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Option: **Computer engineering**

Title:

Development of a 2D ultrasound anemometer using HC-SR04

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Registration Number ………/2021

Dedication

I would like to dedicate this modest work:

To my parents, my father: Mohamed and my mother: Fatiha, my dearest brother: Salah Eddine,my oldest brother Ibrahim, my sisters:ALaa,Safa,Belkis, and my dearest aunt: Hassiba Belal. I would like to dedicate it to all my friends who shared with me the best moments, supported and encouraged me in the hardest moments of my life especially: Nedjma Hammadi, Nahla Ait Gacem, Thiziri Chabane, Younes Riache and Lina Ladgi.

This report paper is dedicated to all engineers around the world who are working hard to make planet earth a better place.

Nour El Yakine

Acknowledgment

First and foremost, I am thankful to God, the most gracious most merciful for helping me finishing this modest work. It is my belief in him that helped me persevere at times when it seemed impossible to go on.

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Last but not least, I am infinitely grateful to my laptop Fujitsu for being with me throughout this journey which I wouldn’t reach without him, my family members, particularly my parents for their patience, unwavering support, continuous encouragement, and believing in me throughout my whole life. We would have never made it this far without them beside us every step of the way.

Abstract

Measurement of wind speed using an anemometer is very important in various fields. The most effective and efficient type of anemometer is the ultrasonic anemometer.
This project describes the design and implementation of an ultrasonic anemometer, usually called ‘sonic’ anemometer, where wind speed is measured based on ultrasound sensors. The digital controller is implemented around the STM32F103C8T6 microcontroller using hardware design approach and a C++ language software with a primary objective of minimizing the noise and obtaining the most precised results.

The 2D Ultrasonic Anemometer consists of four bi-directional ultrasonic transducers HC-SR04, in pairs of two which are opposite each other at a certain distance, and a display unit LCD-16x2, to display the wind speed.

The advantage of ultrasonic anemometer is not having analogue signal conditioning and analogue filters, thereby reducing the possibility of having noise, low cost, and can be monitored remotely.

The respective measurement paths and their direction values are selected via electronic control which is in our case an STM32. When a sensor starts, a sequence of four individual measurements in all four directions along the paths is carried out at maximum speed.

The measurement directions (acoustic propagation directions) rotate clockwise, south to north, west to east, north to south and east to west. The overall digital controller is downloaded onto the STM32 development board. To test the feasibility and functionality of the system, a wind blow is needed.

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Nomenclatures

IOT Internet of things

TOF Time of flight

UA Ultrasound anemometer

General introduction

Electronics is a fast growing field and its purpose is to connect, objects with other objects or humans through control, and provide some useful data. Exploitation of data, gathered from objects of certain type, can help in making human life easier by making better decisions particularly in business weather. As such, the need for weather prediction became essential in many fields, such as military, aviation, shipping, weather monitoring, farming, and many more. Therefore, we need an instrument to measure wind speeds that have high accuracy, are easy to apply, are durable, and are monitored in real-time. An instrument for measuring wind speed is called an anemometer.

The need for wind speed measurement isn't only for weather stations, but also for educational purpose at universities for students or professors as well as for interested individuals. The high cost and expensive maintenance by experts make it quite hard to be obtained .The development of ultrasound anemometer using HC-SR04 project that can address these problems will be time and cost effective. In this project, it overcome many defects and improves the performance system in which no analogue filters are needed.

First, testing the effectiveness of the HC-SR04 module if it is applicable is first covered and has been worked for several times to check the results. After that the implementation of the circuit design is handled according to the mathematical approach and the wind velocity equations that lead to the target results. At the end, a test on the field is taken place where wind velocity is calculated accurately depending on the code commands. Error is also discussed and improvement has also made during the experiment.

Chapter One

Chapter one: Project overview

Introduction

With the overall rapid development taking place in all spheres, the living standard of human being has tremendously increased thank to modern solutions that have been implemented by motivated engineers.

In this chapter, a brief introduction about anemometers is presented. Where the three most common types are illustrated; namely: mechanical anemometer, thermal anemometer, and ultrasonic anemometer. Their operating principles; advantages and disadvantages are also listed.

1.1 Study focus

The focus of the study is on the sonic anemometer field. There is one type of sonic anemometer called ultrasonic anemometer (UA), which use ultrasonic propagation time as the parameter to wind speed. The ultrasound is generated from an ultrasonic source and received by an ultrasonic receiver. Due to the speed of sound is really fast, the propagation time is really short. Assume that the distance between the transceivers is around 0.1 m; the theoretical propagation time will be 0.3ms. When wind speed is parallel to the sound propagation direction, the time will be shorter and vice versa. By measuring the propagation time, the wind speed can be determined.

1.2 The Problem

As the problem of precision and cost spreads, there is a pressing need for the introduction of a simple advanced technology and equipment to improve the state-of-the-art of ultrasound anemometer and make it available and accessible by farmers and individuals. Complexity and expanses of such type is increasing because of the growing needs for such device.

1.3 Solution

Development of Ultrasonic Anemometer Using HC-SR04 Based on Microcontroller is Proposed and developed to enable the purpose of measuring wind speed easily and precisely and works efficiently. Hence this research develops an STM32-based ultrasonic anemometer using the HC-SR04 sensor. The advantage of ultrasonic anemometer is not having analogue signal conditioning and analogue filters, thereby the objective is reducing the possibility of having noise and low cost.

1.4Anemometer History

1.4.1 Definition:

The meteorological device that is used to measure the speed of the wind and its direction is known as an anemometer. These instruments are essential tools used for meteorologists to study the patterns of weather. These devices are used by the physicists while studying the moves of air .

The word anemometer comes from the Greek root, anemos, meaning “wind”, and most anemometers sole function is to measure the speed of wind in one of the following most commonly used units of measure:

- knots

- miles per hour
- feet per minute
- feet per second
- kilometers per hour
- meters per minute
- meters per second

For more than 550 years, mankind has had the ability to observe and measure the pressure and velocity of the wind through the use of the anemometer. The earliest anemometer was designed by Italian inventor and architect Leon Battista Alberti in 1450. His device consisted of a disk placed perpendicular to the direction of the wind that would spin due to the wind, the angle of inclination of the disk momentarily revealing its force. This same anemometer was later “re-invented” many years later by Englishman Robert Hooke, who is often mistakenly credited as the anemometer’s inventor.

The most common anemometer, still widely used today, is the Hemispherical Cup Anemometer, which has three or four small hollow metal cups of hemispheres set to catch the wind and revolve around a vertical rod. The revolutions of the Hemispherical Cup Anemometer are used to calculate the velocity of the wind. The hemispherical cup anemometer was invented by John Thomas Romney Robinson of Ireland in 1846. A combination of wheels recorded the number of revolutions in a given time frame. Anemometers today employ a range of new technologies to measure wind speed and pressure, including sound waves, laser and Doppler technology, and electrical currents .

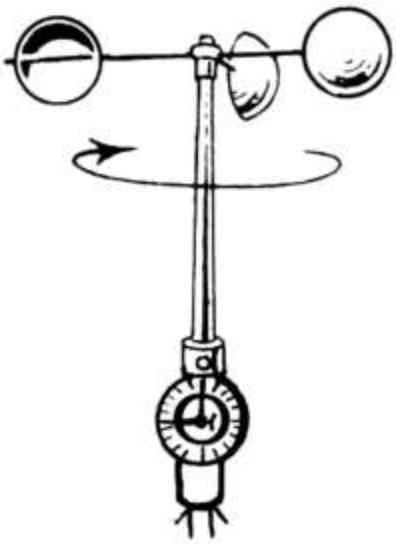


Figure 1.1: A picture of an early anemometer in history

1.5 Types of Anemometers

There are three most common types: mechanical anemometer, thermal anemometer, and ultrasonic anemometer.

1.5.1 Mechanical Anemometer

Usually called Cup Anemometer, It was invented in 1846 by John Thomas Romney Robinson. Commonly installed mechanical anemometers consist of three or four cups that are attached to horizontal arms. At the centre, the arms are connected to a vertical rod, the cups catch the wind, moving the arms and spinning the rod, the faster it spins, the faster the wind is blowing.

Often confused with providing wind velocity, the cup anemometer is unable to determine wind direction.

Figure 1.2: A Cup Anemometer

1.5.1.1 Advantages

- Low price
- Simple implementation
- Most technicians understand easily operating principles and necessary connections

1.5.1.2 Disadvantages

- Due to strong winds, the instrument may get damaged. So protection must be taken while installing the device.
- Without provisions for heating, they don’t work well in snow and freezing rain
- They don’t work well in rapidly fluctuating winds

- Due to moving parts, such type of anemometers is more susceptible to wear and tear and thus loss in accuracy.

1.5.2 Thermal Anemometer

They're also known as Hot-wire type, is a technique for measuring the velocity of fluids. It consists of two probes with a wire stretched between them; the wire is usually made of tungsten, platinum or platinum-iridium. A small glass coated thermistor bead is often used on constant temperature circuit versions.

Its working principle: an electric current is sent through the wire, causing the wire to be hot. As fluid (typically air) flows over the device, it cools the wire, removing some of its heat energy. An energy balanced equation can be used to describe this heating and cooling of the wire. This equation can then be solved to determine the velocity of the fluid flowing over the wire

If the speed of the wind is high, then more input power is required to maintain the wire at a constant temperature. The wind speed is calculated at the rate at which the hot-wire gets cooled down with respect to wind flow. These types are sensitive and mainly used in low wind speed measurements .

