UTILIZING LIGHT DETECTION AND RANGING TECHNOLOGY FOR WATERSHED DELINEATION AND MAPPING OF PHILIPPINE HYDROLOGIC DATASETS IN QUEZON WITH DEPTH VALIDATION USING UTRASOONIC SENSOR AND MOBILE APPLICATION

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ABSTRACT: Addressing the problems arising from poor flood management and water budgeting, as well as from the outdated map of watershed features, this paper introduces the development of a map showing the stream and drainage networks, irrigation systems, and inland wetlands located in the province of Quezon in Philippines. The development of a mapping hydrological features such as streams, inland wetlands, as well as irrigation using commercial software. The study performed standard processes of automated delineation of features using 1 meter by 1 meter-size LiDAR Digital Elevation Model, manual intervention is performed preventing the complexity of the sub-components of the image processing, and reducing the personal errors that may be committed along the process. The developed map is tested to be accurate through performing ground truth. In as much as irrigation system are concerned, the created maps yielded 97.47% for completeness, 96.25% for correctness, and 93.90% for quality. On the other hand, the map for inland wetlands has shown 93.83% completeness, 95.00% correctness, and 88.37% quality. Lastly, for streams and drainage systems, the accuracy assessment gave values of 96.15% for completeness, 93.75% for correctness, and 90.36% for quality. In addition, a depth finder system developed using MB7386 HRXL ultrasonic sensor is used to investigate on the levels of water depth correlating the depth acquired using LiDAR data. Regression analysis was used in order to obtain a relationship between the predictor and response variable. The depth finder developed system was calibrated and found to be working successfully under water at different turbidities as the results show a little difference as compared with the actual depth measurements. The uncertainties of the device for each component above are 0.013 m, 0.046 m, and 0.031 respectively.

1. INTRODUCTION

Watersheds are one of the most crucial hydrologic entities that play a major role in the industrial, agricultural, and domestic needs of the people (O'Keefe, Thomas C.; Elliott, Scott R.; Naiman , Robert J.;, 2017). Urban areas are congested and highly populated which became vulnerable when a disaster strikes. Depending on the intensity, any kind of natural disaster like earthquake and flood, can damage the whole city or to some extent. To avoid mass casualty and major damage of properties, disaster monitoring and management plays a critical role. In this regard, this research has come up with an idea of utilizing the data coming from Light Detection and Ranging (LiDAR) Technology in developing and extracting a map of hydrologic datasets for stream and drainage basins, wetlands and irrigation networks within the delineated watersheds here in the Philippines. On the other hand, since the design of the LULC is fast paced. Hence, the previous outline of the resources is soon become outdated. Furthermore, the research has validated the generated result from the machine analysis and validated using ground truth.

This paper mainly aims to develop a map by utilizing LiDAR technology for watersheds in Quezon province particularly in Bolbok and Malaking Ilog. Specifically, it aims to (1) delineate all three subcomponents of PHD which include the irrigation networks, inland wetlands and stream and drainage system using ArcMap 10.2 and Google Earth Pro; (2) provide accuracy assessment by verifying and comparing the generated map which shows the extracted features of irrigation networks, inland wetlands and stream and drainage system with the actual site of watersheds in Bolbok and Malaking Ilog; (3) design a depth finder integrated with ultrasonic sensor and mobile application to measure water depths at different watershed and assess the accuracy of the developed depth finder device using statistical tool. With this study, the water budget for certain communities can be ensured, as well as the quality of the water supply for them (Lopes, Thomas J.; Smith, J LaRue;, 2016). Moreover, the irrigation systems for rice fields, farms, and other agricultural stakeholders can also be regulated. The present study is focused on the inland wetland, drainage basins and streams, and irrigation networks found in the province of Quezon. In as much as the depth finder device is concerned, the ultrasonic sensor used can only detect from 0.5 meters to 10 meters in air and its measurements under water can be easily influenced by interference in water (MaxBotix Inc., 2012). Finally, actual testing of the device prototype must be done in a clearer watershed for more accurate results.

2. RELATED WORKS

In comparison with this paper, many researches address the mapping of river basins as well as the use of ultrasonic sensor in as the measuring sensor for water depths. Consequently, presented below are the related researches for these two categories.

