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Development of Localized 3D-Printed Ultrasonic Wind Anemometer with Cloud Data Transfer and Storage

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The core aspects to characterize the wind condition of the environment around us are direction and speed, simply the value of velocity. This encourages the researchers to address the lack of locally fabricated ultrasonic anemometers available in the Philippine market. The study develops a locally fabricated ultrasonic wind anemometer that can measure a wide range of wind speeds and determine its direction. The casing of the anemometer will be manufactured using 3D-printing technology and utilize ultrasonic sensors to achieve accuracy and customizability. In this paper, testing has been conducted to test and validate the capability of the ultrasonic anemometer in which the data gathered from these tests will be used to calibrate the system and design of the ultrasonic wind anemometer. The wind speed and direction measured by the ultrasonic anemometer are collected and employed in the cloud for easy access when the data is needed. The developed ultrasonic wind anemometer with cloud data transfer and storage has been fabricated successfully for wind monitoring and the device could be a stand-alone wind measuring instrument or can be integrated within a weather monitoring system. Improving the wind velocity obtained by the localized ultrasonic wind anemometer using other ultrasonic sensors and exploring different microcontrollers may be employed for more testing and validation in the future.

1. Introduction

Over the last decades the strength of typhoons and hurricanes that showed up in the whole world showed increase strength which resulted in higher effects in the countries and communities it swept through. In the study of Pandey and Liou (2022), it showed a 35 % increase in the strength of typhoons that hit Taiwan from 1977 to 2016. According to PAGASA, the number of tropical cyclones that enter the Philippine Area of Responsibility (PAR) has increased compared to other countries with an average of 20 tropical cyclones per year and about 8 or 9 that cross the Philippines. The increase and the constant change of weather conditions pose a problem for daily life activities (PAGASA, 2022). The Philippines, having a lack of modern anemometers, depends on the traditional cup or mechanical anemometer to gather wind data for various purposes like weather forecasting. With wind data being in demand in the present time, there is a need for devices to provide accurate results due to the country being vulnerable to the impacts of climate change (Cabico, 2022). With this in thought a problem in the current state of weather monitoring in the Philippines is seen in which the studies aim to provide a solution to this problem by creating a standalone ultrasonic wind anemometer that can measure high and low wind velocity, be set up in any locations, and is able to be integrated to an existing weather monitoring system.

Mechanical sensors, according to a report by the Institute for Renewable Energy Sources (CRES), need to be reconfigured after 12 mth of field use. The inability to detect abrupt changes is what prompted the National Weather Service (NWS) to switch all of its Automated Surface Observation Systems (ASOS) from mechanical devices to ultrasonic sensors. Nowadays, ultrasonic sensors are weighed as an option for wind profiling because ultrasonic sensors are durable and economically sustainable than mechanical anemometers as it does not have any moving parts (Remington, 2010).

The development of a new product requires testing of the product in terms of performance, strength, and other parameters that is necessary to ensure that the product is working properly and safe. Fabrication of such

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products are time consuming by which normally subtracting manufacturing is employed to create such prototypes and subtracting manufacturing offers little to no design customizations limiting the freedom of researchers to customize. With the rise and advancement of additive manufacturing researchers are now able to customize and create intricate designs on their own and subsequently fabricate it themselves using any of the available additive manufacturing process that exist nowadays (Macdonald et al., 2014).
Currently, researches that use 3D printing in creating anemometers is scarce. Daniel et al. (2020) fabricated a fully 3D printed hot wire anemometer in which is the first demonstration of such feat, and it showed potential but needed more improvement in terms of response time and operation.
The value of an ultrasonic wind anemometer in measuring wind speed is clear in the context of wind energy. Cruzatt Quispe et al. (2022) gathered wind and solar data to properly assess the electricity generation of a wind-solar hybrid system. Also, the amount of wind data scarce data having a limited amount of wind data that can be utilized for wind energy mapping and other related applications requiring wind data (Elliott, 2000). Most testing in the wind energy industry uses measurement methods (sensors, data collection) that are also used in other fields. Ultrasonic sensors are becoming more commonplace due to their benefits, and because they are so accurate, they can detect minute changes in location.

2. Methodology

The concept of an ultrasonic wind anemometer started with the idea of helping communities to monitor the weather condition in their area in real time specifically with regards to wind velocity. Figure 1 below shows the methodological framework of the study.