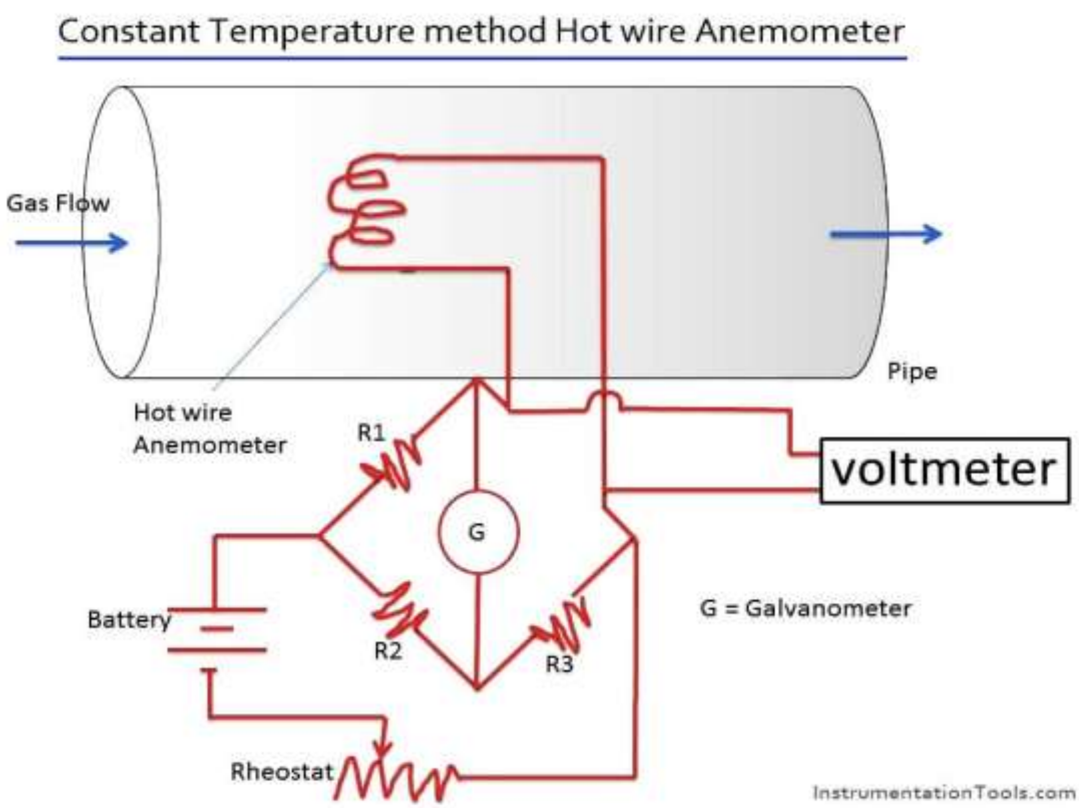


Figure 1.3: Thermal anemometer

Figure 1.4: Modern customised thermal anemometer

1.5.2.1 Advantages

- More widely used due to their reduced sensitivity to flow variation.
- High frequency response (up to 400 KHz).
- Can be used in many different fields.
- They can be made very small to minimize their disturbance of the measured flow.

1.5.2.2 Disadvantages

- Can only be used in clean gas flows
- Need to be recalibrated frequently due to dust accumulation
- These types are sensitive and mainly used in low wind speed measurements.

1.5.3 Ultrasonic Anemometer

The sonic anemometer was developed in the 1970s. It uses ultrasonic sound waves to determine instantaneous wind speed by measuring how much sound waves travelling between a pair of transducers are sped up or slowed down by the effect of the wind. Sonic anemometers can take measurements with very fine temporal resolution, 20 Hz or better, which makes them well suited for turbulence measurements.
Ultrasonic anemometers can be one (1D), two (2D) and three (3D) dimensional and they employ sound waves with frequency greater than 20 kHz to work efficiently .

Though these days the more advanced weather stations use sonic sensors that measure air particle velocities and have no moving parts.

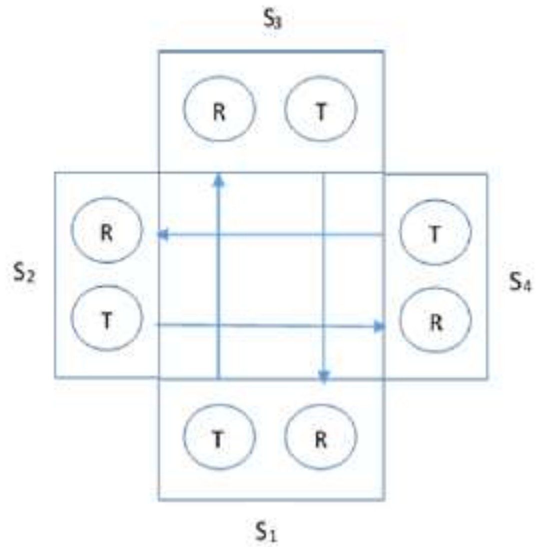


Figure 1.5: A model for ultrasound anemometer

The principle of operation:

The working principle of an ultrasonic anemometer uses sound waves as a method of Measuring wind speed. The method for determining wind has three types of methods, namely: the time of flight difference method, the phase difference method and the Doppler method. The most used method is the time difference method because it has an easy application. Anemometer measurements using the time difference method get wind speed based on the Time of Flight (ToF) value.

The basic element of a sonic anemometer consists of an ultrasonic sound emitter and receiver at opposite ends of a sampling volume as shown in the above figure. The operating principle has been described in detail by Kaimal and Finnegan (1994), van Boxel et al. (2004), and Walker (2005), and is based on the transit times, t_1 and t_2, in each direction between the transducers of the ultrasonic sound signal over the path length, *L*, where the sonic speed in still air *C*, is offset by the speed of the airflow component, *V*. The measurement of transit times across both directions of the path length allows the explicit determination of the speed of sound, which is dependent on the density of the air. As air density is principally controlled by air temperature the sonic measurement of *C* therefore also yields an estimation of the temperature in conjunction with wind component speed, which can be useful for atmospheric stability assessment.

Figure 1.6: principle of Tof method

1.5.3.1 Advantages

- One of the great advantages of ultrasonic anemometers is its robustness. By not having moving parts, such anemometers do not require lubrication nor has abrasion, thus avoiding the need for maintenance.
- They provide very fast sampling at very low threshold, and are very useful in microphysical studies.
- They're much precised.

1.5.3.2 Disadvantages

- They're quite expansive.
- They may need analogue or digital filter in case of programmable transducers.

1.6 Why Ultrasound anemometer?

The lack of moving parts makes it appropriate for long-term use in exposed automated weather stations and weather buoys where the accuracy and reliability of traditional cup-and-vane anemometers is adversely affected by salty air or large amounts of dust.

2D anemometer: Two-dimensional sonic anemometers are used in applications such as weather stations, ship navigation, wind turbines, aviation, and weather buoys.

Therefore, in this report a controller enabled ultrasonic 2D anemometer has been designed which calculates wind speed.

Conclusion

To sum up, this chapter illustrates mainly why the ultrasound anemometer is chosen over the other types, based on the accuracy and their cost. The types have been discussed and explained their working principle briefly to show the advantage of ultrasound anemometer, which is today widely used by physicians and aerospace stations for accurate measurements.

Chapter two

Chapter 2: Design and Implementation

Introduction

In this chapter, the description and interconnection of the different components is discussed in more details where the circuits ‘schematic is introduced. The development and implementation of 2D ultrasound anemometer system is divided into two steps, the first step is the circuit design where the different components are interfaced with the microcontroller and the second step is writing the program for the microcontroller.

2.1 The Components List

This section is to list all the used components, the components selection is based on two
Parameters:

- To reduce power consumption.
- To reduce the hardware size.
- The decrease the product cost.

The list:

- Four HC-SR04 Ultrasonic Transducers (40kHz)
- STM32F103C8 microcontroller
- ST-LINK V2
- Breadboard
- Jump wires
- Wooden or cardboard platform
- LCD 16X2
- Potentiometer
- Power supply

2.1.1 STM32F103C8

STM32 is a family of microcontroller integrated circuits by STMicroelectronics [Appendix A]. The STM32 chips are grouped into related series that are based around the same 32-bit ARM processor core, such as the Cortex-M33F, Cortex-M7F, Cortex-M4F, Cortex-M3, Cortex-M0+, or Cortex-M0. Internally, each microcontroller consists of the processor core, static RAM, flash memory, debugging interface, and various peripherals. The development board not only has tons of features it also has terrific processing speed making it suitable for advanced applications .

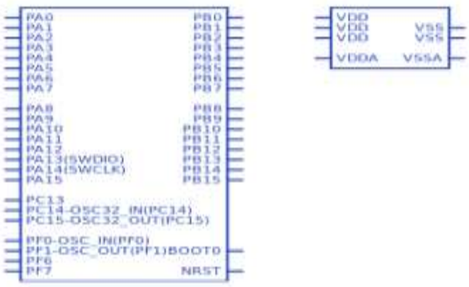


Figure 2.1: STM32 model

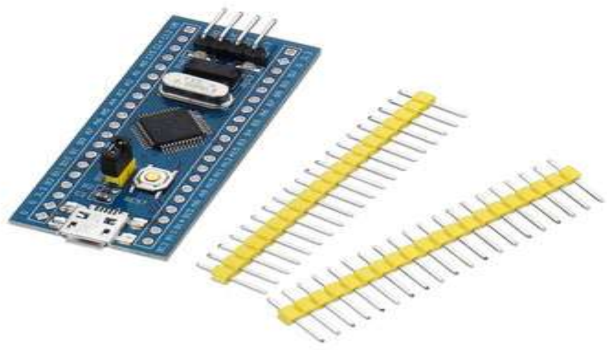


Figure 2.2: STM32F103C8 system board

Why STM32?

32-bit microcontrollers are gaining more popularity as they become more affordable in comparison to traditional 8- and 16-bit microcontrollers. ARM is one of the most popular 32-bit architectures available, and STMicroelectronics offers a suite of controllers that meet almost every need in the 32-bit range .