2.1. Watershed Map Delineation

The use of LiDAR as the remote sensing technology for mapping resources has been widely used specifically in delineating river networks. LiDAR is a type of optical locator that has the capability of measuring hydro-optical parameters and it can quantify biological resources. According to National Oceanic and Atmospheric Administration (NOAA), the bathymetric LiDAR is used in determining water depth with the use of time delay between the transmitted pulse and its returned signal. There are two laser pulses used in this system. The lower frequency infrared pulse reflects off, the surface whilst a higher frequency green laser can penetrate through the water and reflects off the bottom. By analyzing these two pulses, the depth of the water as well as the shoreline elevations can be calculated. With good clarity of water, the system can reach depths up to 50 meters (NOAA, 2016). In addition, a design called Ship Lidar “Gidrobiont” (SLG) aims to solve problems regarding ocean logical monitoring. When it was subjected to a marine test with a controlled environment it came up with a conclusion that with the LiDAR data, different mathematical methods can be derived to come up for a specific medium characteristic (Goryainov, Buznikov, Chernook, Vasilyev, & Goldin, 2016). In a study conducted by Shilpi, et. al (2014), the river network of Gomati basin was identified with the use of GIS (Geographical Information System) and remote sensing. To come up with the extracted drainage and stream or river network of Gomati basin, ArcGIS was used (Shilpi, Singh, & Maurya, 2014). In contrast, in a study conducted by Maderal (2016), network extraction from LiDAR data was automatically performed with different methodology (Maderal, Valcarcel, Delgado, Sevilla, & Ojeda, 2016).

2.2. Ultrasonic Sensor for Depth Finder System

According to University of Rhode Islands (2016), in as much as the application of ultrasonic sensor under water is concerned, there are three factors to be considered. First, the speed of sound in water increases with increasing water temperature. The speed of sound can vary up to 4.0 m/s with a one centigrade change in temperature. Next is the salinity of the water which makes the speed of sound 1.4 m/s faster with an increase of 1 PSU (Practical Salinity Unit) in its value. Finally, an increase in depth (pressure) of 1 km makes the speed of sound under water to be 17 m/s faster (Univeristy of Rhode Island, 2017). In a related research conducted by McArthur, MB7062 ultrasonic sensor was used in sonar obstacle detection system. In his research, a multiplier was used as a compensation for the distance in the velocity of sound under water. He based the velocities of the sound at a temperature of 25ºC. The testing proved to be able to detect obstacles near the remotely operated underwater vehicles (ROVs) with the use of LEDs. However, in this research, the salinity and water temperature at the time of testing were unknown; hence, can be the source of uncertainty of the device (Sonar obstacle detection system for underwater rovs PDF, ePub eBook, 2016).

3. METHODOLOGY

3.1. Extraction of Hydrological Components

For extraction and compilation of irrigation networks, streams and drainage, pre-processing were initially performed. In as much as pre-processing is involved, the Digital Terrain Model (DTM) was reconditioning by calculating the possible sink. A sink is a cell where there is no adjacent cell is lower.

3.1.1. Irrigation Networks

For the extraction of irrigation features, Map Gully Depth (MGD) tool using Whitebox was primary used to map the gullies from the DTM. See Fig. 1. The calculation of the gullies is based from the primary parameters such as: maximum gully width, minimum and maximum gully depths, threshold in difference of mean elevation (DFME). The values of the raster to produce are always positive since the MGD provides depth measurement. The higher the value, the deeper the depression, the more like to be a gully. This will be the basis of the digitization / extraction of the irrigation.

3.1.2. Stream Delineation

The delineation of stream line was processed using archydro tools to calculate the cells contributing accumulation to the next lower cell based from the direction of the flow
Processing started with the fill sink method which enabled the flow direction to ensure that no gap would exist in the data which might affect the output process. Flow accumulation was then implemented which allowed us to identify the stream channels through the cells with concentrated values. After identification, the stream networks were separated from other features in the flow accumulation raster. Drainage line processing was done in order to convert the stream definition raster into a polyline feature. During this process, drainage line points can now be obtained which would be used in watershed delineation. When done with the processing, refinement and digitization of the map were executed in order to correct the slight errors during the stream extraction process. The data was further refined in order to improve its quality.