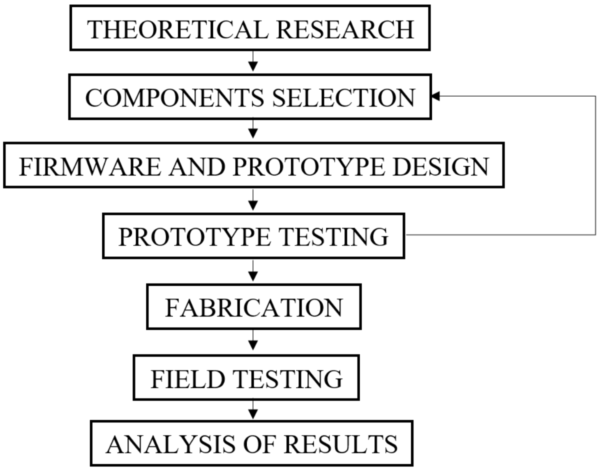

Figure 1: Framework of the study

Research about how an ultrasonic sensor can be used to measure wind velocity was done to familiarize and be given more context on the idea. After necessary research was done, the components needed to build the anemometer was gathered. The firmware and design of the anemometer was then created and after the design and firmware is finished the prototype is then tested. If the results of the prototype testing are not viable or not up to standards the study will then go back to the component selection phase and throughout the study multiple trial and error was done due to some sensors and designs are not viable based on the results of the trial testing. Once a viable and acceptable prototype is selected fabrication of the prototype which consists of assembly, firmware and design finalization, and installation will take place and field testing will then proceed and the results of the field testing will then be analyzed.

2.1 Ultrasonic Anemometer Design

The idea for an anemometer that would allow users to retain the information that the instrument would gather and then use that information for a variety of purposes, including forecasting the impending weather. After extensive trial and error in building the ultrasonic anemometer, multiple ultrasonic sensors, designs and codes were worked on. The microcontroller Arduino Mega 2560 receives the data measured by the HC-SR04 sensors which is then converted in terms of m/s and subsequently transferred to the cloud or stored in a SD card for later data transfer to the cloud. The figure shows the connection of each component to the Arduino Mega 2560, four HC-SR04 ultrasonic sensors were connected to the microcontroller together with the SD-card module, OLED, and DHT11 sensor.

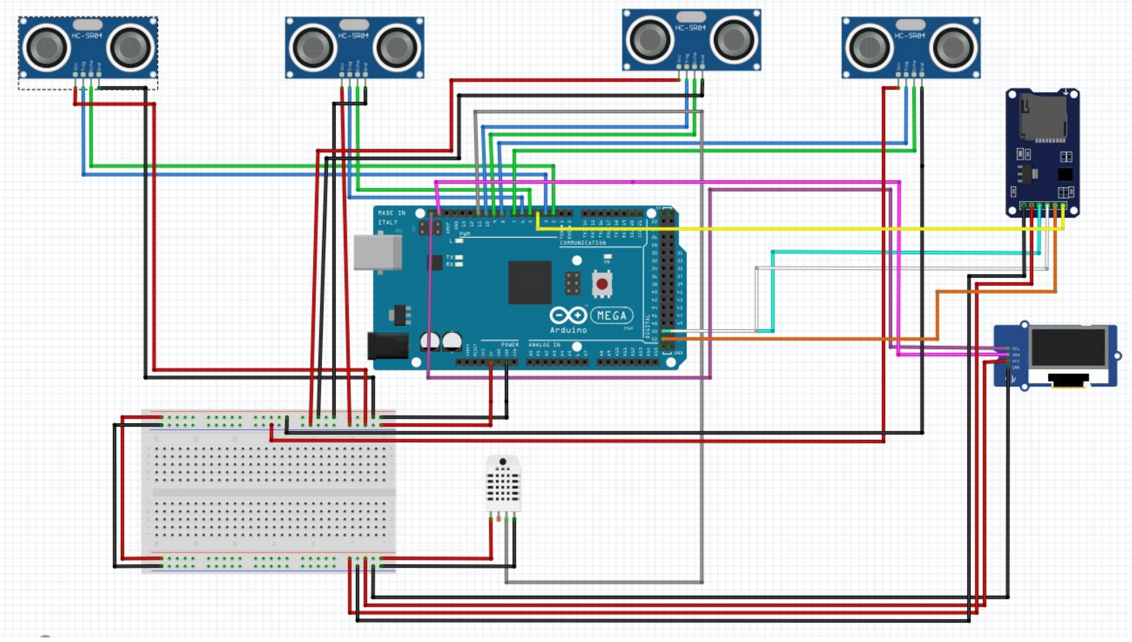

Figure 2: Connection Diagram of the Ultrasonic Anemometer

The wind velocity is accumulated through programming all of the components in series of codes for each component. Each ultrasonic sensor will emit pulses to each other and the program will calculate the time of flight of each sensor. Following the calculation of the time of flight the code proceeds to calculate and determine the angle and wind direction, after that an equation for solving the wind velocity is programmed to run with the real time ambient temperature recorded by the DHT11. The obtained data is flashed in the OLED screen and stored in the SD-card. The researcher utilizes the Kalman Filter to stabilize the data transfer from one sensor to another sensor due to environmental factors affecting the flow of the pulses. Figure 3 shows the 3D printed ultrasonic anemometer design which consists of 3D printed housing which houses the electronics and Figure 4 shows the actual prototype.