2.1.2 ST-LINK V2

The ST-LINK/V2 is an in-circuit debugger and programmer for the STM32 microcontrollers. The single-wire interface module (SWIM) and JTAG/serial wire debugging (SWD) interfaces are used to communicate with any STM32 microcontroller located on an application board.

STM32 applications use the USB full-speed interface to communicate with the STM32CubeIDE software tool or with integrated development environments from third parties .

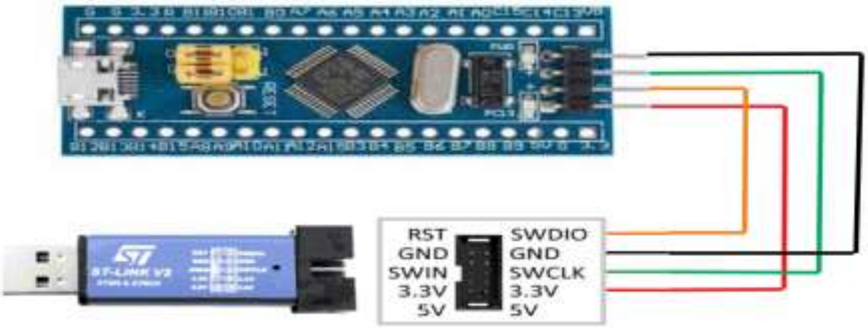


Figure2.3 : St-LINK V2 interface

2.1.3 LCD 16X2

The term LCD stands for liquid crystal display. It is one kind of electronic display module used in an extensive range of applications like various circuits & devices like mobile phones, calculators, computers, TV sets, and many other devices. These displays are mainly preferred for multi-segment light-emitting diodes and seven segments. The main benefits of using this module are inexpensive; simply programmable, animations, and there are no limitations for displaying custom characters, special and even animations.[8] It is used in the experiment to
Display the wind speed calculated.

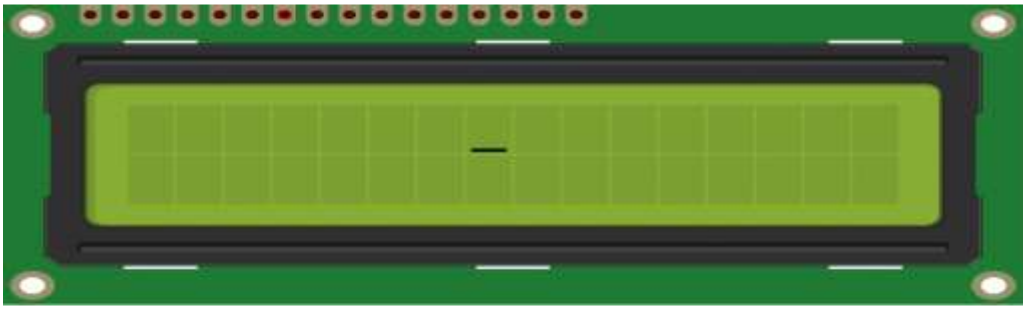


Figure 2.1 :LCD16X2

2.1.4 Ultrasound sensor HC-SR04

Ultrasonic ranging module HC - SR04 [Appendix B] provides 2cm - 400cm non-contact measurement function, the ranging accuracy can reach to 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of work: Using IO trigger for at least 10us high level signal, The Module automatically sends eight 40 kHz and detect whether there is a pulse signal back. IF the signal back, through high level , time of high output IO duration is the time from sending ultrasonic to returning. Test distance = (high level time×velocity of sound (340M/S) /2 .

However, in this experiment the time of light was the concern, therefore it is measured through a function in the software.

Figure2.5 : Ultrasound sensor HC-SR04 with wire connection pins

2.1.5 Cardboard platform

It is used to support the circuit and the four sensors.

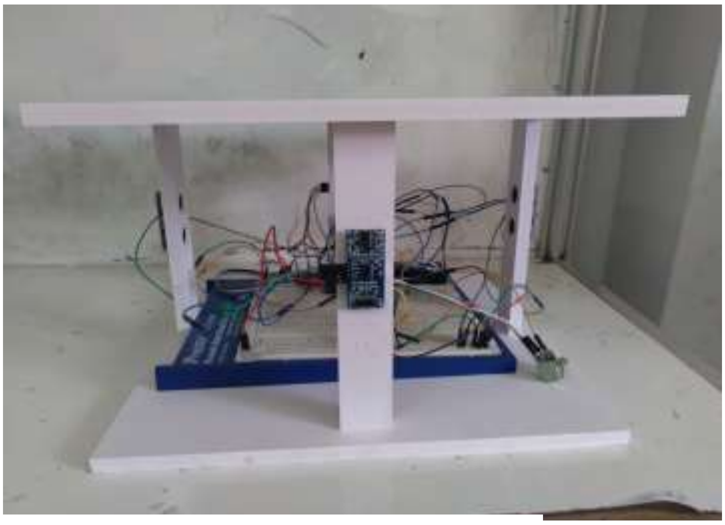


Figure2.6 : The wooden Platform

2.2 Mathematical approach of the design

There are two types of 2D ultrasound anemometers:

-Orthogonal ultrasonic 2D anemometer

-Equilateral triangle ultrasonic 2D anemometer

In the research experiment, the orthogonal design is adopted and has been worked on to have less complicated prototype and calculations.

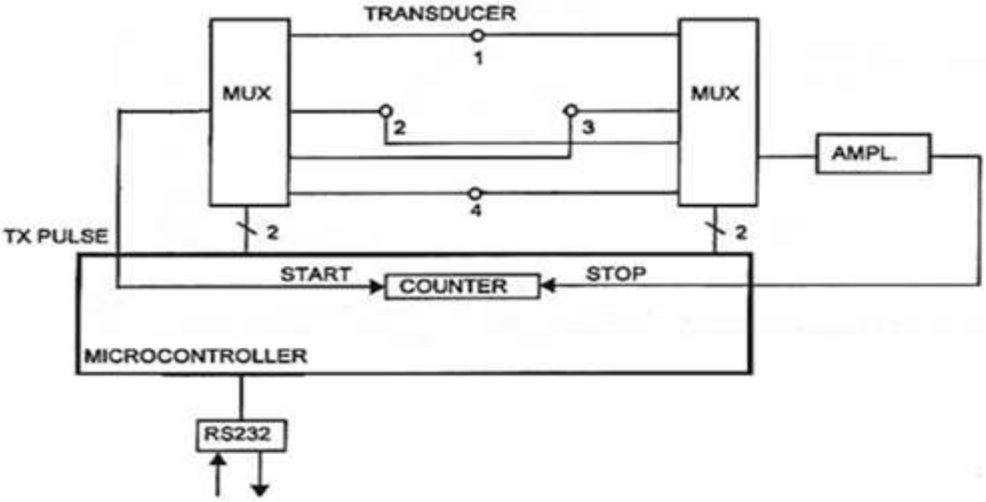


Figure 2.7 : Orthogonal ultrasonic anemometer block diagram

2.2.1 Speed of wind

The speed of a sound wave in air depends upon the properties of the air, namely the temperature and the pressure. At normal atmospheric pressure, the temperature dependence of the speed of a sound wave through air is approximated by the following equation:

$$V = \frac{331.45m}{s} + (0.6 * T) \text{............ (1)}$$

Where T is the temperature of the air in degrees Celsius.
In the experiment it was taken as T=24°C

- **C=345.9m/s**

Since the speed of a wave is defined as the distance which a point on a wave (such as a compression or a rarefaction) travels per unit of time, it is often expressed in units of metres/second (abbreviated m/s).
In equation form, this is:

$$\text{Speed} = \frac{Distance}{Time} \text{............. (2)}$$

The Ultrasonic Anemometer 2D is designed to detect the horizontal components of wind velocity and wind direction. Where wind direction is produced in the form of angles that are obtained from the calculated horizontal and vertical components.
The resulting angle is between –phi to phi or -180 to 180.
The wind angle:

$$\theta = \tan^{-1}\left(\frac{Vy}{Vx}\right) \text{............ (3)}$$

Each wind direction is represented by a certain angle given in the following table:

Table 1 : Relationship of the angle with the direction of the wind

Angle	Direction
-10 < θ < 10	North
10 < θ < 80	Northeast
80 < θ < 100	East
100 < θ < 170	Southeast
-180 < θ < -170 or 170 < θ < 180	South
-170 < θ < -100	Southwest
-100 < θ < -80	West
-80 < θ < -10	Northwest

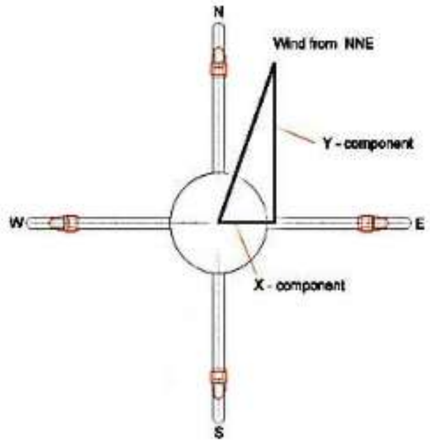


Figure2.8 : The Cartesian representation of the wind velocity

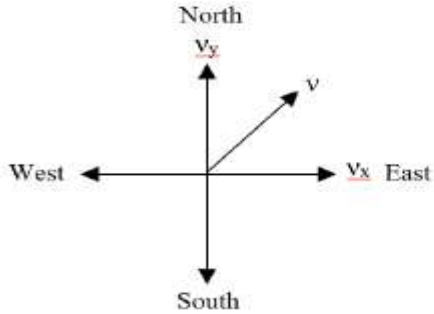


Figure2.9 : Representation of sensor in Cartesian coordinates

The speed on the x-axis (vx) is based on the measurement results of the west sensor (vw) and the east sensor (ve). The velocity on the y-axis (vy) is based on the measurement results from the north sensor (vn) and the south sensor (vs). The measurement results between the east sensor and the west sensor are always inversely proportional. If the wind blows eastward, the measurement value of the east sensor will be positive and the west sensor will be negative. The velocity on the x-axis is the result of the measurement value of the sensor which is positive so the velocity on the x-axis is the same as the measurement result on the east sensor. To determine the speed on the x and y-axis can be seen in the following table.