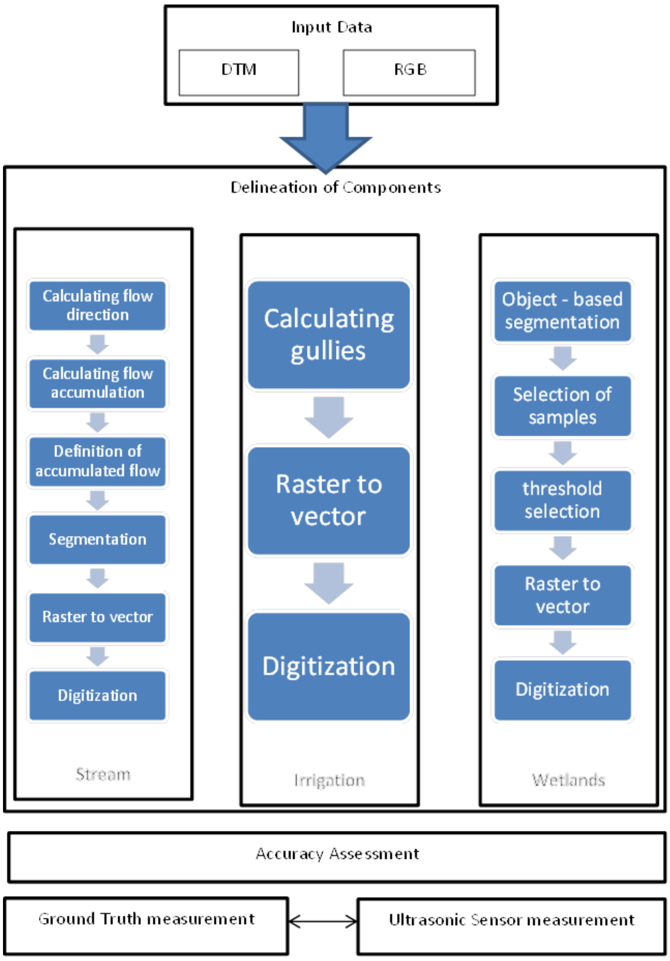


Figure 1. General Workflow

3.1.3. Wetlands

Inland wetlands boundaries were determined through the use of Object-Based Image Analysis (OBIA) technique in which it was executed to extract the data gathered utilizing image analysis software, namely eCognition. Moreover, the process of extraction of inland wetlands in OBIA involves the segmentation and classification based from the threshold value of elevation. The first step of OBIA was segmentation in which the contiguous image pixels were combined based on its features such as textural, spectral and dimension characteristics resulting to an image object. Aside from reduction of heterogeneity, MRS was also used to weight each layer depending on the level of their importance. The elevation and spectral character layers have an equal weight of 1 in this process. However, Near-infrared layers (NIR) have a weight of 2 which has a higher degree of significance compared to the other layers because the bodies of water is distinguished in this part (David, Sarte, Pula, & Ballado, 2016).

After the process of segmentation, the next step was to select samples and determine manually whether the selected sample is classified as wetland or not. In selection of samples, the sample must agree with the two classifications: it must be located in the area of an inland wetland and have a deep and shallow surface. With the help of Separability and Threshold analysis, the best separability in each object based on the calculation of its threshold statistically was automatically given. The measurement of separability of an object is employed by distance (J) which ranges from 0 to 2; the higher the distance means the higher separability it has. Upon the classification of the entire image, eCognition software automatically identified the image objects based on the calculated threshold and training set.

3.2. Accuracy Assessment

Before using it for its designated purpose, a map's reliability is tested through an accuracy assessment. For irrigation systems, three quality metrics are being calculated namely – completeness, correctness and quality. This accuracy assessment is done once the features have been extracted and digitized. The metrics are based on the following length measurements: true positive (TP), false positive (FP), and false negative (FN). The formulas are shown below:

$$completeness = \frac{TP}{TP+FN} \tag{1}$$

$$correctness = \frac{TP}{TP+FP} \tag{2}$$

$$quality = \frac{TP}{TP+FN+FP} \tag{3}$$

Completeness can be defined as the ratio of true positive or those correctly identified stream to the sum of correctly identified and incorrectly rejected stream. Correctness, which is also called as precision, is the ratio of the number of correctly identified watersheds to the total number of correctly and incorrectly identified watersheds. Lastly, quality is defined as the ratio of the number of correctly identified watersheds to the total number of correctly and incorrectly identified, as well as the incorrectly rejected watersheds (Tiwari & Pande, 2016).

