4. Overall Design of the Prototype

Table 1 shows the numerical elevation data points from the 12 predetermined points by using both Laser Topographic and GPS-based system methods. Both data sets were obtained with a metric in meters. As observed, the Laser Topographic Survey method produced negative values as the method's vertical magnitude is based on the transmitter equipment, which in the conducted data gathering, the transmitter is higher than the ground. On the other hand, GPS-based system produced positive values around 61 meters as it is extracted in the $GPGGA sentence, where altitude was based on the mean sea level.

Table 1. Elevation of Data Points Using Laser Topographic and GPS-based System Methods

Points (Center of each cell)	Elevation from Laser Topographic Survey m	Elevation from GPS-based System m
A	-1.92	61.62
B	-1.97	61.56
C	-2.07	61.51
D	-2.03	61.49
E	-1.93	61.50
F	-1.82	61.70
G	-1.81	61.72
H	-1.86	61.68
I	-2.00	61.54
J	-2.06	61.49
K	-1.80	61.73
L	-1.75	61.77
Mean	-1.92	61.61

Table 2 and Table 3 show the grid layout provided the height in each grid. For the conventional method, Laser Topographic Survey, a -1.92 m of mean was obtained. On the other hand, the GPS-based system method produces a mean of 61.61. The mean was obtained using the elevation values of the 12 data points gathered from each method. This will be the reference height to obtain the cut or fill data of each grid. The cut or fill data was attained by calculating the difference between the identified points and the reference level applied in the two methods shown in Table 4.

Table 2. Elevation Measurements From Laser Topographic Survey

-1.75	-1.81	-1.82	-1.92
-1.80	-1.86	-1.93	-1.97
-2.06	-2.00	-2.03	-2.07

Table 3. Elevation Measurements From the Developed GPS-based System

61.77	61.72	61.70	61.62
61.73	61.68	61.50	61.56
61.49	61.54	61.49	61.51

The line graph, as observed in Figures 5 and 6, shows the trend of elevation data gathered from the two methods at each point. As observed, the trend of the two graphs is almost similar making the vertical behavior of the GPS-based method similar to the Laser topographic survey. The cut or fill data between the indicated points was obtained using the elevation data as well as the mean or reference level for the two methods. High positions are referred to as Cut, whereas low positions are referred to as Fill.

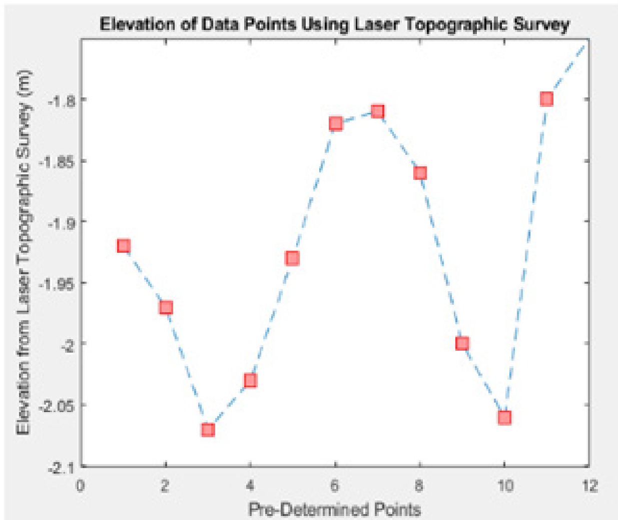

Figure 5. Line Graph of Elevation Points Using Laser Topographic Survey

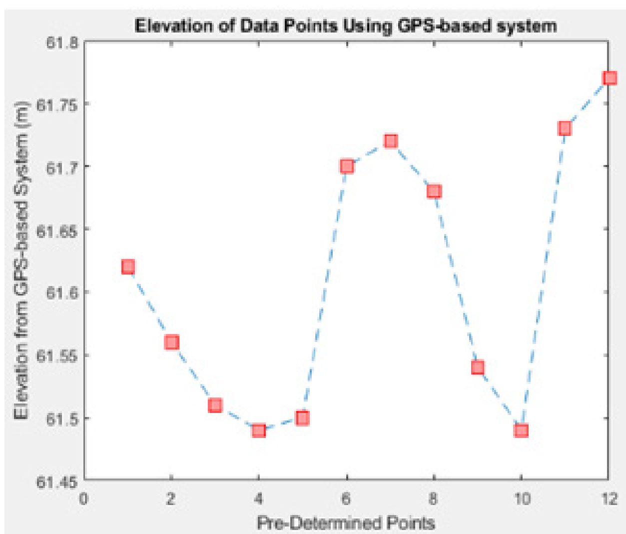

Figure 6. Line Graph of Elevation Points Using GPS-based System

Cut and Fill Data Acquisition. The cut or fill data between the indicated points was obtained using the elevation data as well as the mean or reference level for the two methods. High positions are referred to as Cut, whereas low positions are referred to as Fill.

