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MULTI POINT WIND SPEED AND DIRECTION MEASUREMENT AND DATA LOGGING OF REMOTE SITES USING MICROCONTROLLERS

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Multi Point Wind Speed And Direction Measurement And Data Logging Of Remote Sites Using Microcontrollers

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Supervisor

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ABSTRACT

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In order to response to the increasing demand on electrical energy requirement of human beings, investigations for alternative energy resources have become intense, recently. The wind is one of the most important renewable energy source. Since the wind potential varies from site to site because of both topographic and climatic conditions, the wind data measurements gain great importance before installing a wind turbine on a site.

In this study, to be able to measure multi point wind speed and direction using microcontroller, storing the gathered data and to construct the database, a portable and wireless data logger is developed.

In the study, Three NRG maximum #40 anemometers and one NRG #200P wind vane located at each 10 m of a 30 m tall mast. Microcontroller based data logger senses the wind speed data coming from anemometers by three different zero crossing detector, and senses the wind direction data coming from wind vane using an analog-to-digital converter. The sensed data are read after calibration processes and both are stored into an EEPROM and are sent with date-time stamps to central unit using an RF modem and are displayed also on an LCD located in front of the device.

With the help of a second RF modem, which is in receive mode, in central unit, all data are transferred to a PC via serial port. Finally, the written software in PC creates a wind database using the measured wind data of the site.

Key Words: anemometer, wind vane, data logger, 8051, wind energy

ÖZET

MİKRODENETLEYİCİ KULLANARAK ÇOK NOKTADAN RÜZGAR HIZ VE YÖN ÖLÇÜMÜ VE ELDE EDİLEN BİLGİLERİN KAYIT EDİLMESİ.

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İnsanoğlunun, gittikçe artan elektrik enerjisi ihtiyacını karşılamak için alternatif enerji kaynaklarını incelemesi son zamanlarda daha da yoğunlaşmıştır. En önemli yenilenebilir enerji kaynaklarından birisi de rüzgardır. Ancak gerek topografik ve gerekse de iklim şartları dolayısıyla rüzgar potansiyeli bölgeden bölgeye fark etmektedir. Bu nedenle, bir alana rüzgar türbini kurulmadan önce o alanın rüzgar bilgilerinin ölçümünün yapılması büyük önem kazanmıştır.

Bu çalışmada, mikrodenetleyici kullanarak çok noktadan rüzgar hız ve yön ölçümlerinin yapılabilmesi ve kaydedilip, veri tabanı oluşturulabilmesi için, portatif ve kablosuz bir kayıt cihazı geliştirilmiştir.

Çalışmada, 30 m uzunluğundaki ölçüm direğine 10'ar metre arayla üç adet NRG #40 rüzgar hız ölçüm cihazı ve bir NRG #200P rüzgar gülü yerleştirilmiştir. Mikrodenetleyici tabanlı kayıt edici, 3 ayrı sıfır geçiş dedektörüyle rüzgar hız ölçüm cihazlarından gelen rüzgar hızını, bir analog-sayısal dönüştürücüyle de rüzgar gülünden gelen rüzgar yönü bilgilerini algılamaktadır. Algılanan sinyaller kalibrasyon işlemlerinden sonra hem bir EEPROM'da saklanmakta hem bir RF modem yardımıyla tarih ve zaman bilgileriyle birlikte merkezi üniteye gönderilebilmekte hem de cihazın ön panel göstergesinde görülebilmektedir.

Merkezi ünitede, alıcı konumundaki ikinci bir RF modem vasıtasıyla gelen tüm bilgiler seri veri yolu aracılığıyla bir kişisel bilgisayara aktarılmaktadır. Kişisel bilgisayarda yazılı olan program vasıtasıyla da ölçüm yapılan bölgenin rüzgar değerlerine ilişkin veri tabanı oluşturulmaktadır.

Anahtar kelimeler: rüzgar hız ölçüm cihazı, rüzgar gülü, kayıt edici, 8051, rüzgar enerjisi

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CHAPTER 1

INTRODUCTION

Electrical energy plays an important role in showing the development of a country. The usage of electrical energy increases year by year because of growing population, being clean and ease of use.

There are various methods to produce electricity energy. According to OECD/IEA World Energy Outlook 2004, almost 65% of total electricity is produced with fossil fuels, 17% of total energy is produced with nuclear power [1]. Although oil and gas are used to generate 26% of electricity, it is understood that it is risky producing electrical energy depending on petroleum products with petroleum crisis in 1973. Additionally, due to limited fossil fuel resources, and their negative environmental impacts such as air pollution, acid rain, greenhouse effects, and threatening human health, renewable energy resources have gained great importance. After the world energy crisis, the World Meteorological Organization (WMO) started to evaluate the wind energy potential with all the data available [2].

Wind energy has been used for centuries by human beings for their social activities such as sailing, graining, and water pumping. The first modern windmill for producing electricity was designed in Denmark at the end of the 19^{th} century. But oil, coal and natural gas were promoted as cheap sources of energy and this prevented the wind turbine technology from improving.

Towards the end of the 20^{th} century, wind turbines were significantly improved. Today, wind energy seems to be the most suitable and cost effective power source for electricity production comparing to other renewable energy sources. [3].

Although, Turkey has a large potential for renewable energy sources, and the potential to fulfill its total energy needs from wind energy, it is an energy-importing country [4]. There are appreciable number of windy days in many parts of Turkey, but the possibility of wind energy generation assessment has not been completed yet.

Before installing wind turbines, a feasibility study should be carried out, to decide the exact site and avoid waste of money [5].

The proposed system in this study can be used to evaluate the wind energy potential of an area. And this helps us to give the exact decision if the area is suitable for wind turbines or not.

Additionally, the topographic and climatic conditions must be taken into consideration while deciding about effectiveness of the wind speed measurement around a site. After selection of a windy site, the first step will come true for installation the wind turbine, if the wind data is satisfactory. Of course, there are a lot of parameters such as the type of wind turbine, the power range, the conversion method, and return of investment, etc.

In this work, portable, flexible, and microcontroller-based wireless data logger is designed in order to take wind measurements of a site. This data logger collects data from wind instruments and transfers them with time stamp using RF modems to Electrical and Electronics Engineering department.

To measure wind speeds 3 NRG #40 maximum anemometers and to measure the wind direction NRG #200P wind vane are located on a 30 m tall mast. These sensors are linked to the microcontroller unit via an interface circuit. The wind data is measured at determined intervals and then is stored in non-volatile memory with the real time stamps.

A written PC software logs all the data coming from receiver unit and process the data in order to create a database for wind speed and direction statistics. The program can also display all data as graphic form. Having user friendly interface, the program can easily be used.

In chapter 2, a general review and short information about anemometers are given. The hardware of the designed system is explained in detail in chapter 3 and the software of both PC and microcontroller are presented in chapter 4. Finally, the obtained results and the work are discussed in chapter 5.

CHAPTER 2

GENERAL REVIEW

2.1 Introduction

Conventional methods of generating electricity burn fuel to provide steam to drive a turbine generator. These technologies may use fossil fuels - coal, oil or gas – or nuclear power to generate heat. All these sources create environmental pollution and contributes to global climate change.

Wind turbines produce electricity by using the natural power of the wind to drive a generator. The wind is a clean and sustainable source, it does not create any pollution and it will never run out.

Wind energy technology is developing fastly. Wind turbines are becoming cheaper and more efficient, bringing the cost of electricity down. Whereas, Europe was at the hub of this industry, all countries have started to work on producing electrical energy from the wind.

Some useful information about wind, wind power, wind turbines and wind sensors are given in the following sections.

2.2 The Wind

As a clean, free, and inexhaustible energy, the wind is caused by the sun. Approximately 2% of sun energy reaching the earth, heats the surface of the earth. The heat coming from the sun is absorbed by the air molecules. When the temperature of air molecules reaches a certain degree, the air begins to rise. And this movement creates low pressure area at ground level and high pressure area above ground level.

Naturally, air flows from high pressure areas to low pressure areas and this flow creates the wind. The sun heats the equator more, because of being close to it. The air molecules of equator move north and south poles after heated. As warm air rises, cooler air fills the space left by rising air. As a result global circulation occurs. Finally, the global circulation and varied air pressure are distributed over a wide geographical area.

But, wind doesn't always flow from the equator in direction of poles. The rotation of the earth creates a force called the corolios force. Around 30º latitude, corolios force prevents the air from moving farther, because of existence of high pressure in those area. And corolios force results low pressure at equator, high pressure at poles [6].

The wind is highly variable both geographically and temporally. Spatial variability causes many different climatic regions in the world.

Winds can be classified by either the scale, the forces that generate them or the geographic regions where they exist. There are mainly two kinds of winds, according to their scales. The geostrophic winds are driven by temperature differences and pressure differences The geostrophic wind is found at altitudes above 1000 meters above ground level. Its speed can be measured using weather balloons. Local winds are largely affected by the surface of the earth. The flat regions, uneven regions, and very smooth regions of the earth affect the wind near the surface of the earth to varying degrees. The local winds are essential for using wind power.

2.3 The Wind Power

The wind has been used for many centuries mainly for grinding grain, or pumping water, while in sailing ships the wind has been an essential power.

Although the use of wind turbines to generate electricity is in late 19th century, the development of wind energy delayed because of cheap petroleum products.[7]

Because of decreasing fossil fuel sources and environmental problems of nuclear energy, the development of wind power based systems has been accelerated, and modern wind technology is growing faster than any other energy technology.

Wind turbines capture the kinetic energy in surface winds and convert it into electrical energy. They have been developed with a range of power from a few kilowatts up to megawatts capacity. Providing power to local grid, such as coal, and hydro electrical generation from wind energy is called large scale wind generation. Small scale wind generation means that providing power to a home or business. These turbines are placed the same site where the electricity will be used.

Electrical power in the wind is a cubic function of speed. If wind speed doubled, it increases eightfold the power.

$$P = \frac{1}{2}\rho A V^3 \qquad (2.1)$$

where ρ is air density, A is the area intercepting the wind, and V is the wind velocity or speed. Air density varies with temperature, warm air density is less than cold air [8].

Wind speed varies with height above the ground level. Topography has a major effect on the wind. Mountains, buildings, trees reduce the wind speed. The effect of these obstacles decreases with increasing height.

Temporal variability of a location means that the amount of wind varies from one year to the next. This variation makes difficult to predict the economic viability for a wind farm project. The economic viability does not only depend on the speed but also depends on cost and performance of installation and energy prices. Before the installation of a wind turbine, it is important to take wind data for at least a year at the site, even longer if possible.

There are two types of wind data, the data taken for a particular site and the data taken for a region. For an accurate prediction of a region, the regional data should be taken instead of a particular site [9].

2.4 Wind Turbines

The wind turbines convert mechanical energy in wind into electrical energy. A typical wind turbine with its parts is shown in figure 2.1 [10].