Table 2 : The x axis and y axis velocity direction for each sensor

x-axis			y-axis		
Sensor		V_x	Sensor		V_y
V_e	V_w		V_n	V_s	
+	-	V_e	+	-	V_n
-	+	$-V_w$	-	+	$-V_s$

- Vertical and horizontal component of wind velocity

$$Vx = \left(\frac{D}{2}\right) * \left(\frac{1}{Twe} - \frac{1}{Tew}\right) \ldots\ldots. \ (4)$$

$$Vy = \left(\frac{D}{2}\right) * \left(\frac{1}{Tsn} - \frac{1}{Tns}\right) \ldots\ldots. \ (5)$$

The minus sign on Vw and Vs indicates that the positive value of the westward velocity is in the opposite direction to the velocity direction on the x-axis and the positive value of the south velocity is in the opposite direction to the velocity in the y-axis. Wind speed and wind direction are obtained by adding the vector at the x-axis and y-axis speeds.

$$\vec{v} = \overrightarrow{Vx} + \overrightarrow{Vy} \ldots\ldots\ldots\ldots.. \ (6)$$

$$v = \sqrt{Vx^2 + Vy^2} \ldots\ldots.. \ (7)$$

This formula's assures that the wind speed does not depend on pressure, temperature and humidity.

The Ultrasonic Anemometer 2D consists of four bi-directional ultrasonic transducers, in pairs of two which are opposite each other at a distance of 25 cm.The transducers act both as acoustic transmitters and acoustic receivers. The respective measurement paths and their measurement direction are selected via electronic control. When a measurement starts, a sequence of four individual measurements in all four directions of the measurement paths is carried out at maximum speed.

The time of flight of the first signal (out) is given by:

To = d / (c + v)......... (8)

Where:
d is the distance between the transducers (0.25m).
C is the speed of sound.
V is the wind speed along the transducer axis.
T is the time taken.

The time of flight of the third signal (back - opposite direction) is given by:

Tb = d / (c - v).... (9)

When there is no wind blow:

ToF =$\frac{D}{S}$....... (10)

ToF=$\frac{0.25}{345.9}$

ToF=722.75us

2.3 Method

The ultrasonic anemometer has two main parts, namely the sensor and data processing. On the sensor there is an ultrasonic sensor HC-SR04 module which is high 10cm from the platform, on a grid support, the transmitter and receiver are placed facing each other at a length of 25cm. whereas in the data processing section there is STM32 microcontroller and LCD 16x2. The working principle of the instrument is illustrated through the block diagram in the figure below.

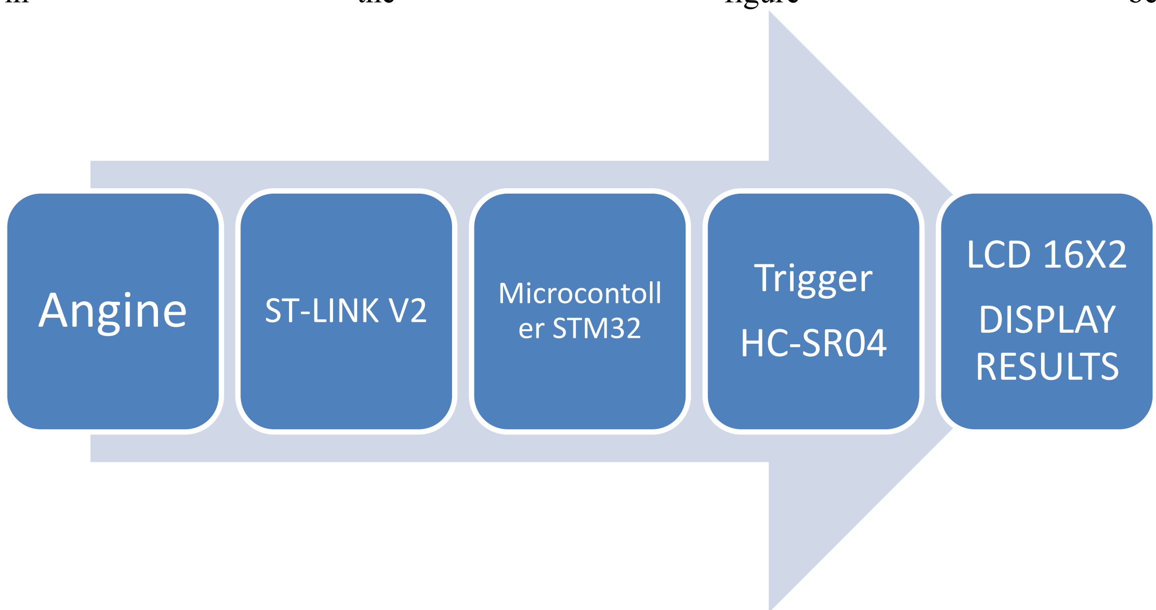


Figure2.10 : Illustration of the working process of the 2D anemometer

The Ultrasonic anemometer uses a microcontroller to carry out the measurement system. The sensor used is the HC-SR04 module which can emit sound waves of 40 kHz, is first triggered about 5us; the output from HC-SR04 is a ToF which is measured digitally by an integrated function PulseIn. Then the ToF is converted to wind speed according to equation (4), (5) and (7). The resulting wind speed is the speed value measured by each sensor Vx and Vy.

The measurement results are saved on the Microcontroller and displayed on the LCD. All commands and logic on the anemometer are done digitally through programs created using the Arduino software (C++). The microcontroller uses STM32. The electronic circuits of all components are described in the form of a circuit scheme shown in figures bellow