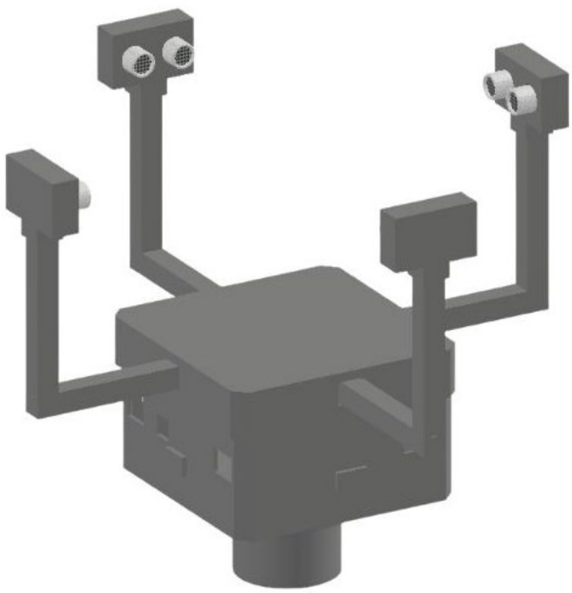

Figure 3: Design of the 3D-printed Ultrasonic Anemometer

Figure 4: Actual Prototype

The data gathered by the anemometer will be displayed in the LED display and it shows the real time measurements and also the data is also sent through the cloud to be stored and can be accessible through the website as shown in Figure 5.

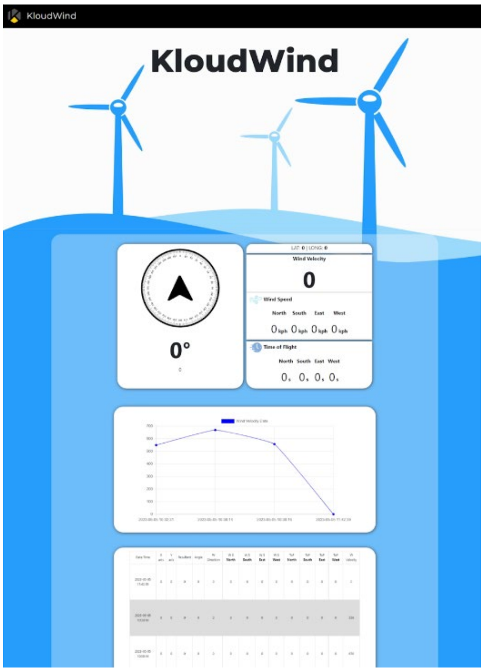

Figure 5: Website dashboard

A user-friendly website called KloudWind was created to display and visualize real-time data obtained from the prototype. KloudWind gives its users a thorough overview of wind speed and direction readings in a visually appealing manner due to its user-friendly interface and interactive features. The website provides interactive maps, graphs, and charts that enable users to explore and examine wind statistics from various areas.

2.2 Testing Procedure

For the data gathering procedure the ultrasonic anemometer was placed in the premises of DOST PAGASA, Bangkal, Abucay, Bataan where the installation of the ultrasonic wind anemometer is ideal. During the testing of the localized 3D-printed anemometer which was conducted in the span of 5 d, a wind vane anemometer which is currently being used by DOST PAGASA to determine and measure the wind speed and direction is present in the area. The data obtained from this device serves as a reference for the output data of the localized 3D-printed anemometer. Throughout the testing duration, from time to time, data was recorded from the reference instruments along with the output signals of the developed ultrasonic anemometer. Following the testing of the device, the data from the two anemometers was compared and analyzed and the results was the basis in the evaluation of the performance of the anemometer.

3. Results and Discussion

The stand-alone 3D printed ultrasonic anemometer was put into operation and in the five-day data gathering, the data gathered was stored and sent to the cloud. The measured data from the ultrasonic anemometer and wind vane anemometer of DOST PAGASA was recorded and compared to evaluate the capability of the ultrasonic anemometer.
Figure 6 shows the average wind velocity by hour taken by the ultrasonic anemometer and DOST PAGASA from 9:00 a.m. to 9:00 p.m. in a span of 5 d.