Here is a brief description of wind turbine's parts [10]:

<u>Anemometer:</u> Measures wind speed and transmits the data to the controller.

<u>Blades:</u> Wind blowing over the blades lifts and rotates the blades.

<u>Brake</u>: Brake stops the rotor in emergencies. It can be applied mechanically, electrically or hydraulically.

<u>Controller</u>: the controller starts up and shuts off the system at preset value.

<u>Gear-box:</u> Gears connect the low speed shaft to the high speed shaft.

<u>Generator:</u> The generator converts the turning motion of the blades into electricity. A coil of wire is rotated in a magnetic field to produce AC electricity.

<u>High speed shaft</u>: Drives the generator.

<u>Low speed shaft:</u> The rotor turns shaft at about 30 to 60 revolutions per minute.

<u>Nacelle:</u> The rotor attaches to the nacelle. Shafts, generator, brake, gearbox and controller are located in nacelle.

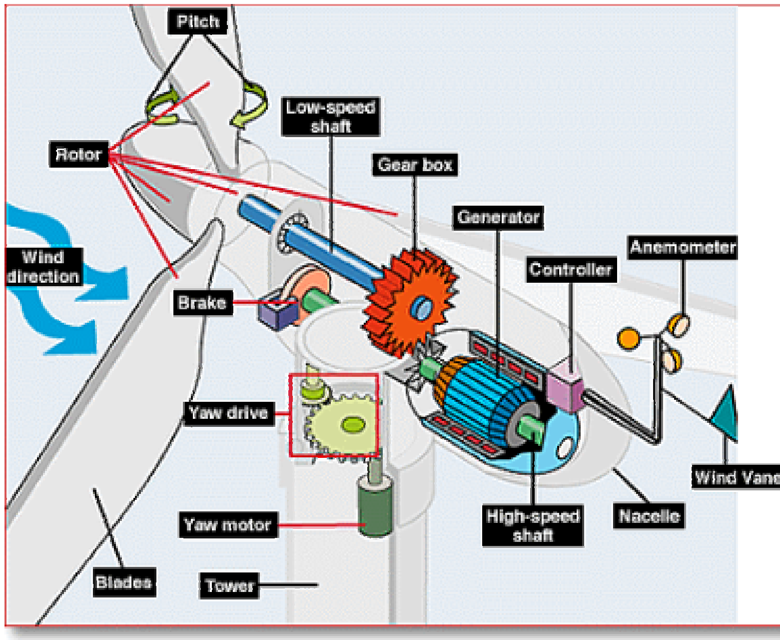


Figure 2.1 The parts of a typical wind turbine

Rotor: The blades and the hub are together called rotor. Rotor collects energy from wind.

Yaw drive: The yaw drive keeps the rotor facing into the wind.

Yaw motor: Powers the yaw drive.

There are also some operation characteristics of wind turbines.

Cut-in speed: The minimum speed at which the blades will turn is called cut-in speed.

Rated speed: The rated speed is the minimum speed at which the wind turbine will generate electricity its designed rated power.

Cut-out speed: The wind speed at which wind turbines shut down is called cut-out speed. To avoid damage, the wind turbines shut down at high speeds.

Betz limit: It is the flow of air over blades and through the rotor area, that makes a wind turbine function. Theoretically, a rotor can collect 59% of the maximum amount of wind energy. This value is known as Betz limit.

Wind turbines are classified into two general types: horizontal axis and vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground. A vertical axis machine has its blade rotating on an axis perpendicular to the ground. Wind turbines can also be separated by the location in which they are to be used: onshore and offshore wind turbines.

2.4.1 Horizontal axis wind turbines

This is the most common wind turbine design because of being parallel to the ground, the axis of blades rotation is parallel to the air flow. Some machines are designed to operate in an upwind mode whereas others operate in downwind mode. In upwind mode, turbine blades are made stiff to prevent the blades from being pushed into the tower by high wind speeds. Downwind machines don’t need an additional mechanism for keeping them in the line with high speeds. The blades can be allowed to bend which reduces the swept area. Because of having turbulence problem of downwind turbines, most horizontal turbines are upwind machines. Figure 2.2 shows a horizontal wind turbine[11].

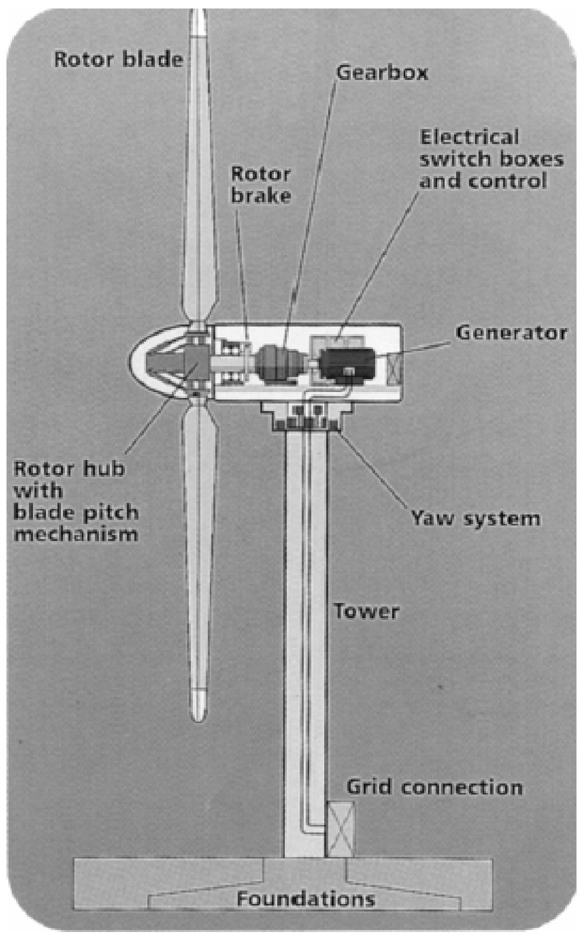


Figure 2.2 Horizontal axis wind turbine [11].

2.4.2 Vertical axis wind turbines

Vertical axis turbines have the main rotor shaft vertically. Although vertical axis wind turbines have existed for centuries, they are not as common as horizontal axis turbines. These turbines don't take advantage of the higher speeds at higher elevations above the ground. Additionally, the pulsating torque produced during each revolution and the difficulty of mounting vertical axis on tower are the disadvantages of vertical axis wind turbines. A vertical wind turbine can be seen in figure 2.3 [11].

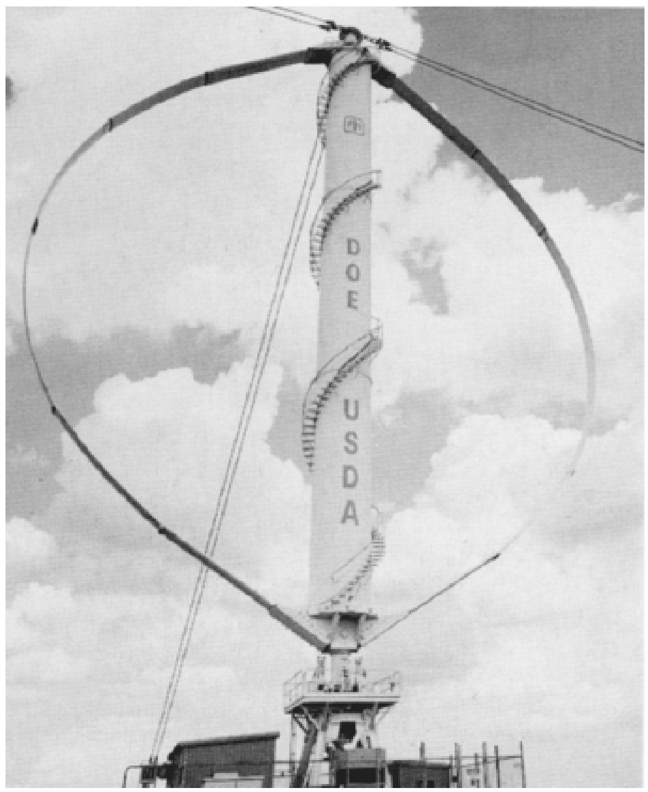


Figure 2.3 Vertical axis wind turbine [11].

But the advantages of this design are that the generator, gearbox can be placed at the bottom, near the ground, and the tower doesn't need to support, and finally the turbine doesn't need to follow the wind. The only vertical axis turbine which has ever been manufactured commercially at any volume is the Darrieus machine, named after the French engineer Georges Darrieus who patented the design in 1931.

2.5 The Wind Direction

Before answering the question if the site where wind tribune will be installed is suitable or not, a wind measurement should be taken. Wind speed and direction data are collected at certain intervals using anemometers and wind vane. Despite the measuring wind direction is optional, it is required especially for the sites which are influenced by obstructions or irregular terrain. Because, the obstacles such as trees, buildings etc. are turbulence creating effects and make the wind direction vary. The direction of wind effects the optimum operation of the wind turbine.

Wind direction is showed by the wind vanes. These instrument generally consist of a weight pointer connected to a small plate. The pointer and plate are attached to a rotating vertical shaft. The air flow causes the instrument to rotate, and it points the source of wind. The weighted pointer reduces the effects of small variations of air flow. Generally, a potentiometer is attached to the rotary shaft and the resistance is varied with rotating of shaft.

A typical wind vane is shown in figure 2.4

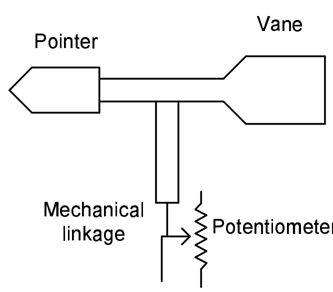


Figure 2.4 Wind Vane

In order to read accurate data, wind vane must be located well above the ground and away from the obstructions. NRG #200P wind direction vane, which is shown in figure 2.5, is used to measure the direction in this study. #200P has a continuous rotary 10 kΩ potentiometer that it generates analog signal output. When shaft turns the wiper moves from top to bottom of the resistance varies from “0” to “R”, the resistance of potentiometer, and the signal varies from “0” to “V”, proportional voltage, direction.

The sensor range is 360° and rotates continually. Other features of #200P wind vane are as in Table 2.1 [12].

Figure 2.5 NRG #200P Wind vane

Table 2.1 #200P specifications

Applications	- wind resource assessment - meteorological studies - environmental monitoring
Signal type	Analog DC voltage
Accuracy	Potentiometer linearity within %1
Dead band	8º maximum, 4º typical
Threshold	1 m/s
Output signal range	0 V to excitation voltage
Lifespan	50 million revolutions (2 to 6 years operation)
Shaft, Bearing	Stainless steel

2.6 The Wind Speed

The second and more important measurement of wind is wind speed measurement. Wind speed is the rate of air flow at a certain point above the ground.