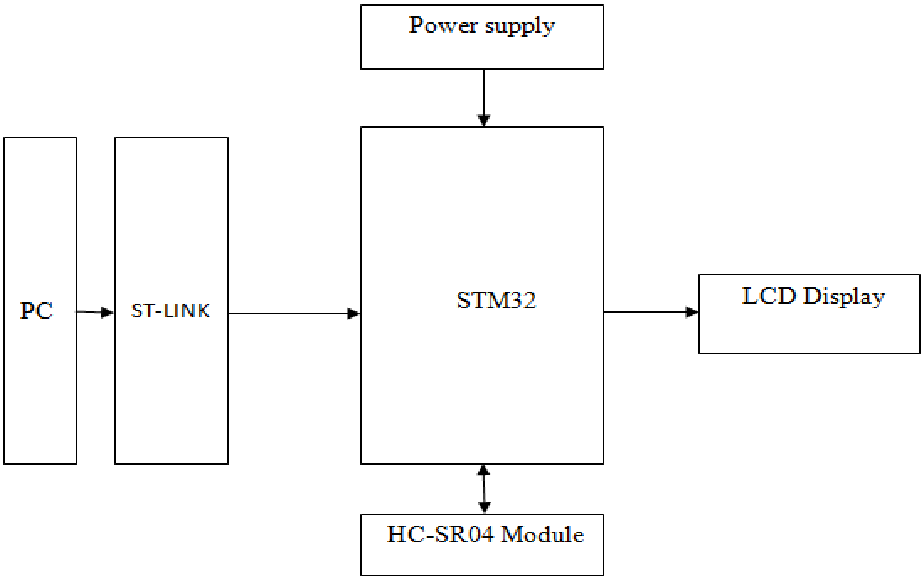


Figure2.11 : 2D ultrasound anemometer block diagram

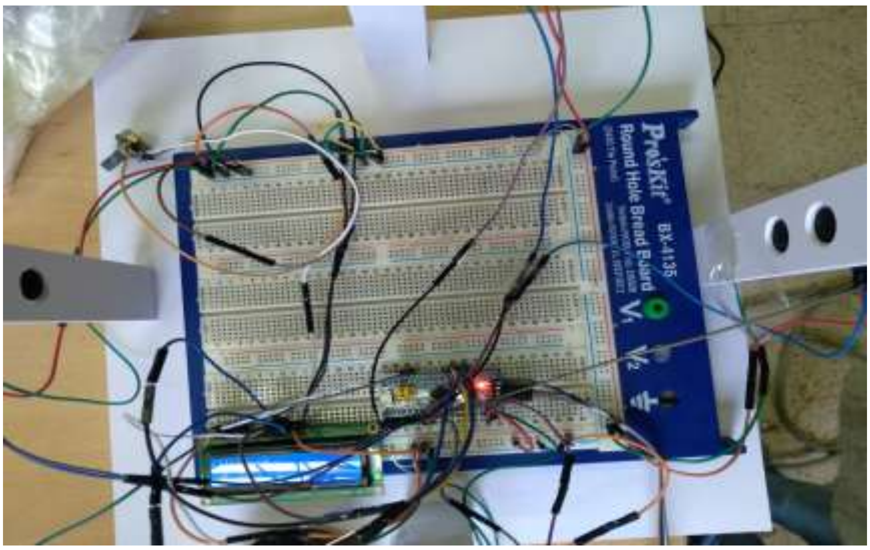


Figure2.12: an upper view of the designed circuit

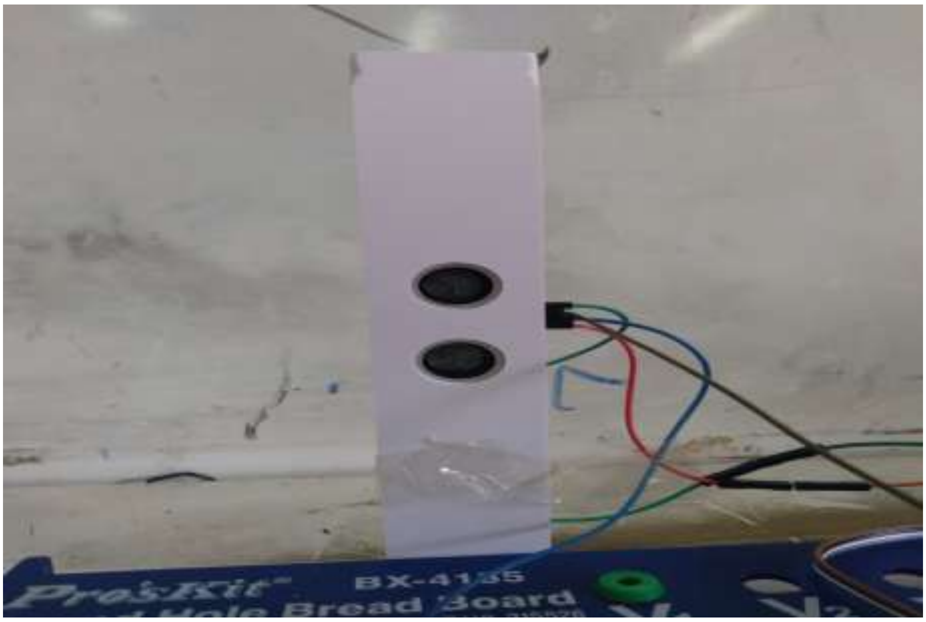


Figure2.13 : HC-SR04 module fixed on a grid support at a height of 10cm

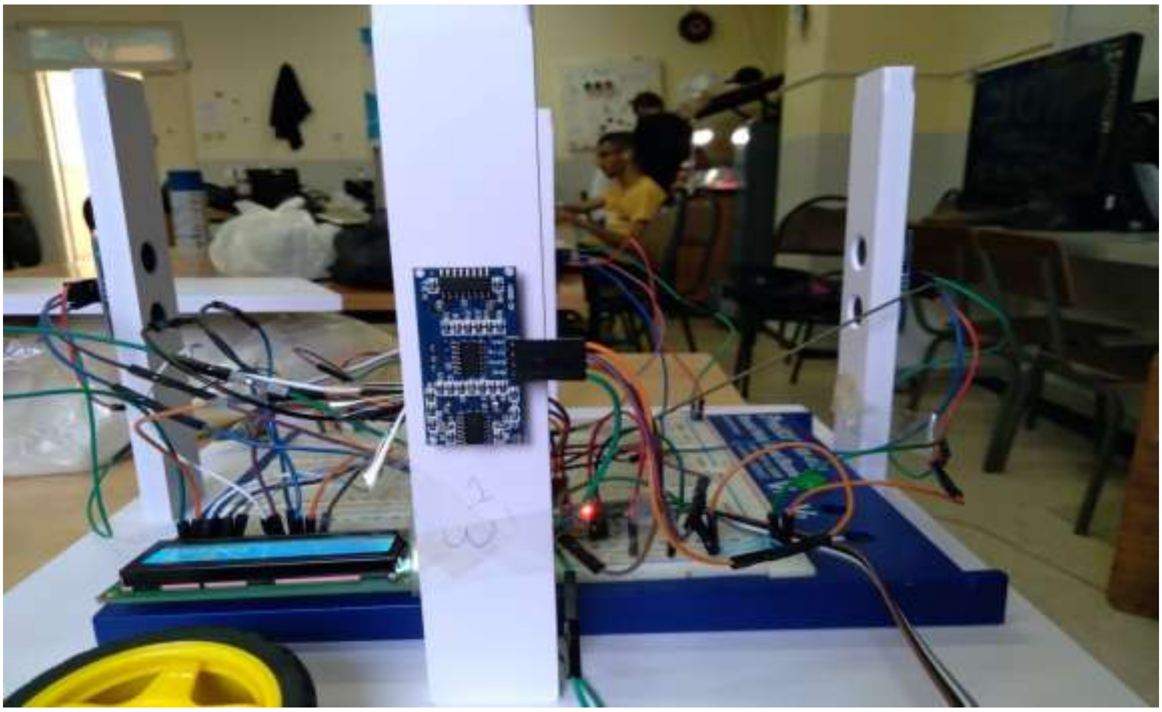


Figure2.14 : The four sensors facing each other on the wooden platform

2.4 Designing Methodology

The following part discusses the wiring of the implemented circuit using the different components

2.4.1 HC-SR04 connection

The south sensor HC-SR04 module trigger is connected to pin A9 and the echo is connected to A8 of STM32.
The north sensor HC-SR04 module trigger is connected to pin B13 and the echo is connected to B14 of STM32.
The west sensor HC-SR04 module trigger is connected to pin A10 and the echo is connected to A11 of STM32.
The east sensor HC-SR04 module trigger is connected to pin B15 and the echo is connected to B12 of STM32.
The ground pin of the four HC-SR04 module is connected to the ground of the STM32 and The Vcc pin of the four HC-SR04 modules is connected to the 5v of the STM32.

2.4.2 LCD 16x 2 connections

The connection of the LCD Display to the STM32 was based on the following:
5V was supplied from STM32 to LCD pins 2 and 15.
Ground of Stm32 was connected to LCD pins 1,5 and 16.
Pin 3 of LCD was connected to 10k potentiometer.
Pin 4(RS) of LCD was connected to pin B11 of STM32.
Pin 6(EN) of LCD was connected to pin B10 of STM32.
Pin 11(DB4) of LCD was connected to pin A4 of STM32.
Pin 12(DB5) of LCD was connected to pin A3 of STM32.
Pin 13(DB6) of LCD was connected to pin A2 of STM32.
Pin 14(DB7) of LCD was connected to pin A1 of STM32.

2.4.3 10k Pot

Pin 3 of LCD was connected to 10k potentiometer.
One terminal is connected to the ground and the other to 5V

2.4.4 ST-link V2

It is connected to the smt32 to upload the software according to **fig2.3**
After connecting the different parts, a circuit design is handled using proteus8.9 version as shown in fig2.15.The Proteus design suite combines ease of use with a powerful feature set to enable the rapid design, test and layout of professional printed circuit boards. It is used both in industry and education.

2.5 Circuit design

After connecting the different components, the design of the circuit is made and shown below according to the above described connections; where it was simulated in the Proteus8.9 software.

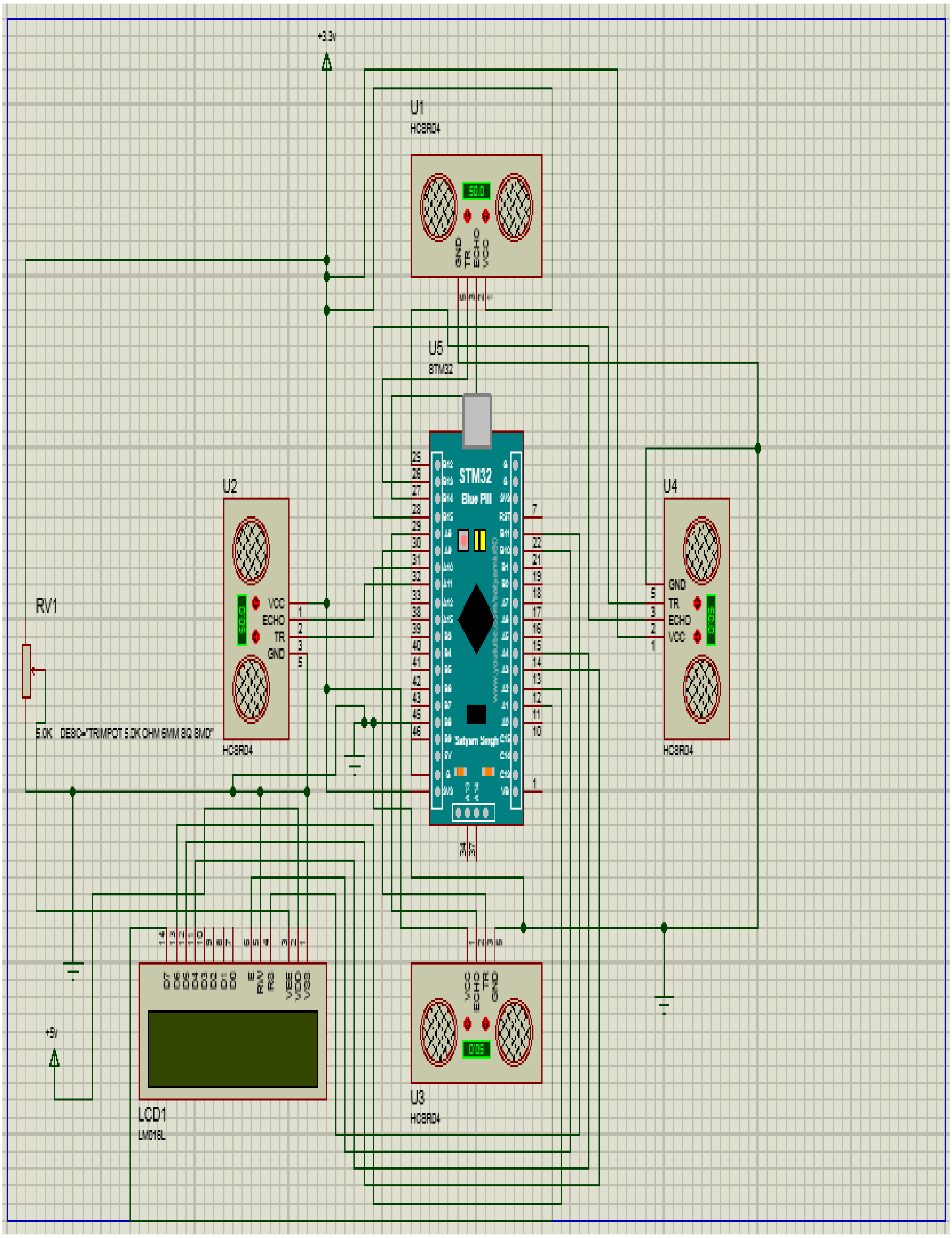


Figure2.15 : The circuit design

2.6 The software approach

2.6.1 Definition

The software part of the project is the one responsible for the safe and efficient operation of the 2D ultrasound anemometer system. The microcontroller's main goal is the decision making and it is by this latter that all calculations and data manipulations are being performed. The thing that gives the software the ability of taking decisions and treating data in some way is the code written in a specific programming language, then after being converted into the machine language by a compiler and saved in the memory associated with the microprocessor, it will be able to execute the program and let the system act according to the instructions.