Table 1. Confusion Matrix

		reference				
extracted		Wetland	Stream	Irrigation	Nonwater	UA
	Wetland	76	2	1	1	95%
	Stream	3	75	1	1	93%
	Irrigation	2	1	77	0	96.25%
	Nonwater	1	0	0	79	98.75%
	PA	92.69%	96.16%	97.47%	97.54%	95.94%

Table 1 shows the overall confusion matrix for all the hydrologic datasets that were extracted. According to the table, the extracted wetlands, streams, irrigation systems and nonwater systems had a producer's accuracy of 92.69%, 96.16%, 97.47%, and 97.54% respectively while the user's accuracy is 95%, 93.75%, 96.25%, and 98.75% respectively. This led us to an overall map accuracy of 95.94% which is greater than 80% ensuring that the created map is of good quality.

3.3. Depth Finder System

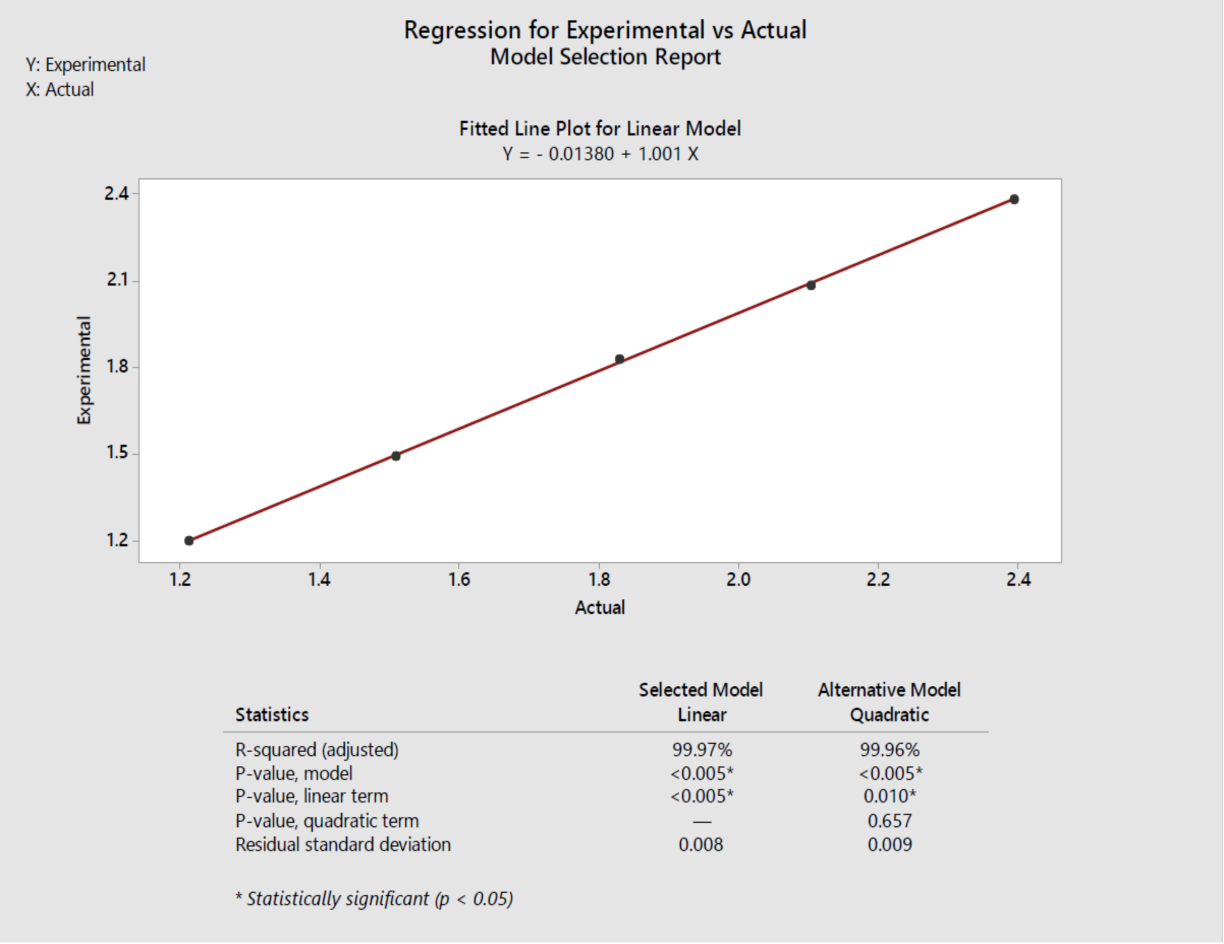
3.3.1. Calibration

The measured distances acquired by using the MB7386 HRXL ultrasonic sensor need to be initially calibrated due to certain variables such as the speed of sound in water and the potential error in the circuitry of MB7386 sensor. Since the sensor is calibrated to measure distance in air, a multiplier was applied to compensate for the difference in the velocities of sound in air and under water. As such, the speed of sound in air was divided by the speed of sound under water at 25°C. Mathematically, the multiplier equals 346.13 meters per second divided by 1497 meters per second resulting to 0.23. This multiplier was applied to the code and the sensor was tested for calibration.

In the calibration process, the sensor was used to measure different data points at varying distances. The location of the testing was held at Bolbok river system with varying depths of four to eight feet (1.22 to 2.44 meters). As expected, the recorded measurements of depth using the sensor have different values as compared with the actual measurements of the depth of the study area. The scaling factor which was computed to be 1.6963 was incorporated into the code in order to adjust the values of the experimental values closer to the actual values.

3.3.2. Experiment