In early part of nineteenth century Admiral Beaufort developed the wind velocity scale that bears his name. This scale is never used to provide accurate wind speed measurement. It is used only to estimate upon the impact of the wind on the environment, the beaufort wind scale is shown in table 2.2 [13].

Table 2.2 Beaufort wind scale

Wind force		Average wind speed(*)			
Beaufort	Name	m/s	km/h	knots	miles/h
0	Calm	0-0,2	< 1	< 1	<1
1	Light air	0,3-1,5	1-5	1-3	1-3
2	Light breeze	1,6-3,3	6-11	4-6	4-7
3	Gentle breeze	3,4-5,4	12-19	7-10	8-11
4	Moderate breeze	5,5-7,9	20-28	11-16	13-18
5	Fresh breeze	8,0-10,7	29-38	17-21	19-24
6	Strong breeze	10,8-13,8	39-49	22-27	25-31
7	Near gale	13,9-17,1	50-61	28-33	32-38
8	Gale	17,2-20,7	62-74	34-40	39-46
9	Strong gale	20,8-24,4	75-88	41-47	47-54
10	Storm	24,5-28,4	89-102	48-55	55-63
11	Violent storm	28,5-32,6	103-117	56-63	64-74
12	Hurricane	>= 32,7	>= 118	>= 64	>=75

(*) 1m/s = 3,6 km/h = 1,944 knots = 2,237 miles per hour

To understand and classify the wind speed measurement easily, table 2.3 can be used.

Table 2.3 A simple description of wind speeds

Wind speed in m/s	Description
<5	Very slow wind
5-10	Slow wind
10-20	Considerable wind
20-30	Very windy, caution is advised
>30	Extreme wind, dangerous

The first wind speed measuring instrument was invented by Leon Battista Alberti in 1400s. Wind speed is measured by anemometers. The term is derived from Greek word ‘anemos’ meaning wind. However, there are many types of anemometers commercially available, anemometers mainly are four different types.

2.6.1 Cup anemometers

Cup anemometers usually are designed with three conical or spherical cups mounted on arms connected to a rotating vertical shaft. The anemometer rotates in the wind and generates a signal proportional to wind speed as shown in figure 2.6.

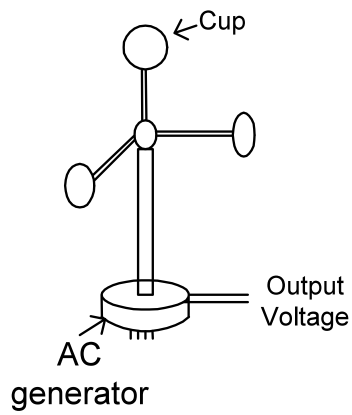


Figure 2.6 Cup Anemometer

The shaft is often coupled to an electric generator so the magnitude of the generator's output voltage and frequency increase with the velocity of wind. The output voltage is at millivolt voltage level. In order to start to rotate at low wind speeds, rotary parts should be as light as possible. Three cups are often used for turbulence measurement and for more routine of wind measurements.

2.6.2 Hot-wire anemometer

Hot-wire anemometers are often used for very accurate laboratory measurements. They are designed with an electrically heated wire on the end of a sensor probe and an electronic module.

Air molecules pass over the heated wire and cool the wire. As heated wire cools, the circuit increase the current in order to heat the wire until reaches the preset temperature. The more air velocity increase, the more current is provided.
A typical how-wire anemometer is shown in figure 2.7.

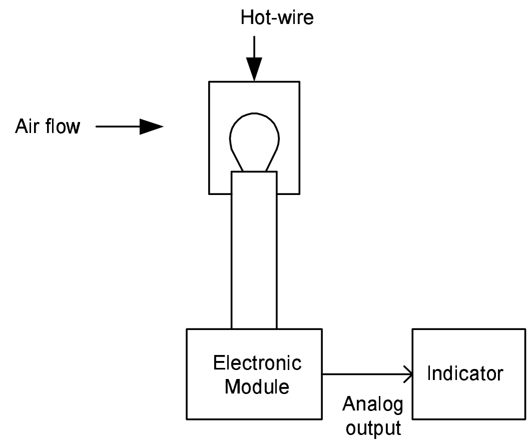


Figure 2.7 Hot wire anemometer

Air velocity is calculated by the difference in the magnitude of control signal. The hot-wire anemometers are expensive instruments and are suitable for laboratory applications.

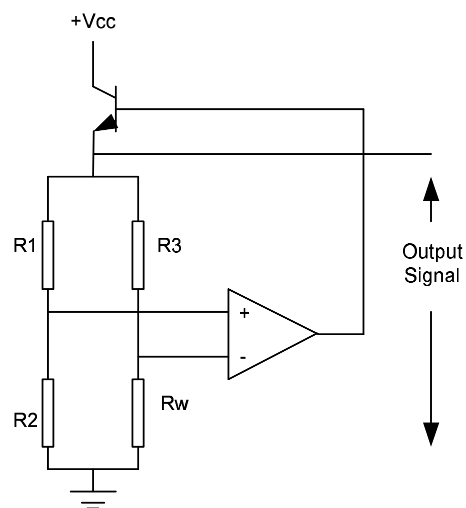


Figure 2.8 Circuit of hot wire anemometer

The base-emitter voltage senses the temperature, and provides power for resistor bridge. When op-amp senses any voltage difference between its inputs, drives the transistor to make the voltage difference zero, see figure 2.8.

If air molecules cool the resistive sensor, the resistance will decrease. The non-inverting input of op-amp decreases and the output increases. Increasing voltage of op-amp output increases the emitter voltage and so the current of resistance bridge.

2.6.3 Pitot anemometers

The pitot anemometer is a simple device for air pressure measurement system. It consists of a tube containing liquid with one end is in horizontal direction to face the wind. When air flows into tube, it causes a dynamic pressure to exert proportional to the velocity of air.

A typical pitot anemometer is shown in figure 2.9.

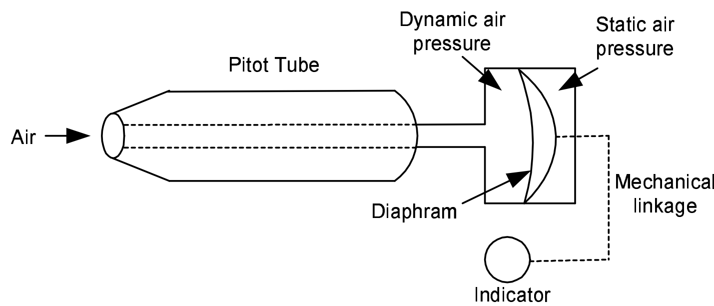


Figure 2.9 Pitot tube anemometer

Since the direction of air molecules is not always with the axis of the tube, this type of anemometers are not as accurate as others. Pitot tube anemometers can be used especially in application at which air flow is fixed.

2.6.4 Acoustic anemometers

The air flow affect the speed of acoustic sound wave. Acoustic anemometers consist of a transmitter and a receiver with a precise distance between them, as shown in figure 2.10. Sound energy is emitted from transmitter and is received by receiver. The passing time for the sound energy to reach the receiver is proportional to the velocity of air flowing in the space between transmitter and receiver.

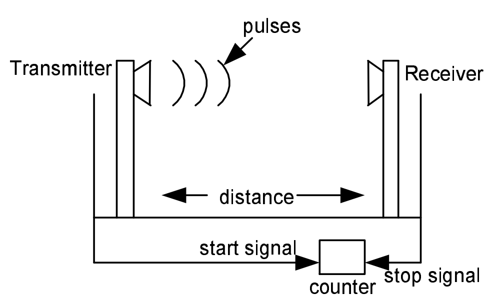


Figure 2.10 Acoustic anemometer

Because of existence the space, this type of anemometers can be effected by temperature and pressure changes. For this reason, acoustic anemometers must be calibrated accurately.

As seen from previous pages, the cup anemometers are more simple, reliable to operate and has relatively lower cost.

Figure 2.11 NRG maximum #40 cup anemometer

The NRG #40 maximum anemometer, which is shown in figure 2.11, is used to measure the wind speed. NRG #40 anemometers have recorded wind speed of 96 m/s. because of their output linearity, these anemometers are ideal for use with various data retrieval system [15]. The specifications of this anemometer is shown in table 2.4.

Table 2.4 Maximum #40 specifications

Sensor type	3-cup anemometer
Applications	- wind resource assessment - meteorological studies - environmental monitoring
Sensor range	1 m/s to 96 m/s (highest recorded)
Signal type	low level AC sine wave, frequency linearly proportional to wind speed
Transfer function	m/s = (Hz x 0.765) + 0.35
Accuracy	within 0.1 m/s for the range 5 m/s to 25 m/s
Output signal range	0 Hz to 125 Hz (highest recorded)
Threshold	0.78 m/s

Table 2.4 (cont.)

Distance constant (63% recovery)	3.0 m
Swept diameter of rotor	190 mm (7.5 inches)
Cups	one piece injection-molded black polycarbonate
Body	housing is black ABS plastic
Shaft	beryllium copper, fully hardened
Bearing	modified Teflon, self-lubricating
Magnet	Indox 1, 25 mm (1 inch) diameter, 13 mm (0.5 inch) long, 4 poles
Coil	single coil, bobbin wound, 4100 turns of #40 wire

Calibration process of these anemometers will be mentioned in next chapter.

2.7 Summary

The wind is a clean, free and renewable energy source. Wind turbines convert mechanical energy in wind into electrical energy. There are two types of wind turbines; horizontal axis wind turbines and vertical axis wind turbines. The wind speed is measured with anemometers and wind direction is measured with wind vanes. NRG #40 maximum anemometers and #200P wind vane were used as wind sensors in this study.

CHAPTER 3

HARDWARE OF SYSTEM

3.1 Introduction

The hardware may be explained in three main sections. The first is reading wind sensors. Sinusoidal signals coming from anemometers are applied to interface circuit in order to convert into square wave and the voltage on potentiometer of wind vane is converted to digital form by an ADC. The second section is connection of microcontroller to the peripherals such as RTC, EEPROM. And the third is the connection of RF modems both to microcontroller and to the PC.

In this chapter, the calibration of sensors, the features of IC2 and devices and connections of peripherals to the microcontroller is explained in details.

3.2 Operation of The Complete System

The operational block diagram of the complete system is shown in figure 3.1. As seen in figure, 3 anemometers are used to measure the wind speed at different heights and these instruments are connected to an interface circuit which includes zero crossing detector. Microcontroller sends a control signal to the interface circuit in order to select the desired anemometer.

The wind vane, sensing the wind direction, is connected to an analog-digital-converter. Microcontroller sends start bit and control word through serial data line, if an analog-digital conversion is needed. Analog input is converted to digital binary code and is sent via digital output pin to microcontroller by ADC.