In this project, a C++ language program was written to control and handle data from inputs like ultrasound sensors to respond accordingly with output signals that are generated to manage the time of flight of the four HC-SR04 modules.

2.6.2Principle of Operation

After connecting all the devices to the corresponding pins in STM32, the Arduino Software from the official website "www.arduino.cc" is downloaded and installed. Then STM32 is connected to the computer using the ST-link and installed the driver software on the computer to write, compile and run the software code on Arduino software.

Arduino code is written in C++ with an addition of special methods and functions. C++ is a human readable programming language. When you create a 'sketch' (the name given to Arduino code files), it is processed and compiled to machine language. The Arduino Integrated Development Environment (IDE) is one of the text editing programs used for STM32 programming. It is where the code will be typed up before uploading it into the board wanted to be programmed.
Down below is a portion of the code used in running the 2D sonic anemometer.

2.6.3The Flow chart

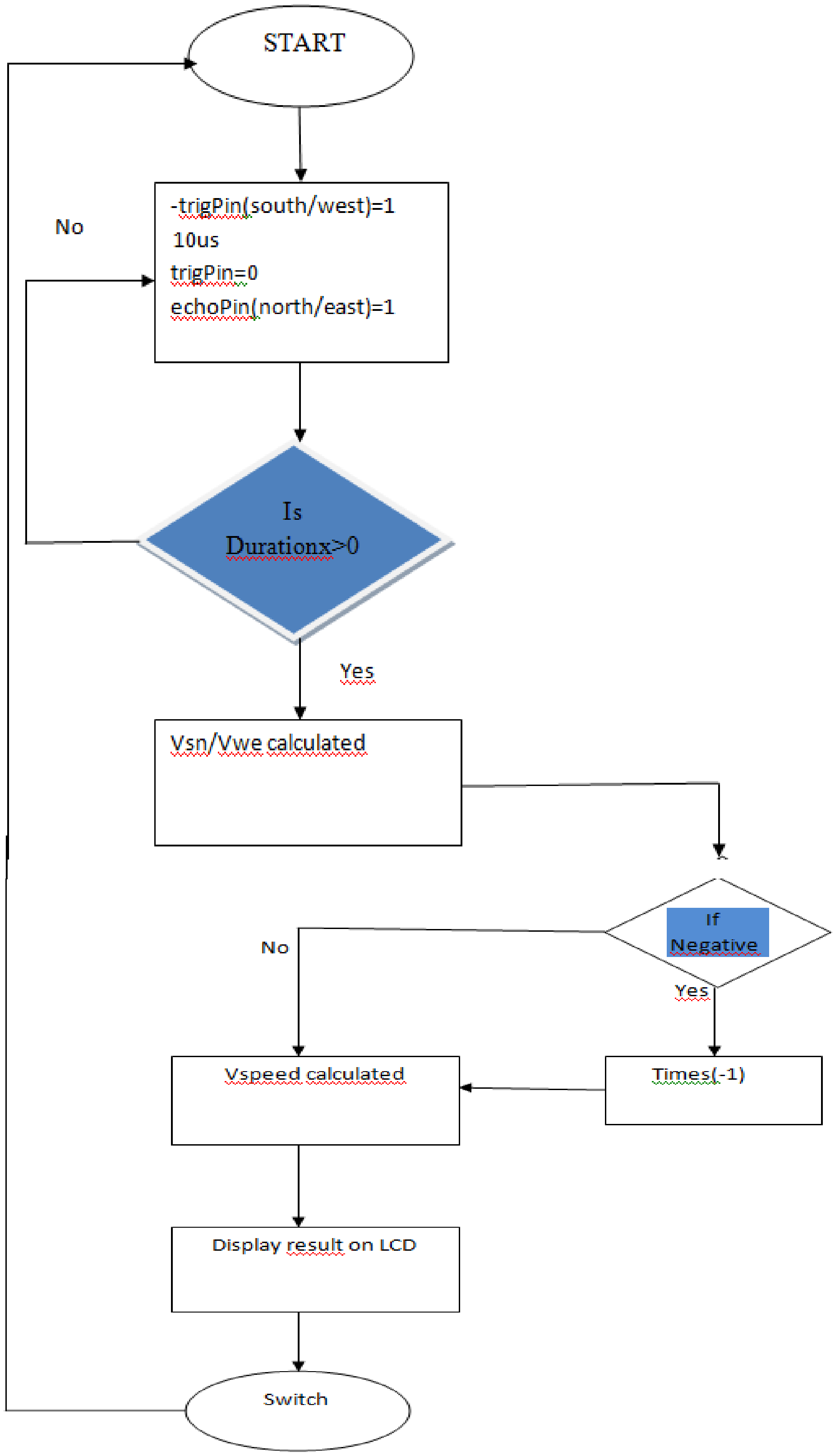


Figure2.16: The flowchart of the system

2.7 The system power consumption

In this section, the system's power consumption is calculated by summing all the components power consumption. The table below contains each component's power max consumption.

Table 3 : Components Power Consumption

The component name	Number of used component	Power consumption(mW)
STM32F103C8T6	1	750
HC-SR04	4	300
LCD16x2	1	20

- The STM32 board draws a maximum of 750mW and it supplies all the sensors and the LCD.
- The four HC-SR04 consumes 300mW.
- the LCD is consuming the least by 20mW supplied by the STM32.

The total power consumed by the system is 750 mW.

Conclusion

This chapter covered the used hardware components and the circuit used to implement this project, as well as the software used to run the 2D sonic anemometer.
It also discussed the mathematical approach and the calculations followed to get the target results which are the wind speed.

Chapte three

Chapter three: Results and discussion

Introduction

In this chapter, the final results obtained from the circuit are listed below and discussed, as well as the difficulties faced during the realisation would be shared. I simulate a situation and use electronic circuits to measure a physical phenomenon.

3.1 Notes

All the measurements were handled in a temperature of 24°C.

- external temperature = 24.04
- external temperature = 24.10
- external temperature = 24.16

The main study objectives are:

1. Construct the test circuit.
2. Measure the wind velocity in different sound propagation.
3. Analyze the data.

3.2 Construction

A wooden platform has been used to make the 2D measurement applied.
The four sensors are separated by 25cm with a height of 10cm.
Separation of the transducers varies from 0.25 m to 0.36 m. The longer the path
The easier it will be to determine the wind speed (larger tof changes).
0.25 m has been chosen as being a reasonable physical size for the anemometer.
The ultrasonic anemometer has a measurement resolution of 0.10 m/s..
The transducers operate at 40,000 Hz which gives a pulse period of 25.0 micro sec.

3.3 Discussion

In the beginning, the southern(S) ultrasound sensor and the western (W) ultrasound sensor will be both triggered in the same time for 10us, and then they would be turned off. The sound wave of the south sensor will be received by the echo of the north sensor ,that travel time is called ToF(time of flight);which is measured by the PulseIn function, this function would return the Duration of the sound wave travel time from south to north and from north to south. The same measurements are handled from west to east and from east to west sensors. After checking that the PulseIn function was returning non-zero values; these last would be passed to calculate the horizontal (Vx) component of the wind, and the vertical component (Vy).
The velocity components are as well checked if they’re negative (backward direction), or positive (forward direction).finally the X and Y components are used to calculate the wind velocity applied to the formula, and it is displayed on the LCD.a time delay is set to calculate the wind velocity each 4 seconds. All the measurements and the data sensed by the HC-SR04 are sent to the STM32. After receiving the data, STM32 will convert it into different digital values where the calculation would be handled and displayed through the LCD.

The normal electronic noise must be minimized by good circuit design.
A significant source of noise is from the wind itself. Any turbulence in the air movement will

Appear as "noise" in the tof measurements. We can ensure that the sensors are high up and clear from any obstructions. This helps but the wind is always turbulent to some extent.

The sensor needs to be calibrated to find out the measurement error made by the sensor. Sensor calibration is done by comparing the results of distance measurements between HCSR-04 sensors.

Table 4 : Sensors calibration

Fixed distance	West sensor		East sensor		North sensor		South sensor	
	R	error	R	error	R	error	R	error
25cm	24.91	0.09	25.15	0.15	25.15	0.15	25.12	0.12

R: represents the measured distance by each sensor digitally.

From the above table we can calculate the average percentage error:
The west sensor measurement error value is 0.09 cm and the Mean Average Percentage Error is 0.36%. The east sensor measurement error value is 0.15 cm and the Mean Average Percentage Error is 0.6%. The north sensor measurement error value is 0.15 cm, which is the same as the east sensor, so the Mean Average Percentage Error is 0.6%. The south sensor measurement error value is 0.12 cm and the Mean Average Percentage Error is 0.48%.