Regression analysis was used in order to obtain a relationship between the predictor and response variables. In this case, the predictor variable which is also the independent variable is represented by the actual measurements whilst the response variable is denoted by the experimental values with the use of the depth finder. The data from the table above were used to obtain an equation for the linear regression and with the use of MiniTab software, the graph of the linear equation was generated.



Statistics	Selected Model Linear	Alternative Model Quadratic
R-squared (adjusted)	99.97%	99.96%
P-value, model	<0.005*	<0.005*
P-value, linear term	<0.005*	0.010*
P-value, quadratic term	—	0.657
Residual standard deviation	0.008	0.009

Figure 2. Linear Regression of Ground Truth and Depth Finder

Based on the graph generated, the equation for the linear regression is:

$$y = 1.001x - 0.01380 \qquad (4)$$

In which x represents the actual depth of the area and y is the experimental depth. The ideal equation for measuring the depth of the area should be y=x, wherein the values of the depth measurements of the sensor match the values of the actual depth measurements. Furthermore, the slope of this ideal measuring system is 1.0. In contrast, it can be noticed that the linear regression equation based on the data gathered gives a slope of 1.001, a value almost equal to 1.0. Figure 2 shows the linear regression between the actual and experimental depth measurements and the depth finder device, respectively.

3.3.3. Actual Testing of the Device on Irrigation Networks, Inland Wetlands, and Streams and Drainage Systems

Tables 2, 3 and 4 show the comparison of depth measurements between the depth finder system and actual measurements on irrigation networks, inland wetlands, and streams and drainage systems, respectively.

Table 2: Comparison of Depth Measurements between Depth Finder System and Ground Truth on Irrigation Network

Sample	Depth Finder Measurements (m)	Actual Measurements (m)
1	0.23	0.25
2	0.25	0.25
3	0.27	0.25
4	0.23	0.25
5	0.20	0.25
6	0.32	0.30
7	0.28	0.30
8	0.27	0.30
9	0.31	0.30
10	0.26	0.30
Mean	0.2620	0.2750

Table 3: Comparison of Depth Measurements between Depth Finder System and Ground Truth on Inland Wetlands

Sample	Depth Finder Measurements (m)	Actual Measurements (m)
1	0.68	0.72
2	0.71	0.72
3	0.67	0.72
4	0.98	1.06
5	1.02	1.06
6	1.00	1.06
7	0.52	0.58
8	0.54	0.58
9	0.53	0.58
10	0.55	0.58
Mean	0.720	0.766