512K EEPROM is connected serially and it is used to store speed, direction, date and time data. If EEPROM reaches its maximum, microcontroller reads all data from EEPROM, sends to serial port and waits for the user to select a function by using keypad.

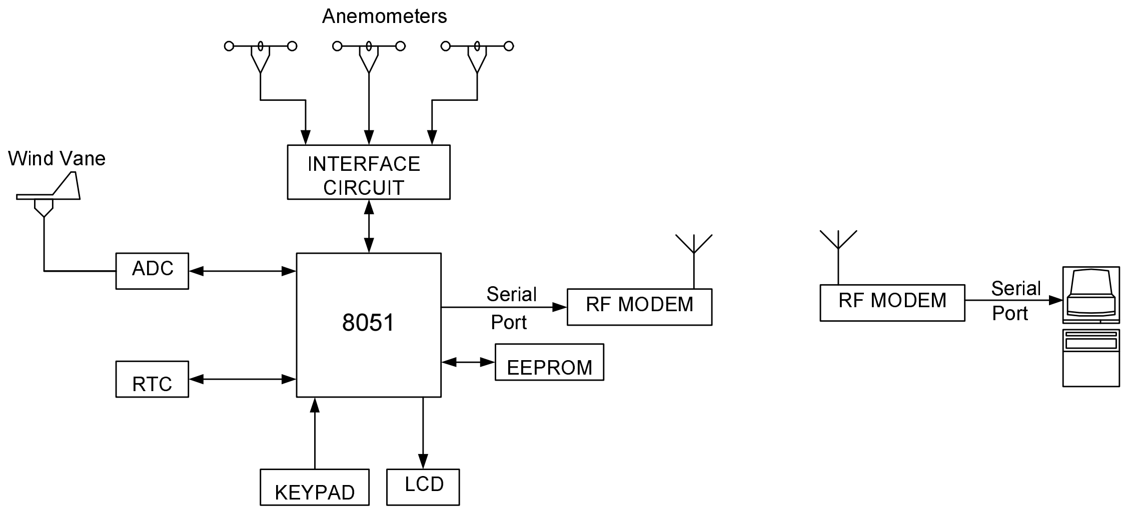


Figure 3.1 The block diagram of complete system

RTC, DS1307, is set with the help of keypad. Microcontroller reads date and time from RTC after every cycle to label wind speed and direction data with date and time. Since RTC is supplied with a +3 V battery, it can track the real time even if the power fails.

A 3x4 keypad is used to enter data and to select function, a 2x16 character LCD is used to display data in the system.

RF modem is connected to the system via serial port and with an on-circuit microcontroller, it logs the data coming from 8051 and sends to the base wireless unit, so an RF serial link is established. The RF modem in base unit writes the data coming from remote unit to serial buffer. A small software reads these data and saves in the file named “wind.dat” in PC. The main program, written in Delphi 6.0, reads “wind.dat” file, processes the data and creates a database. This database can be used for a wind map of the area where the remote unit is placed.

3.3 The Calibration of Anemometers

The NRG maximum #40 anemometers were calibrated in fluids mechanics laboratory of Mechanical Engineering of Gaziantep University. In order to use as a wind tunnel, a pipe had been made which was 5 meters of length and about 30 cm of diameter. The pipe had three parts and it was mounted carefully to prevent any turbulence creating element. The designed wind tunnel is shown in figure 3.2.

The air flow was provided by an inverter controlled motor located in the one end of the pipe. A handheld anemometer was mounted in the other end of the pipe, and the air velocity was measured and recorded in almost every step of frequency by changing the frequency of inverter. Then, the handheld anemometer was replaced with the cup anemometers one by one, and the frequency of the pulses from the cup anemometers was measured and recorded with a digital frequencymeter.

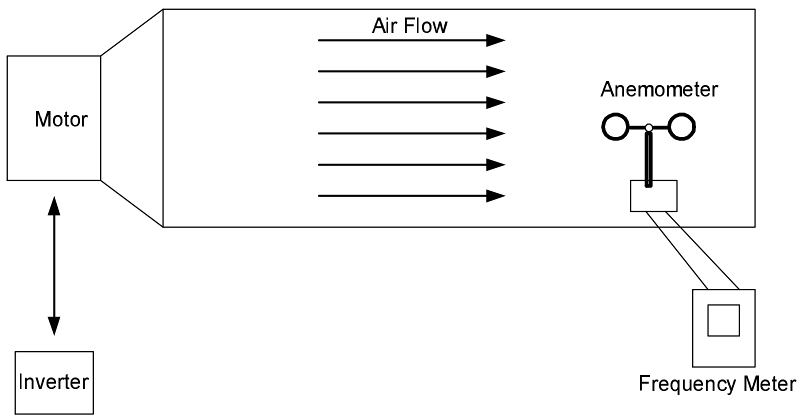


Figure 3.2 Calibration procedure of cup anemometers

The values of experiment are presented in table 3.1;

Table 3.1 Measured values of anemometers' calibration procedure.

Measured speed by handheld anemometer (m/s)	Frequency of Anemometer 1 (Hz)	Frequency of Anemometer 2 (Hz)	Frequency of Anemometer 3 (Hz)
1,42	1,046	1,193	1,129
2,00	1,857	2,421	2,092
2,50	2,785	2,968	2,719
2,90	3,429	3,281	3,295
3,30	3,759	3,766	3,705
3,70	4,641	4,446	4,405
4,20	5,133	5,245	5,034
4,60	5,420	5,690	5,526
5,00	5,872	6,042	6,123
5,50	6,800	6,790	6,470
6,00	7,669	7,260	7,416
6,50	8,268	8,043	7,959
7,20	8,606	8,236	8,627
7,80	9,040	9,355	9,214

In general transfer function for the anemometer is

$$v = A.f + B \tag{3.1}$$

where v is speed (m/s), f is frequency (hz), A is the slope and B is v-intercept. In order to determine A and B, we can apply a statistical treatment known as linear regression to the data.

$$A = \frac{n\sum(vf) - \sum f \sum v}{n\sum(f^2) - \left(\sum f\right)^2} \tag{3.2}$$

$$B = \frac{\sum v - A\sum f}{n} \tag{3.3}$$

where n is data points.

The wind measurement mast is 30 m tall. It has three cup anemometers which are at 10 m, 20 m, and 30 m heights, and one wind vane at 30 m height. The mast can be seen in figure 3.3. The pictures of installation of mast can be seen in appendix C. The reason for measuring wind speeds at three different height is to observe changes in the speeds with heights.

Figure 3.3 The erected mast.

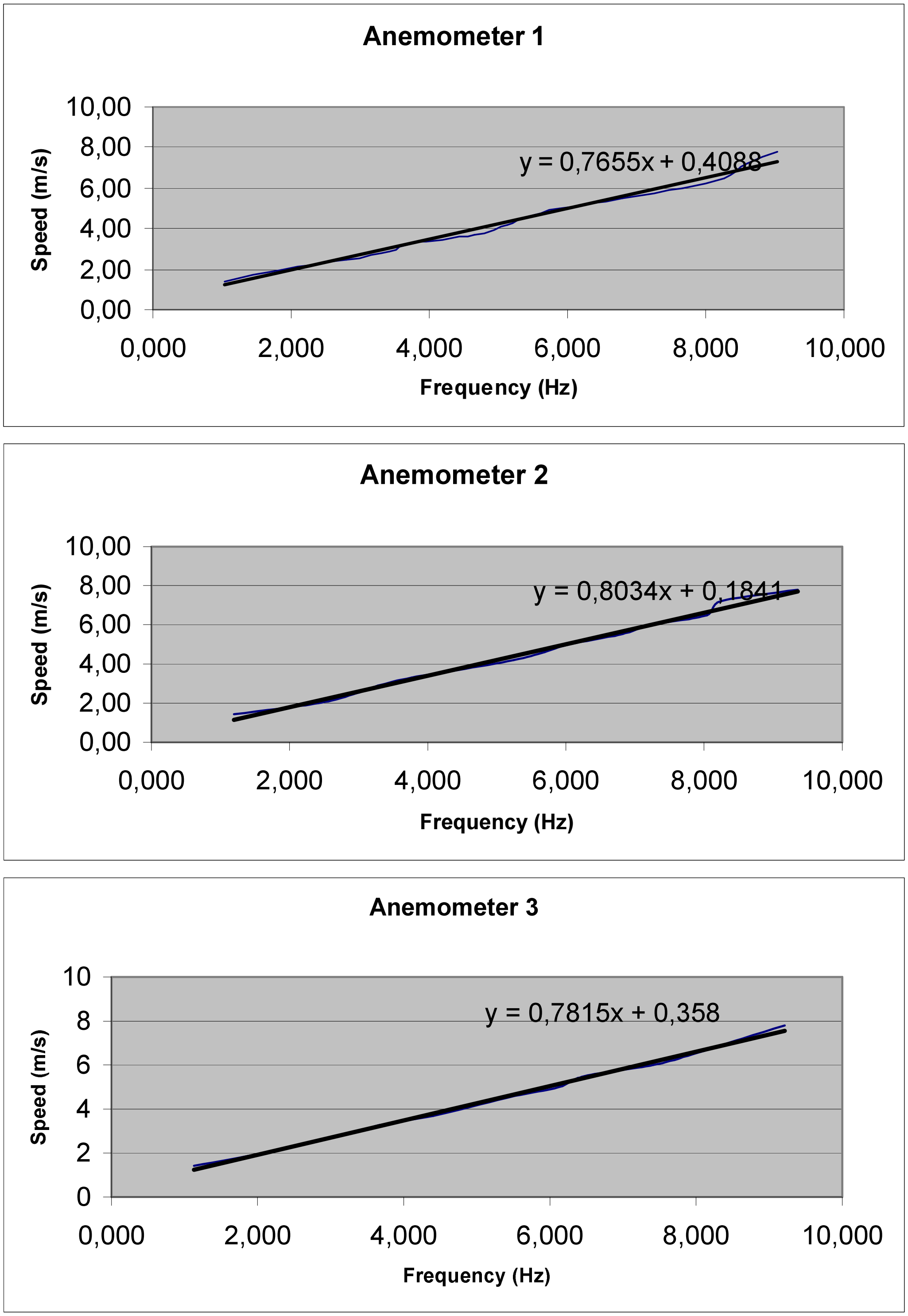


Figure 3.4 The transfer functions of cup anemometers

3.4 Calibration of Wind Vane

Wind vane contains a 10K potentiometer, and the resistance of terminals are changed by changes of wind direction, as mentioned before. In order to calibrate, the wind vane was located in the center of a smooth regular plate as shown in figure 3.5.