Table 4. Cut and Fill Data Calculation for Conventional and GPS-based System Methods

Points (Center of each cell)	Elevation from Laser Topographic Survey m	Elevation from GPS-based System m	Error -
Mean	-1.92	61.61	-
A	0.00	-0.01	0.01
B	0.05	0.05	0.00
C	0.15	0.10	0.05
D	0.11	0.12	0.01
E	0.01	0.11	0.10
F	-0.1	-0.09	0.01
G	-0.11	-0.11	0.00
H	-0.06	-0.07	0.01
I	0.08	0.07	0.01
J	0.14	0.12	0.02
K	-0.12	-0.12	0.00
L	-0.17	-0.16	0.01

It can be observed that both methods similarly describe a certain point if the area is recognized to be cut or fill. To further distinguish the difference between the theoretical and experimental elevation values, the group computed the error between the two methods at each point as shown in Table 4. The largest error was situated in point E having a 0.10 m or 10 centimeters of error. However, the elevation error in other points has a lower value. In points B, G, and K, the elevation error gathered was 0, obtaining no difference in the said points between the two methods.

Table 5. Cut and Fill Data Map Using Laser Topographic Survey Method

-0.17	-0.11	-0.10	0.00
-0.12	-0.06	0.01	0.05
0.14	0.08	0.11	0.15

Table 6. Cut and Fill Data Map Using the Developed GPS-based System Method

-0.16	-0.11	-0.09	-0.01
-0.12	-0.07	0.11	0.05
0.12	0.07	0.12	0.10

As observed in the grid layout in Tables 5 and Table 6, the cut and fill characteristic of each cell is almost identical for the two methods. The Cut (-) refers to high positions, while Fill (+) refers to low positions. It can be identified that both methods similarly describe a certain point if the area is recognized to be cut or filled.

Provided below is a line chart to further compare the accuracy of the GPS-based system results. Large differences between Laser Topographic Survey and GPS-based system occurred at points 3 and 5. Possible factors that affect the GPS reading could be owing to signal interference and satellite position when the rover passed through those points [15]. An overlapped line at some points, including points 2, 7, and 11, is apparent.

It can be expressed that the two sets of data are quite close to each other. The results clearly indicate that a GPS-based system can deliver elevation with centimeter-level accuracy, providing an accuracy of 0-10 centimeters in the measurement of elevation. With reference to studies, this provides a reasonable accuracy given the lower initial equipment cost [15,16]. With that, the concept of using a GPS-based system can be applied in GUI for land level assessment.

Conclusion

Poorly leveled rice fields result in an unequal distribution of resources such as irrigation water and fertilizers, resulting in inferior crop yields. Although conventional methods are primarily used in land level assessment operations, small-scale farms, on the other hand, does not implement this method due to several reasons, making it not compatible with small-scale farms. Thus, this study introduces a GPS-based system remote-controlled rover for an alternative land level assessment method. The vertical data of the GPS were tested in 12 predetermined data points situated in the area to be surveyed. The distance between each point was set at approximately five (5) meters apart. These data points represent the center of a cell that would make the grid to obtain the cut and fill areas. The gathered height data of the GPS was analyzed in comparison to the acquired data points from the conventional method using Laser Topographic Surveying Equipment. Based on the results, a GPS-based system may be an alternative in the land-level assessment of rice fields. When compared to Laser Topographic Surveying, the GPS-based system created, provided reasonable vertical accuracy with an elevation error on the order of 0 to 10 centimeters. Thus, it can offer elevation with centimeter-level accuracy. The findings show that a GPS-based system is sufficient for land-level assessment activities and that it may be used as an alternative approach for creating Cut-and-Fill maps for small-scale rice farm fields.

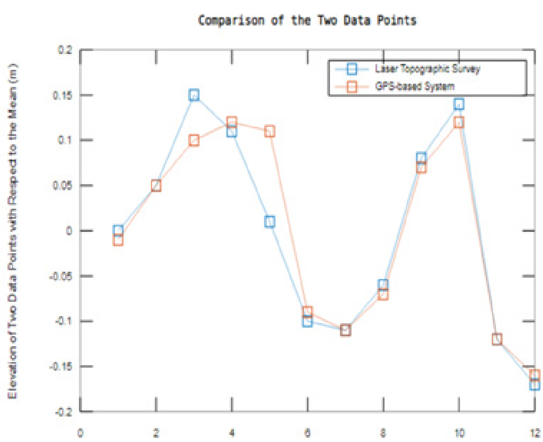

Figure 7. Line Chart of the Two Data Sets

To further improve the desired accuracy of vertical data of the GPS-based system rover, the distances between each pre-determined data points may be shortened to maximize differences in altitude of the area coverage to be tested. Also, using RTK-GPS and the integration of additional measuring components such as digital compass and Inertial Measuring Unit (IMU) can be considered to further enhance the accuracy in data gathering. With regards to the mechanical part of the rover, the different types of soil may be considered for its mobility. Since the study was conducted on a dry field only, improvements to the rover's engine and wheel may be introduced to withstand different types of soil in data collection. Also, since the rover is powered by a battery, it is recommended to perform a battery test in terms of area coverage to determine the rover's longevity upon utilization. Moreover, future development might include a solar-powered rover to further promote sustainability in small-scale farms. Also, autonomous navigation may also be recommended to fully address labor in operation. Lastly, an improvement on GUI's interface may be developed for better visualization and more suitable for future users. It is also recommended to evaluate the GUI to promote a less complex GUI operation.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, M. Bautista and A. Bautista; methodology, C. Abante; data collection, M. Bautista and A. Bautista; analysis and interpretation of data, C. Abante, R. Balerite and A. Cariño; MATLAB executions, A. Cariño; Python program, A. Malabanan and A. Fong; prototyping, R. Balerite and A. Malabanan.

All authors have read and agreed to the final version of the manuscript.

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