The covariance value of the sensor measurement is the variation value from several existing samples. Samples are obtained by measuring ToF at the same distance continuously until a certain time with no wind blow.
The collected data were organized in a table, then have been drawn as a graph using the excel 2007

Table 5 : The measurement results of time of flight with no wind blow

the time of flight(microseconds	SN	NS	EW	WE
0	796	747	295	806
4	732	747,5	788	794
8	705	745,5	655	794
12	808	538	380	784
16	720	470	763	782

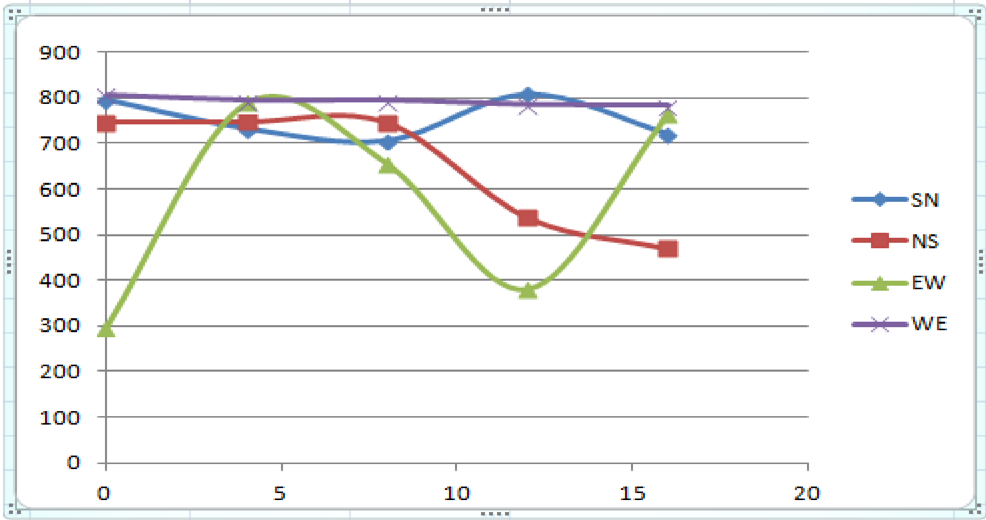


Figure 3.1: A graph showing the measurement results of the four sensors with a constant distance

The above measurements were obtained for no wind blow each four seconds, where we can clearly see that the time of flight from west to east (WE), and from south to north (SN) were almost fixed. However the east to west (EW) time of flight was fluctuating from 295 to 763 microseconds which is justified by the error of the HC-SR04 module.
The error measurements are affected by the temperature and the commercial modules.

The measurements have been repeated with the wind blow and the results down below were obtained:

Table 6 : The time of flight when wind is applied from south to north

SN(microseconds)	NS(microseconds)
707.5	746
352	885

We can see that the time of flight from south to north has decreased to 352us because the wind is in the same direction; and time of flight from north to south has increased because the wind was opposite, then it decreased slightly back to 746.Which approve the concept of time of flight method.

Table 7 : The time of flight when wind is applied from east to west

EW(microseconds)	WE(microseconds)
754	761
573	1008

We can see that the time of flight from east to west has decreased to 375us because the wind is in the same direction; and time of flight from west to east has increased to 1008us after it was 761us because the wind was opposite. Which also approve the concept of time of flight method.

After obtaining the ToF, it will be passed to the formula then we can find the wind speed value.

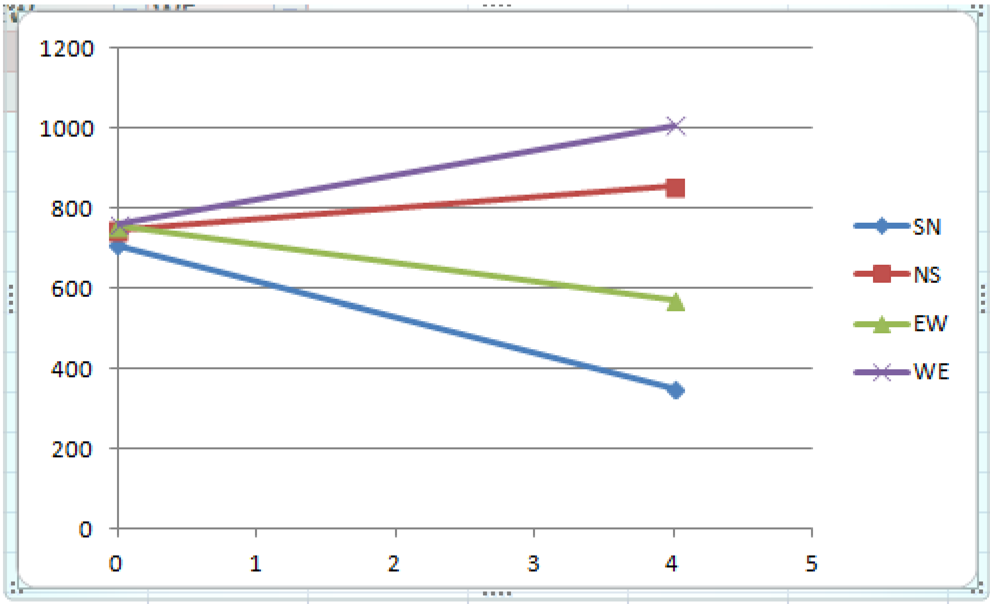


Figure 3.2: Time of flight variance after applying a wind source

3.4 Results

Measurements on the ultrasonic anemometer are unstable because there are several factors, such as air temperature, air pressure, and air turbulence around the anemometer , as well as the measurements error of the HC-SR04 modules that may occur as shown above in the sensor calibration .Testing of the wind direction by comparing the display on the LCD and the direction of the wind source given to the ultrasonic anemometer. Tests carried out with 8 variations of the wind direction, namely, east, southeast, south, southwest, west, northwest, north, and northeast. The test results are given in the following table 5. However; If wind direction is exactly in line with one measuring path (NS or SN or WE or EW), this will cause turbulence due to transducer structure. This will cause erratic readings and needs to be compensated for in software.

Table 8 : Wind direction calibration

Theory		LCD display	
Angle	Direction	Angle	Direction
0	North	8	North
45	Northeast	43	Northeast
90	East	88	East
135	Southeast	155	Southeast
180	South	177	South
-135	Southwest	-108	Southwest
-90	West	-88	West
-45	Northwest	-42	Northwest

The results of wind direction testing have no errors in determining the direction of the wind. But there is slight error in the results of the angle measurements. The biggest measurement error is at an angle of -135° and +135. The error is caused because at that angle has greater turbulence than the angle of 0.

Wind direction resolution can reach 1° with the biggest measurement error of 27° .

Table 9 :The hardware verification of well conductance

Device name	Input data	Verified results	remarks
STM32 board testing	Digital signal	Count the Vspeed and display results	Hardware is accurate
HC-SR04 testing	Echo Pulse In	Duration(TOF)	Hardware is accurate
LCD testing	Digital input	Display results, light intensity	Hardware is accurate

The 2D sonic anemometer has been tested on a field, and down below are some results where the wind speed was changed increasingly.

Table 10 :Some wind speed measurements

The time	The wind speed measured(m/s)
T1	0.16
T2	0.25
T3	0.13
T4	0.29
T5	2.19

After calibration of wind speed and wind direction, we can end up to the result of this implementation, that it works around the limitation of the error measurements of the sensors and external factors like turbulence , air pressure and temperature . The test results showed that the results of measurements indoor ranged from 0.1 to 2.19 m/s which blew from different sides.

3.5 Not included

Some factors will not be discussed in this study such as humidity. The humidity will affect the sound propagation. However as the experiment is done indoors, the humidity can be regarded as a constant and a normal value. So the humidity will not have too much influence to the sound propagation. In this experiment, the wind speed and direction are the two factors that be considered. Other factors are ignored.

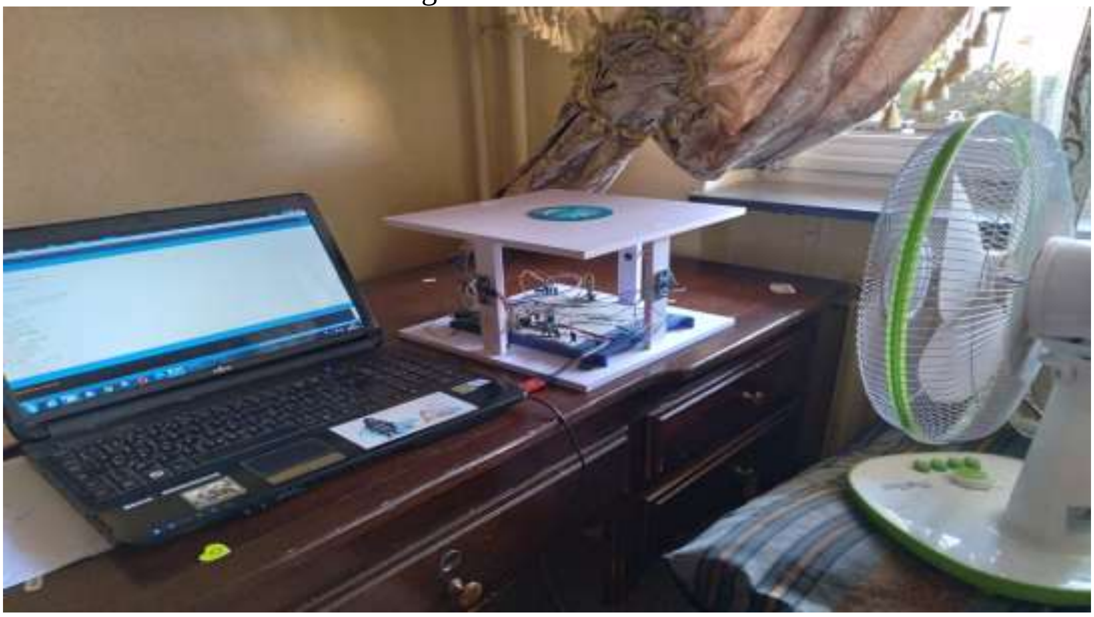


Figure3.2: the whole system being tested

Conclusion:

The proposed wind speed measurement system is a cost effective and the accurate way that is simplified to be used by individuals.