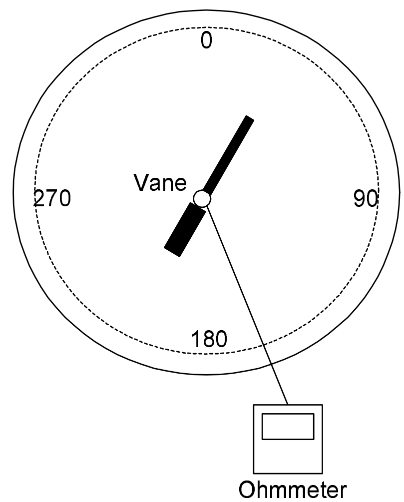


Figure 3.5 Calibration procedure of wind vane

The terminal resistance of vane was measured with an ohmmeter in every 20º increment by rotating the wind vane. The relation of angles and resistance is found as in table 3.2;

Table 3.2 Measured values of wind vane's calibration procedure

Angle	Resistance (ohm)
0	94
10	10860
30	10240
50	9620
70	9000
90	8330
110	7790
130	7180
150	6600
170	5940
190	5310
210	4690
230	4120
250	3430
270	2830
290	2200
310	1630
330	900
350	344

The direction is divided into 32 sectors. Thus each (360/32) 11.25° points one sector of the direction. The related resistance for one part is (10k/32) 312,5 ohm. This means dividing the resistance value of vane by 312,5 gives us the number of direction.

3.5 AT89S8252 Microcontroller

The 8051 microcontroller was developed by intel in 1980. Although it was very popular in the 1980's. Today, more than 20 manufacturers, Atmel, Maxim, Motorola, Dallas etc., developed and made more powerful 8051-based microcontrollers one of them called 8052.

The 8051-based microcontrollers typically include 8-bit CPU, 64K code memory addressing area, 64K data memory addressing area, 4K code memory, 128 or 256 byte internal data RAM, 2 or 3 timers/counters, 32 pin I/O lines, 1 or 2 UARTs.

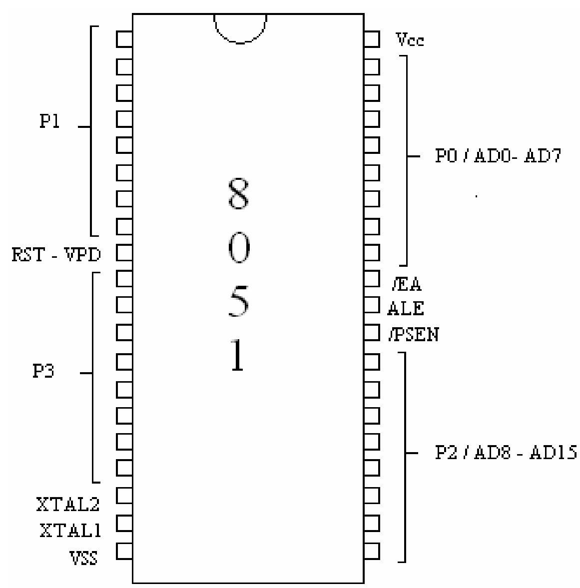


Figure 3.6 8051 pin outs

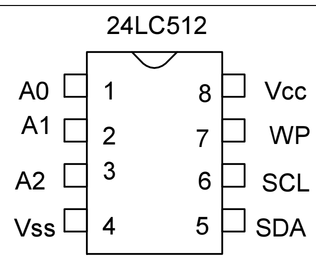
AT89S8252 8-bit microcontroller, from Atmel, is used in this study. This microcontroller has three 16-bit timers/counters, 8 KB flash memory, 9 interrupt sources, 32 input/output lines. Port 0 pins are assigned to keypad, port 1 pins are linked to LCD, some pins of port 2 and port 3 are used for other purposes, such as interrupt input, serial communication.

For further information about 8051 based microcontrollers, please look at appendix A.

3.6 EEPROM

An EEPROM (Electrically Erasable Programmable Read Only Memory) is a non-volatile storage chip used in many devices. Two types of EEPROM are commercially available, parallel EEPROMs and serial EEPROMs. The main feature of serial EEPROMs is the ability to communicate through a serial interface where it can be done through a parallel interface in parallel EEPROMs.
Serial EEPROMs require only two lines to communicate, thus the hardware interface requirements are kept at minimum.

A 24LC512 cmos serial EEPROM is used in the system for storage. The pin assignment and pin descriptions of EEPROM is shown in figure 3.7.



	A0	User defined Chip select
	A1	User defined Chip select
	A2	User defined Chip select
	Vss	Ground
	SDA	Serial Data
	SCL	Serial clock
	WP	Write protection
	Vcc	Power supply

Figure 3.7 24LC512 pin description

This EEPROM is a 64Kx8 (512 bit) serial EEPROM, supports a bi-directional 2-wire bus and data transmission protocol. As all devices that use i2c protocol, 24LC512 has a unique address, A0H, for controlled by master device which is 8051 in the system. Before all read and write operations a control byte must be written on SDA line. The control byte consists of a control code, chip select bits, and read/write bit [18].

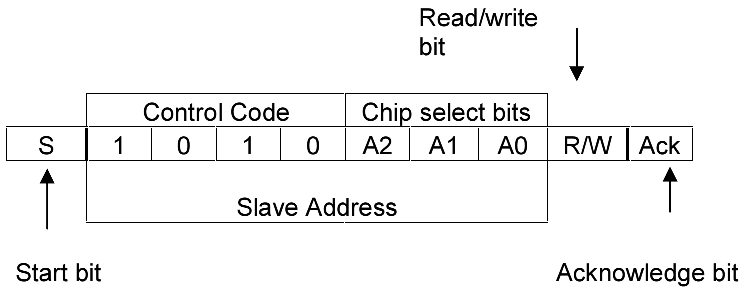


Figure 3.8 Control word of serial EEPROM

High order address byte and low order address byte follow acknowledge bit. So the device allow user to access any location of memory.

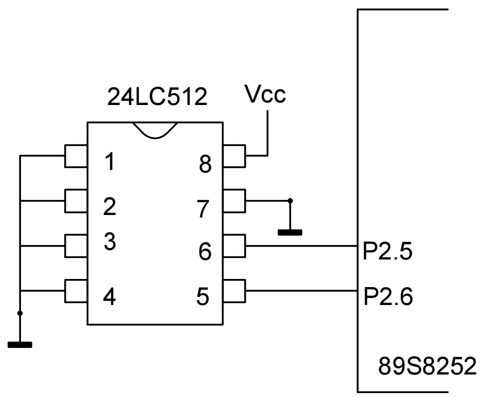


Figure 3.9 Connection of EEPROM to Microcontroller

Up to 8 serial devices can be used as slave devices in serial communication. If 2 or more devices are located on the bus, chip select bits are used to select the device which master to communicate. Only one EEPROM is used in the system. Thus, chip select pins are strapped to ground. As connection of ADC and RTC, SCL pin is connected to P2.5 and SDA pin is connected to P2.6. WP (write protection) is grounded to disable the protection, as shown in figure 3.9.

To write data on EEPROM byte write and page write operations are applied whereas to read data from EEPROM current address read, random read, and sequential read operations can be used. In byte write operation, master (8051) sends start bit and control byte, if slave (EEPROM) acknowledges, high order address byte and low order address byte are sent by 8051 before data. After receiving the last acknowledge bit, master sends data to be written on memory location and the operation ends by a stop bit generated by 8051.

The page write operation is executed in the same way but before stop bit, master can send up to 127 byte data. An internal address counter increments the address by 1.

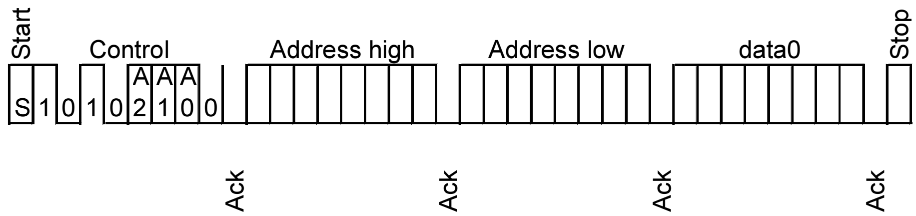


Figure 3.10 Byte write operation

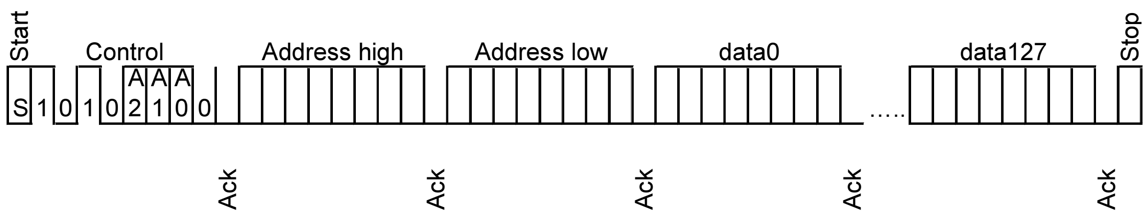


Figure 3.11 Page write operation

Random read allow the 8051 to access any memory location. Before read operation 8051 has to set control byte as if a write operation will be executed and generates a start bit following low order byte. Finally, the control word for read operation (R/W is logic high) is set.

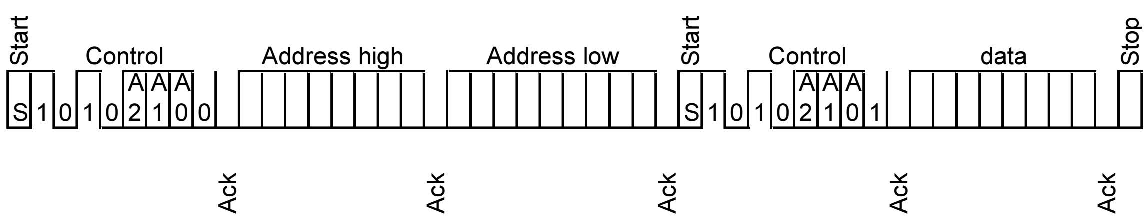


Figure 3.12 Random Read operation

3.7 Serial Real Time Clock

A real-time clock (RTC) is an integrated circuit chip that keeps track of the current time. It is used in many kinds of computers, and is present in all modern personal computers. RTCs are also present in many embedded systems.

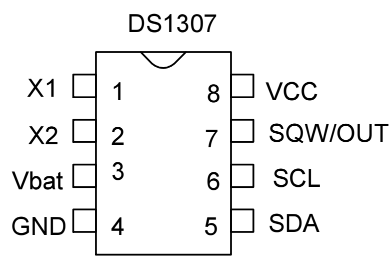


Figure 3.13 DS1307 pin assignment

DS1307 serial real time clock is used to stamp the collected data with time. This RTC provides seconds, minutes, hours, day, date, month and year. The addresses and data are transferred serially via a 2-wire bi-directional bus. DS1307 has 8 pins, and the description of pins is as in table 3.3 [19];

Table 3.3 Pin Description of DS1307

VCC	Power Supply
X1, X2	32.768 kHz Crystal Connection
VBAT	+3 Volt Battery Input
GND	Ground
SDA	Serial Data
SCL	Serial Clock
SQW/OUT	Square wave/Output Driver

SCL is used to synchronize data transfer on serial interface and SDA is the input output pin for serial interface.