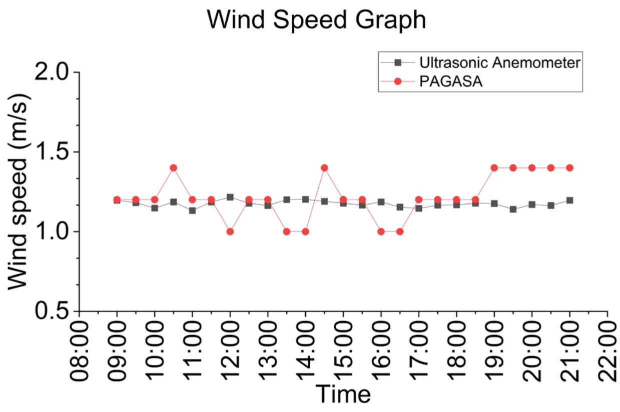

Figure 6: Hourly average wind velocity result of the two anemometers

Figure 7 shows the average wind direction angle by hour taken by the ultrasonic anemometer and DOST PAGASA from 9:00 a.m. to 9:00 p.m. in a span of 5 d.

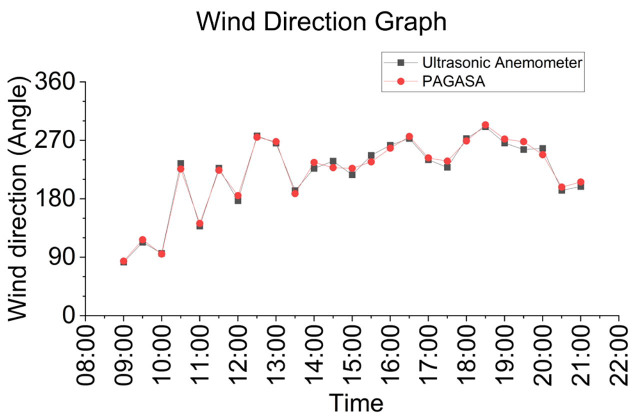

Figure 7: Hourly average wind direction angle result of the two anemometers

As shown in Table 1, the average % error in the wind velocity data is 9.96 % which is still in the desired percentage error of 0 % to 10 %. It also shows the highest and lowest percentage error which is 22.8 % and 0.3

% respectively. The reason why the percentage error value has a big difference is due to the wind velocity data gathered from PAGASA. The way PAGASA measures the wind velocity is through an anemometer that has an analog display and the wind velocity is only recorded as a whole number without decimals while the fabricated ultrasonic anemometer has a digital display that records wind velocity up to two decimals.

Table 1: Percentage of Error of the Average Wind Velocity

Average % Error	Highest % Error	Lowest % Error
9.96%	22.8%	0.3%

As shown in Table 2, an average percent error of 2.65% for the hourly wind direction was calculated. Also, the highest and lowest percentage error of 4.6% and 0.7% was gathered. A lower percentage error was recorded due to the wind direction angle data of PAGASA is measured using the same anemometer but with a compass display which shows the exact angle the wind comes from.

Table 2: Percentage of Error of the Average Wind Direction

Average % Error	Highest % Error	Lowest % Error
2.65%	4.6%	0.7%

4. Conclusion

In summary, the results showed that the development of localized 3D-printed ultrasonic wind anemometer with cloud storage and data transfer can accurately measure wind velocity and wind direction with comparative data to DOST PAGASA wind vane anemometer. The percentage error with regards to the wind velocity results was quite high an average 9.96 %, this is due to DOST PAGASA's anemometer having an analog display while the average percentage error of the wind direction angle only has a 2.65 % which is lower because the display for the wind direction is much more accurate. By comparing the results of the two anemometers it slightly showed the performance of the prototype which is enough for the first trial of testing. A laboratory test using a wind tunnel was firstly planned but due to the limited availability of such facility in the area this type of test was not done. Further testing and optimization will be needed in order to enhance the performance of the device, comparing it to other existing anemometers can be done but conducting laboratory tests such as using a wind tunnel would greatly show the true capabilities of the prototype. The localized 3D-printed ultrasonic anemometer is a low-cost ultrasonic anemometer that can be an advanced alternative to the traditional wind anemometer compared to the existing ultrasonic anemometer in the market. The ultrasonic anemometer is an emerging technology that can change the way how wind monitoring is done by installing it to rural communities or islands they will have the ability to assess the weather condition in their area.

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