Table 4: Comparison of Depth Measurements between Depth Finder System and Ground Truth on Streams and Drainage

Sample	Depth Finder Measurements (m)	Actual Measurements (m)
1	0.37	0.37
2	0.33	0.37
3	0.38	0.37
4	1.20	1.25
5	1.22	1.25
6	1.23	1.25
7	1.56	1.60
8	1.54	1.60
9	1.55	1.60
10	1.57	1.60
Mean	1.095	1.126

Variance was used to determine if there is significant difference between the means of the actual and experimental values of depth measurements using measuring tape and ultrasonic sensor, respectively. A 2-sample t-test or independent t-test was used for the reason that the two samples of data were not related. This test only tells how close with each other the values measured using different approach.

The hypotheses are given as follows:

Null Hypothesis (H_0): (There is no significant difference between the measurements of actual depth of the study area and the experimental values respectively).
Alternative Hypothesis (H_1): (There is a significant difference between the measurements of actual depth of the area and the experimental values respectively). It can be seen from Table V that for all the subcomponents of Philippine Hydrologic Datasets which are the irrigation networks, inland wetlands, and stream and drainage systems, the $t_{statistical}$is less than the value of $t_{critical}$, arriving at a conclusion of accepting the null hypothesis.

Table 5: Summary of hypothesis testing using 95% Confidence Interval

Watershed	$t_{statistical}$	$t_{critical}$	Conclusion
Irrigation Networks	0.9077	2.120	Accept H_0
Inland wetlands	0.4933	2.110	Accept H_0
Streams and Drainage Systems	0.1292	2.110	Accept H_0

4. DISCUSSION

The results show that for all the three components, the depth finder's measurements have only a little difference with that of the actual measurements. Using independent t-test, the statistical value of t is less than that of the critical value. A conclusion that there is no significant evidence that their means differ at 0.05 level of significance can be drawn.

The uncertainties of the device were calculated by getting the difference between the means of the actual and experimental depth measurements. The difference between the means of actual and experimental measurements for irrigation networks, inland wetlands, and streams and drainage systems are 0.013 m, 0.046 m, and 0.031 m respectively, values that give the uncertainty of the device. These values are small enough and acceptable for the device to be reliable in measuring water depth. Nonetheless, this error of the device might have been contributed by the interference during the testing as well the factors affecting the speed of sound. The value used for the speed of sound in the Arduino program was just an approximation, since the water temperature was not known at the time of testing.

5. CONCLUSION

This paper emphasizes the idea of developing a map showing the different extracted water features of Quezon province with the use of LiDAR technology and data processing software such as ArcMap and Google Earth Pro. In the study, the researchers were able to generate a map successfully containing the delineated watersheds in Quezon Province. Field validations commenced by the researchers verify the enhancement of the developed map showing the watershed features of Quezon province. In as much as irrigation systems are concerned, the created maps yielded 97.47% for completeness, 96.25% for correctness, and 93.90% for quality. On the other hand, the map for inland wetlands has shown 93.83% completeness, 95.00% correctness, and 88.37% quality. Lastly, for streams and drainage systems, the accuracy assessment gave values of 96.15% for completeness, 93.75% for correctness, and 90.36% for quality. The assessment therefore shows that the processed LiDAR data are tested to be accurate in terms of completeness, correctness, and quality. The series of tests conducted both in the controlled and uncontrolled environments have shown a successful depth measurement system that has no significant difference at 0.05 level of significance in comparison with the actual measurement using the measuring tape. The difference between the means of actual and experimental measurements for irrigation networks, inland wetlands, and streams and drainage systems are 0.013 m, 0.046 m, and 0.031 m, respectively. The calculated uncertainties of the device are small enough and acceptable for it to be reliable in measuring depth of watersheds.

6. FUTURE WORKS

This paper has presented a new file format that will speed up the processing of the LiDAR data without any drawbacks in the computation of triangulation. Also, the study proved the identification of possible flooding area can be determined based on its Geographic location. However, there are many factors to be considered when applying the spatial analysis to real world decision-making: type of soil, slope, land use, and the rainfall.

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