The DS1307 operates as a slave device on the serial bus. Access is obtained by implementing a START condition and providing a device identification code followed by a register address. Subsequent registers can be accessed sequentially until a STOP condition is executed. When VCC falls below 1.25 x VBAT the device terminates an access in progress and resets the device address counter. Inputs to the device will not be recognized at this time to prevent erroneous data from being written to the device from an out of tolerance system. When VCC falls below VBAT the device switches into a low current battery backup mode. Upon power up, the device switches from battery to VCC when VCC is greater than VBAT+0.2V and recognizes inputs when VCC is greater than 1.25 x VBAT.

Figure 3.14 RTC Address Map

The real time clock registers are located in 00H – 07H. If the program writes 02H for address byte, the register for hours can be changed or read. Address map of DS1307 is shown in figure 3.14. The DS1307 supports i2c protocol (bi-directional serial data transmission protocol). A further information about this protocol will be given later.

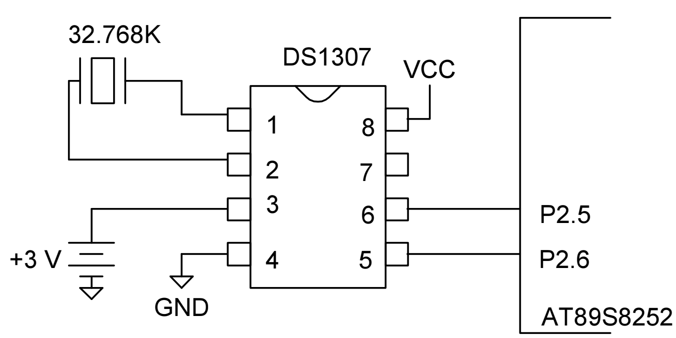


Figure 3.15 Connection of DS1307 to Microcontroller

A +3 V battery connected to real time clock so that it can track the time even if the system is off. P2.5 and P2.6 are used for serial clock and serial input output data respectively. As all other serial devices that uses i2c protocol, DS1307 has an unique address, D0H for writing data and D1H for reading data, to access the device. Figure 3.15 shows the connection of RTC. Two sub routine is written for real time clock, the first is used to set the parameters of RTC by using keypad and the second is used to read time and date when needed.

3.8 Analog to Digital Converter

An analog to digital converter, ADC, converts an analog signal to digital codes that consist 1's and 0's. So, typically an ADC has an analog input and either a serial or a parallel output. Analog to digital converters has many forms.

In this work successive approximation ADC was used. This type of ADC has 3 main parts which are; digital analog converter, successive approximation register and a comparator. In a successive approximation ADC, the SAR generates a series of digital codes as it is clocked, which are fed into the reference DAC one at a time. The digital codes are generated in binary, the bits are toggled to logic '1' one at a time starting with the MSB. If the bit toggled to '1' causes the DAC to output an analog voltage that exceeds Vin, then it is returned to '0', otherwise it is kept at logic '1'. Eventually all the bits would have been exercised, and the resulting digital code is the one that causes the DAC to produce an analog voltage that is as close to Vin as possible without exceeding it. Thus, this will be the same digital code released by the ADC to its outputs, since it was basically the code that produced a voltage equal to Vin using the internal reference DAC.

ADC0832 is used in this work. The pins of ADC can be seen in figure 3.16. It is 8-bit successive approximation analog digital converter with a serial I/O and configurable input multiplexer with 2 channels. The input multiplexer are configured by software as single ended or differential inputs [20].

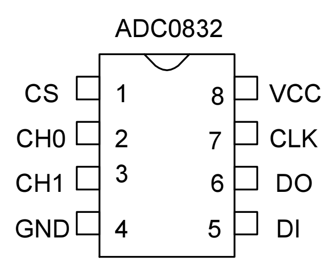


Figure 3.16 ADC0832 Top View

Multiplexer Addressing: The actual converted voltage is the difference between "+" input terminal and "-" input terminal. The polarity of each input terminal of the pair being converted indicates which line the converter expects to be the most positive. If the assigned “+” input is less than the “-” input the converter responds with an all zeros output code. Before starting of a conversion, the mux address selects which of the analog inputs are to be enabled and whether this input is single-ended or differential. In the differential case, it also assigns the polarity of the channels.

Single Ended Mux Mode			
Mux address		Channel	
SGL / DIF	ODD/ SIGN	0	1
1	0	+	
1	1		+

Differential Mux Mode			
Mux address		Channel	
SGL / DIF	ODD/ SIGN	0	1
0	0	+	-
0	1	-	+

Figure 3.17 Multiplexer modes of ADC

Since the input configuration is under software control, it can be modified, as required, at each conversion. A channel can be treated as a single-ended, ground referenced input for one conversion; then it can be reconfigured as part of a differential channel for another conversion.

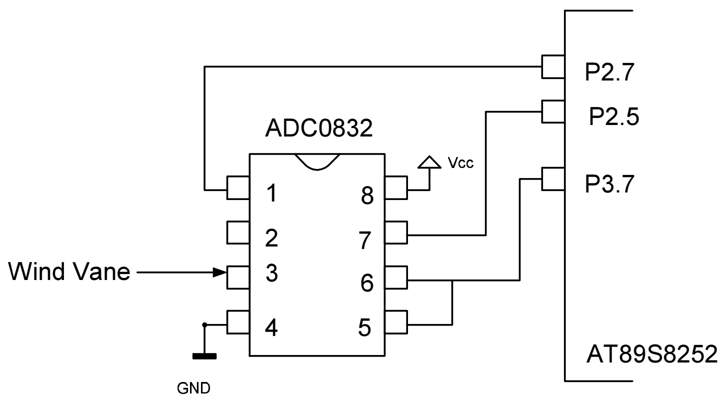


Figure 3.18 Pin Connections of ADC to Microcontroller

Wind vane (analog input) is connected to CH1 pin, P2.7 is used to start conversion connected to chip select pin. The output signal is read by P3.7, and the clock signal produced by P2.5, as shown in figure 3.18. Single ended mode is selected in the program of microcontroller to read ADC.

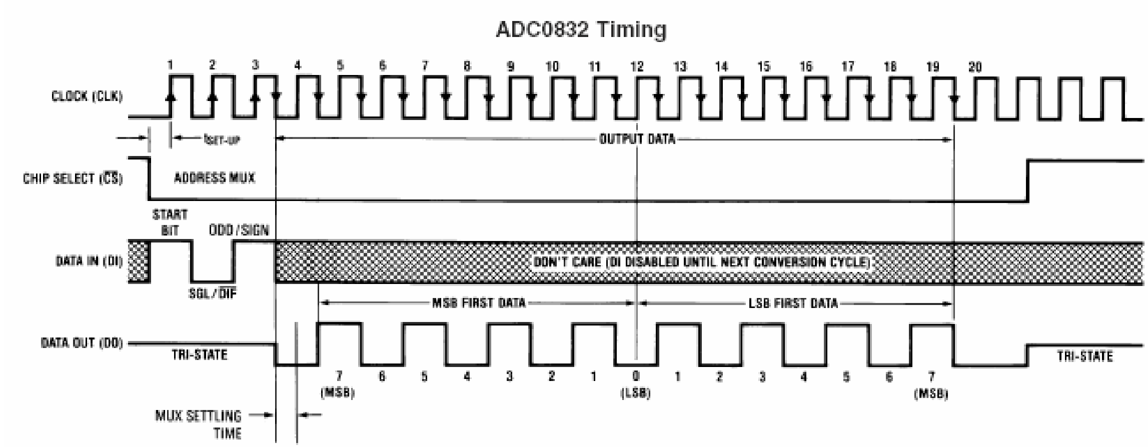


Figure 3.19 Timing diagram of ADC

In the program, chip select signal is made low and the control word, 7Fh, is sent to ADC via P3.7. Control word contains start bit, single ended mode, and the channel, Ch1. Converted binary data is received and loaded in memory location after setting the digital output.

3.9 LCD

LCD's (Liquid Crystal Display) are manufactured by many companies with many types. There are up to 4 rows and 16 to 40 characters in each row in LCD modules used. Although LCD's are manufactured in various types, they use the same protocol to communicate with controllers and the data bus between controllers and LCD can be 4-bit or 8-bit. A typical 2x16 LCD pins are shown in figure 3.20.

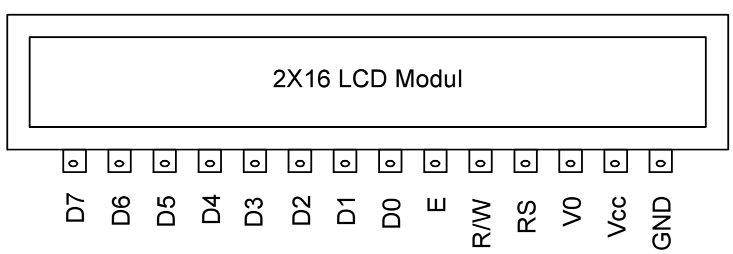


Figure 3.20 LCD pin outs

LCD modules include an internal RAM (display data RAM) to store display data represented in 8-bit character codes, its capacity is up to 80 characters. 16 characters appears at a time. If the data is longer than 16 characters, the others can be displayed by shifting the text.

CGRAM (character generator RAM) is another memory in LCD modules which stores 192 characters. 96 characters are ASCII, 64 characters are from Japanese alphabet and 32 characters are from Greek alphabet.

Table 3.4 LCD pin description

Pin #	Symbol	Function
1	GND	Ground
2	Vcc	Power supply
3	V0	LCD contrast
4	RS	Register Select
5	R/ $\overline{W}$	Read / $\overline{\text{Write}}$
6	E	Enable
7	D0	Data bit 0
8	D1	Data bit 1
9	D2	Data bit 2
10	D3	Data bit 3
11	D4	Data bit 4
12	D5	Data bit 5
13	D6	Data bit 6
14	D7	Data bit 7

The LCD has two 8-bit registers, an instruction register and a data register. The instruction register stores instruction codes, such as display clear and cursor shift, and address information for display data RAM (DDRAM) and character generator RAM (CGRAM). The data register temporarily stores data to be written into DDRAM or CGRAM and temporarily stores data to be read from DDRAM or CGRAM. Data written into the data register is automatically written into DDRAM or CGRAM by an internal operation. The data register is also used for data storage when reading data from DDRAM or CGRAM. These two registers can be selected by the register selector (RS) signal

To determine LCD mode, shifting cursor, clear display, cursor home etc., there are some LCD control commands. These commands can be divided into 5 categories;

1- Initialization commands

2- Cursor commands

3- Display commands

4- CGRAM commands

5- Status Check Commands

The address counter (AC) assigns addresses to both DDRAM and CGRAM. When a "set DD RAM/CG RAM address" instruction is written into the instruction register, the address information is sent from the instruction register to the address counter. Selection of either DDRAM or CGRAM is also determined by the instruction. After writing into (or reading from) DDRAM or CGRAM, the Address counter is automatically incremented or decremented by 1 . The AC contents are output to DB0 to DB6 when RS = 0 and R/W = 1.