It helps us to get rid of filters, which means less noise and most importantly, primary cost and maintenance can be decreased easily without forgetting the fact that it consumes less power.

This presented work has more advantages which can overcome the present limitations. This system can be easily implemented in, home automation, agriculture field monitoring, education, universities and industries, as well as all individuals who need such results.

During the realisation, one of the major problems with the HC-SR04 was that wind has been observed a soft obstacle for the sensors, in that case it was returning zero for the duration of time of flight. To solve such problem, we should develop an efficient way of triggering the sensor, as well as it can be regulated by disordering the module and change some parameters

One way to improve the ultrasonic anemometer is to increase the number of transducers more transducers will increase the accuracy because it increases the reference axis. It will also increase the sensitivity due to it decreases the measurement interval. It is the same meaning with increasing the sampling rate.

General conclusion

In this report, we have described the design and implementation of an STM32-based two-Dimension ultrasound anemometer control system. we have used the STM32CubeMX and C++ software's to implement the digital controller of the system. This methodology allows the instantiation and simplification of the calculations.

The advantage of this approach is its configurability which provides the designer with almost limitless flexibility by allowing parameter modification or addition of any desired peripheral at any stage of the implementation. Moreover, it cuts down the budget traditionally spent on maintenance of sonic anemometers in case of component failure; it also returns accurate results due to the unmoving parts.

To realize this project, HC-SR04 modules were used to provide sound waves that are used in the main calculations of wind velocity, where it returns the time of sound flight, refered as duration. The duration of each sound travel time was measured and displayed on a display unit.

Most of efforts and time were spent to debug hardware problems and software bugs. The fact that I have used breadboards to implement the off-chip design has caused me plenty of problems due to the bad wire connections or damaged components. Therefore, I have lost an invaluable time during the debugging process. One more problem I have faced was soft obstacle returning zeros in the PulsIn function.

Although the system was implemented and tested successfully, it can be upgraded by working on other aspects. Based on what I have learned from the implementation of this project, I can suggest the following:

- ✓ The 2D prototype can be improved by adding Digital kalman filter in the programming software for flawless results.
- ✓ The designed prototype can be controlled remotely by using microcontroller integrated IoT with a Smartphone application.
- ✓ Bidirectional ultrasound sensors can be used instead of HC-SR0.

Appendix A

Features:

• Core: Arm® 32-bit Cortex®-M0 CPU,

•frequency up to 48 MHz

• Memories – 16 to 256 Kbytes of Flash memory – 4 to 32 Kbytes of SRAM with HW parity

• CRC calculation unit

• Reset and power management – Digital & I/Os supply:

VDD = 2.4 V to 3.6 V – Analogue supply: VDDA = VDD to 3.6 V – Power-on/Power down reset (POR/PDR) – Low power modes: Sleep, Stop, Standby

• Clock management – 4 to 32 MHz crystal oscillator – 32 kHz oscillator for RTC with calibration – Internal 8 MHz RC with x6 PLL option – Internal 40 kHz RC oscillator

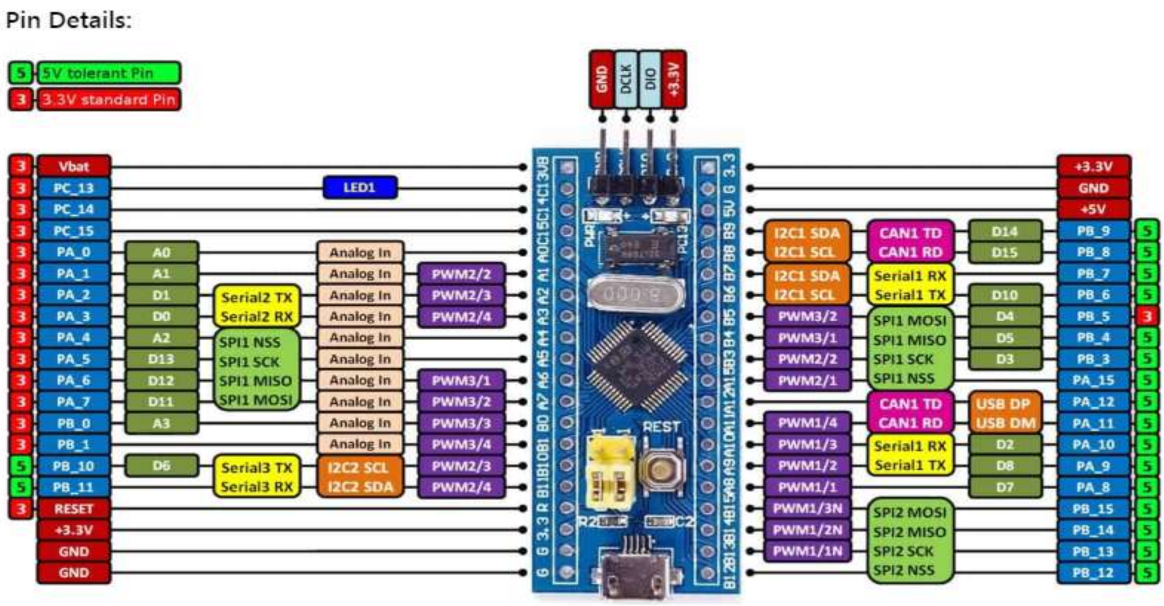
• Up to 55 fast I/Os – All mappable on external interrupt vectors – Up to 55 I/Os with 5V tolerant capability

• 5-channel DMA controller

• One 12-bit, 1.0 µs ADC (up to 16 channels) – Conversion range: 0 to 3.6 V – Separate analogue supply: 2.4 V to 3.6 V

• Calendar RTC with alarm and periodic wakeup from Stop/Standby

• 11 timers – One 16-bit advanced-control timer for six-channel PWM output – Up to seven 16-bit timers, with up to four IC/OC, OCN, usable for IR control decoding – Independent and system watchdog timers – SysTick timer .



FigureA.1: pin configuration of the STM32

Appendix B

The ultrasonic sensor (or transducer) works on the same principles as a radar system. An ultrasonic sensor can convert electrical energy into acoustic waves and vice versa. The acoustic wave signal is an ultrasonic wave travelling at a frequency above 18 kHz. The famous HC SR04 ultrasonic sensor generates ultrasonic waves at 40 kHz frequency.

Typically, a microcontroller is used for communication with an ultrasonic sensor. To begin measuring the distance, the microcontroller sends a trigger signal to the ultrasonic sensor. The duty cycle of this trigger signal is 10µS for the HC-SR04 ultrasonic sensor. When triggered, the ultrasonic sensor generates eight acoustic (ultrasonic) wave bursts and initiates a time counter. As soon as the reflected (echo) signal is received, the timer stops. The output of the ultrasonic sensor is a high pulse with the same duration as the time difference between transmitted ultrasonic bursts and the received echo signal.

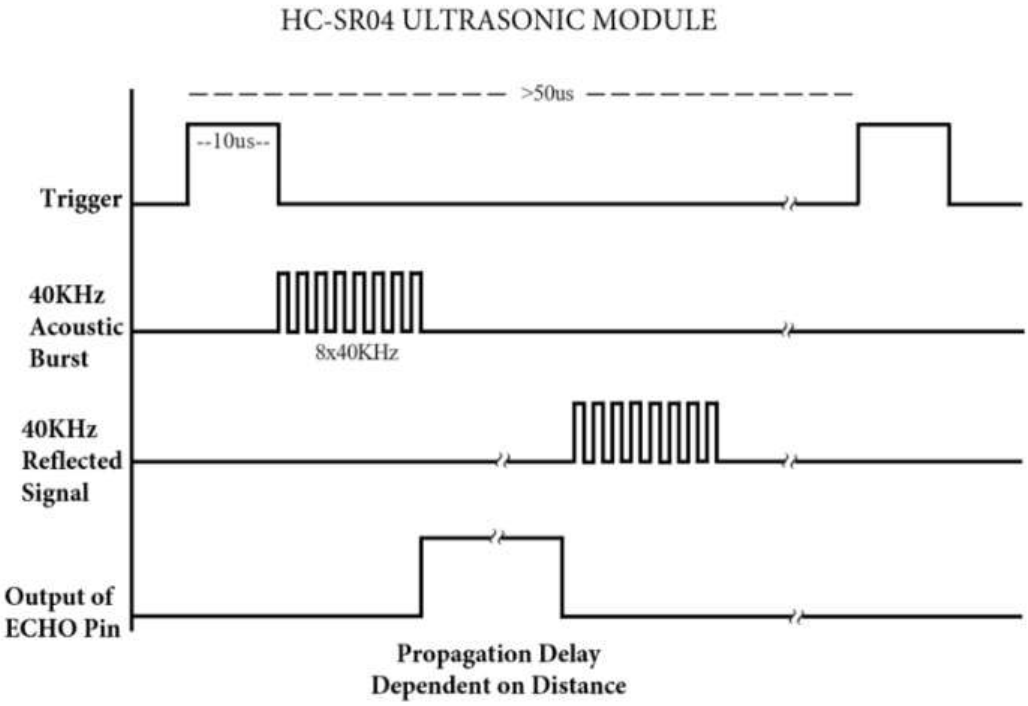


Figure B.1: Representation of trigger signal, acoustic bursts, reflected signal and output of echo pins

Theoretically, the distance can be calculated using the TRD (time/rate/distance) measurement formula. Since the calculated distance is the distance travelled from the ultrasonic transducer to the object—and back to the transducer—it is a two-way trip. By dividing this distance by 2, you can determine the actual distance from the transducer to the object. Ultrasonic waves travel at the speed of sound (343 m/s at 20°C). The distance between the object and the sensor is half of the distance travelled by the sound wave.[iv] The following equation calculates the distance to an object placed in front of an ultrasonic sensor:

$$Distance = \frac{time\ of\ travelxspeed\ of\ sound}{2}$$

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