To display a character, data is written into instruction register. A character code is then written into data register and the LCD unit displays the corresponding pattern at the specified location. The LCD unit can either increment or decrement the display position after each character entry.

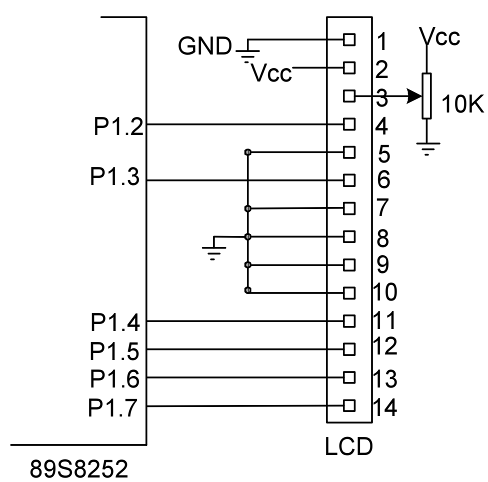


Figure 3.21 Connection of LCD to Microcontroller

Port1 pins are assigned to connection of LCD. The connection of LCD is shown in figure 3.21. The adjustment of contrast is implemented by using a 10K potentiometer. 4-bit data bus is used, thus 4 pins of port1 are connected to 4 data pins of LCD. Since LCD is in write mode, Unused data bits and R/W pin are grounded. Register select and enable signal functions are controlled by P1.2 and P1.3.

3.10 Keypad

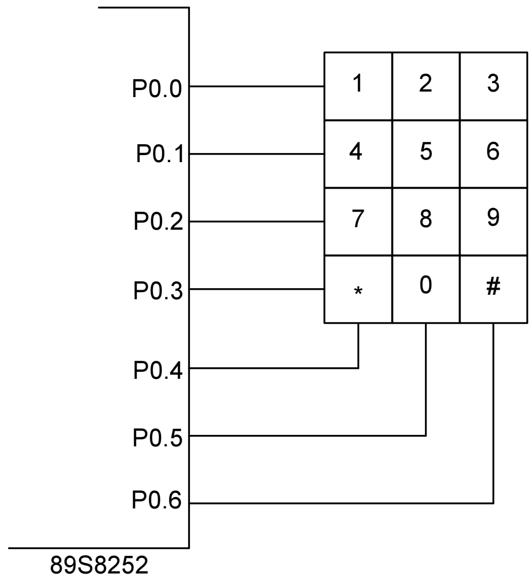


Figure 3.22 Connection of Keypad to Microcontroller

Keypads are often used as a primary input device for embedded microcontrollers. The keypads actually consist of a number of switches, connected in a row/column arrangement. A 3x4 keypad is used in system and some keys are assigned to functions to help the user to control the program.

To determine the pressed key, microcontroller scans the keys one by one. Various methods are used to scan the keypads. P0.0, P0.1, P0.2 and P0.3 pins are outputs and P0.4, P0.5 and P0.6 pins are inputs in this study.

In order for the microcontroller to scan the keypad, it outputs a zero to force one (only one) of the rows low and then reads the columns to see if any buttons in that row have been pressed. Consequently, as long as no buttons are pressed, the microcontroller sees a logic high on each of the pins attached to the keypad rows. The only way the microcontroller can find a 0 on any column pin is for the keypad button to be pressed that connects the row set to 0 to a column. The controller knows which row is at a 0-level and which column reads 0, allowing it to determine which key is pressed.

Table 3.5 Keypad functions

Key	Function
1	Set Date and time
2	Display Wind direction
3	Display Wind speed
4	Display Date and time
5	Start Logging
6	Enter deviation for wind vane
7	Clear Display
8	Send serial without delay
9	Send serial port
*	Enter

3.11 RF Modem

An RF modem is multiple access device that can be used a transceiver. It consists of a whip antenna, a receiver, a transmitter and a RS232 computer interface.
In addition to acting as a transceiver, the modem is also capable of repeating reviewed data packets. In other words, it can receive, store and re-transmit data packets along the address.
In this study, UMD-B12 RF modem, manufactured by UDEA, is used to transmit data from remote unit and receive data to base unit. UMD-B12 contains a voltage regulator, a data module and a RS232 interface. It has 6 channels which are shown in table 3.6, and works in 434 Mhz ISM band [21].

Table 3.6 RF modem channels and frequencies

Channel	Frequency
Ch1	433.0560 Mhz
Ch2	433.3440 Mhz
Ch3	433.6895 Mhz
Ch4	433.9200 Mhz
Ch5	434.3232 Mhz
Ch6	434.7263 Mhz

The serial data is transmitted at 9600 bps, using 8N1format, and if a data packet will be sent to RF Modem from computer, the following format should be applied.

<SRC+DST+D1+D2+……….DX>

where;

<: start of text

SRC: source address, TX modem address

DST: destination address, RX modem address

D1: data1

D2: data2

.

.

.

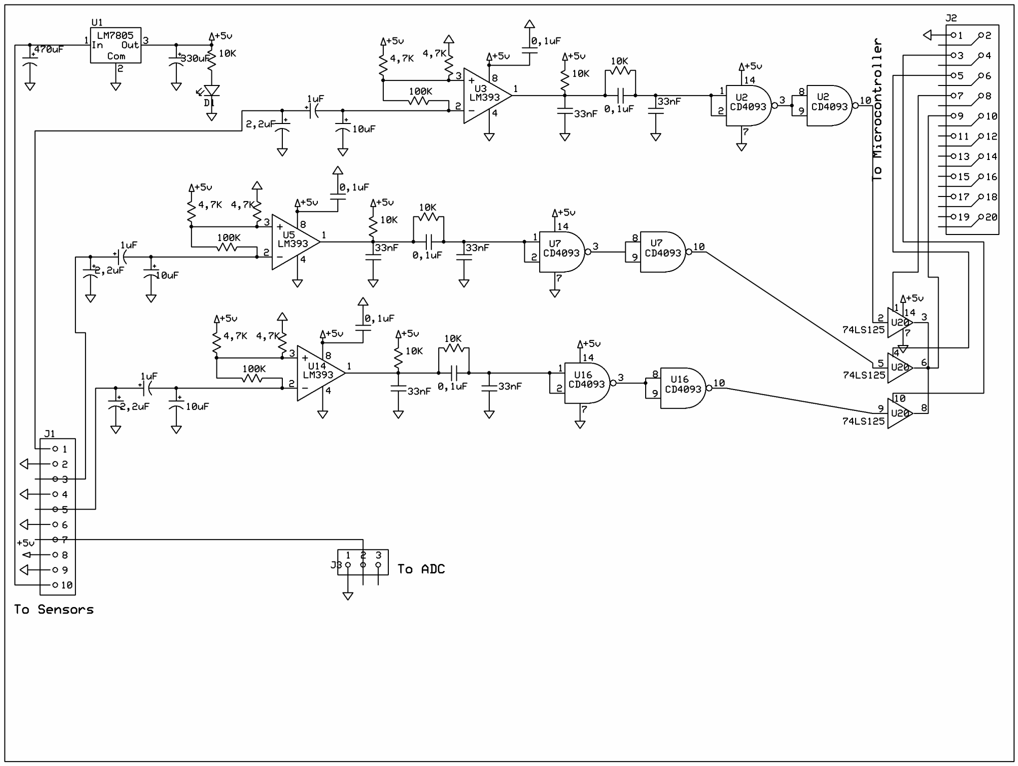
DX: dataX (maximum 75 byte)

>: end of text

In order to select one of six channels, the number of channel must be sent to modem preceding a "C" letter. As an example, If user wants to select channel 4, it is required to type "C4" and sent to both modem via serial port.

3.12 Interface Circuit

An interface circuit is designed to overcome the difficulty of reading sinusoidal signal coming from anemometers and to avoid any conflict while reading anemometers. Interface circuit, whose schematic and a photo are shown in figure 3.23, includes a voltage regulator, 3 zero crossing detectors, and a tri-state buffer to control outputs. Each anemometer has a corresponding zero crossing detector, as name indicates it generates pulses when detects the point where the signal crosses zero in either direction.



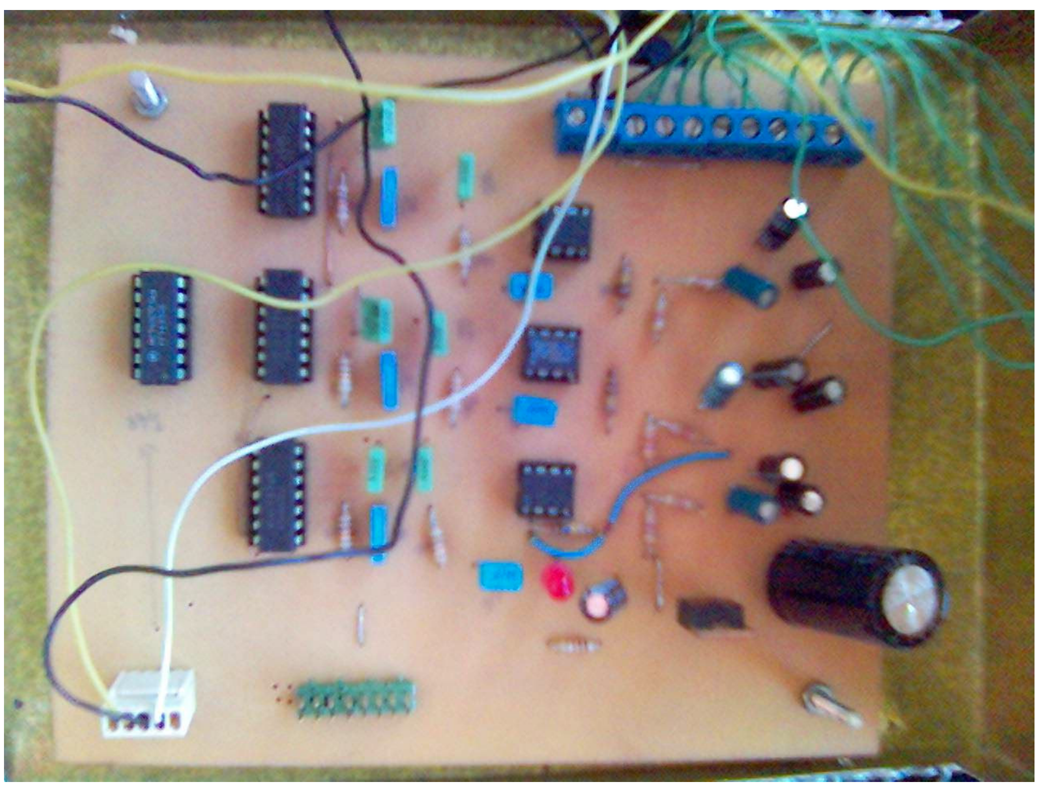


Figure 3.23 Interface circuit

Thus the sine wave is converted to square wave. A schmitt trigger IC is connected to output of zero crossing circuit in order to minimize noise. The Schmitt Trigger is essentially a comparator with hysterisis; it has a threshold of approximately 0.01 volts for a rising input signal, and 0 volts for a falling signal.

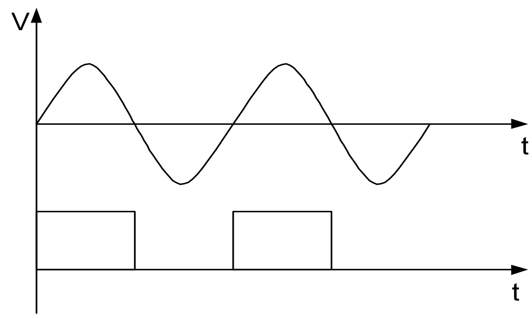


Figure 3.24 sine wave to square wave

The output of schmitt trigger IC's is connected to tri-state buffers in order to be able to controlled by microcontroller.

P3.3, P3.4 and P3.5 pins of microcontroller are used for control signals. The output of tri-state buffers are connected to P3.2 (INT0) pin of microcontroller. Thus if an anemometer will be read, the assigned control pin must be logic 1 while other control pins are logic zero.

The Power Supply circuit is responsible for providing constant voltages to all the other stages in the circuit The components in the power supply circuit were chosen to give clean supplies. The regulator chip (7805) is designed to produce +5V supply, and has safety features to prevent the circuit from overloading.

To ensure that the circuit was functioning properly, the outputs at various stages were monitored during construction of the circuit, using a standard laboratory oscilloscope and a function generator.

3.13 Summary

NRG #40 maximum anemometers were calibrated in Fluids Mechanic laboratory. The anemometers and wind vane were located on a measurement mast. In order to convert the output of anemometers to square wave, an interface circuit was designed. Serial real time clock and serial EEPROM are used i2c protocol to communicate with microcontroller. In the following chapter, the written softwares are discussed.

CHAPTER 4

SOFTWARE OF SYSTEM

4.1 Introduction

A software for microcontroller is written in assembly language whereas Delphi and visual basic are used to write PC program. Because of being too long to print, the algorithms of sub-routines of microcontroller software are described here shortly. Similarly, the functions and used components in PC program are explained to help the reader to understand the program fundamentally. All softwares are loaded into attached CDROM.

A short information about i2c protocol, the microcontroller uses it to communicate with serial devices, is given also in this chapter.

4.2 Microcontroller Program

However microcontroller can be programmed in C or basic, because of flexibility and free of use, assembly programming language is used.

After definition of variables, addresses and bits, program scans whether any key is pressed or not. In case of an pressed key, the related sub-routine is called by main program. If the user specifies to start the data logging with the help of keypad, microcontroller reads the measurement devices periodically which is defined before. Then the data is stored in EEPROM till EEPROM reaches its capacity. When EEPROM is full, program sends all data in EEPROM via serial port to base unit and waits for user to press any key. There are mainly 8 subroutines in the program as seen in figure 4.1.

The RTC device address defined as 0D0H for write operations and 0D1H for read operations. In the setting RTC subroutine, the program waits for user to enter day, month, year, hour, and minute using keypad, respectively. After getting each data, program writes device address and RAM address on data bus. Writing of data follows the address write operations. Finally, user presses star '*' key and RTC starts to run from entered date and time. When user wants to display date and time on LCD, key '4' needs to be pressed.

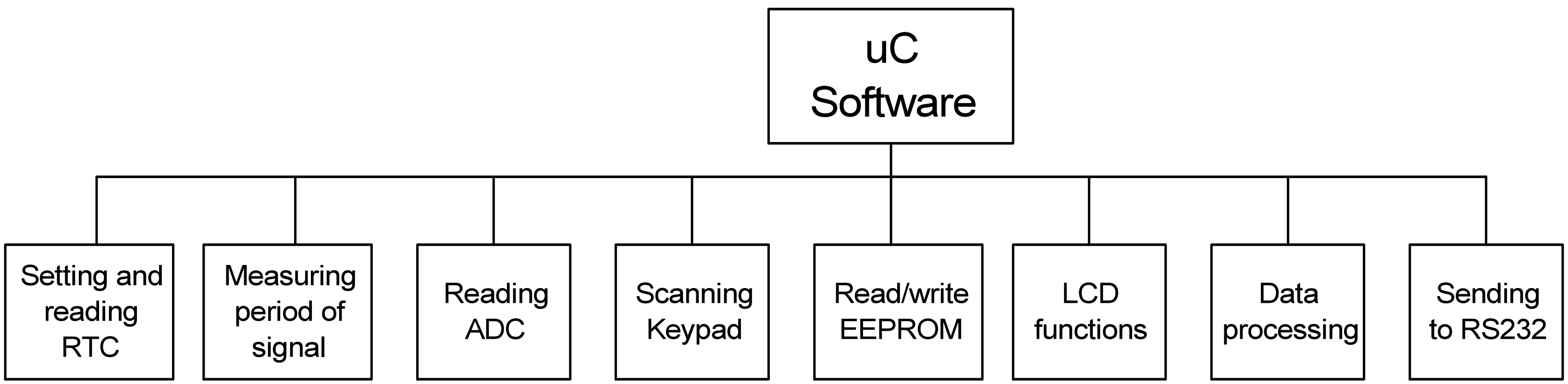


Figure 4.1 Sub-routines of microcontroller program

The program writes device read address and ram address related to date and time. These data are showed on LCD.

In this study, microcontroller runs with an 18,432,000 Hz crystal. Since a single machine cycle consists of 12 crystal cycles, a running timer is incremented

$$\frac{18432000}{12} = 1536000$$

times per second. This means;

$$1\ machine\ cycle = \frac{1}{1536000} = 6,510x10^{-7}\ \text{sec}$$

16-bit counter resets to zero after 65536 cycle and register R2 is used as a second counter to count overflows of timers.

Timer 0 and timer 1 are set to run as an 16-bit timer/counter by initializing TMOD for measuring period of pulse. Initializing of timers, interrupts, and register are in speed1 subroutine.

1	0	0	0	0	0	0	1	=81H

Figure 4.2 TMOD's initial value

LSB of TCON SFR, IT0, is set in order to trigger interrupt INT0 in high-to-low transition. The MSB and LSB of IE SFR are set to enable INT0 interrupt before executing subroutine.

The operational flowchart of the program is given in figure 4.3.

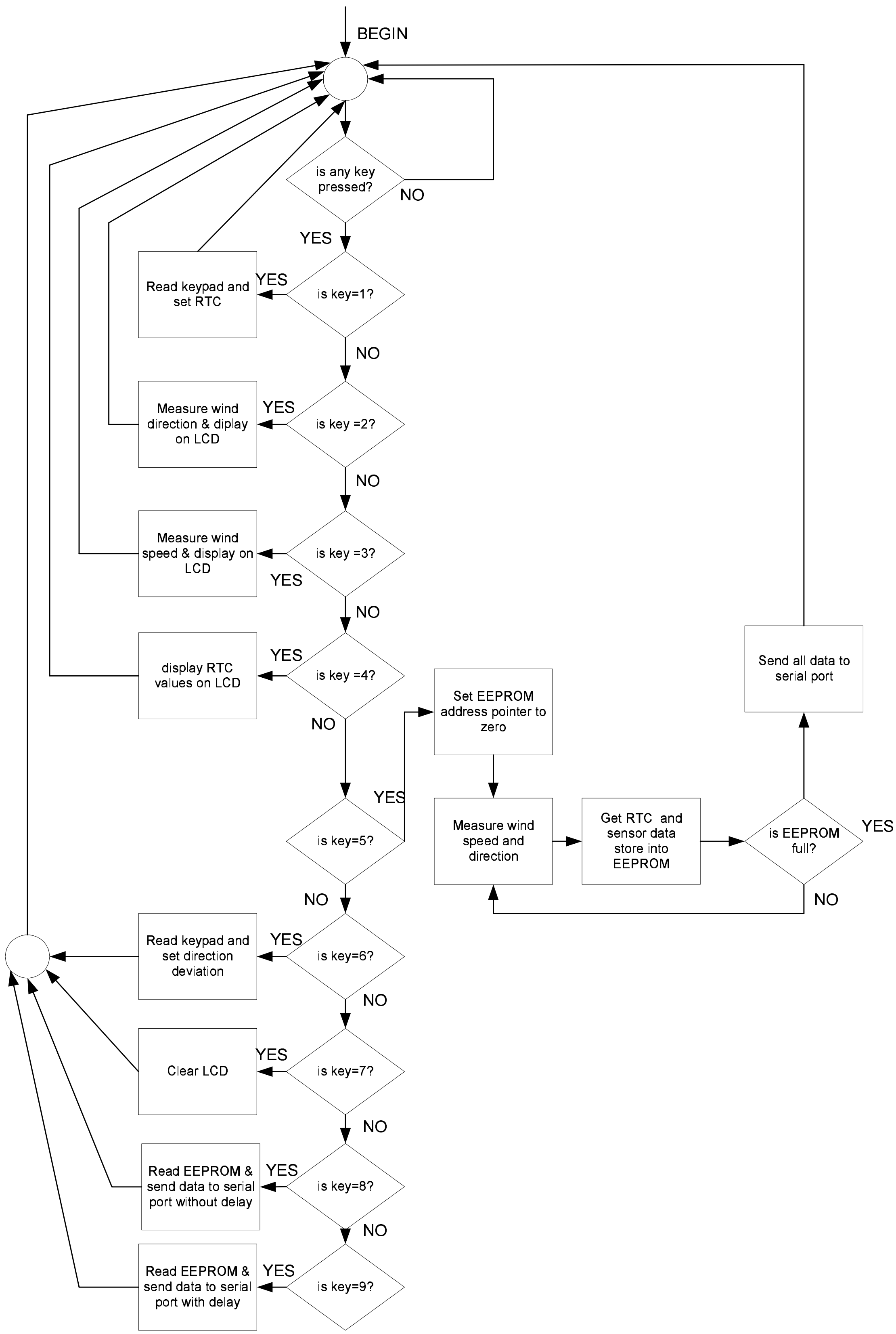


Figure 4.3 Flowchart of microcontroller program

Program checks spdflg to inform if interrupt INT0 is triggered, and jumps to interrupt service routine as soon as senses the event. In the first falling edge of pulse, 16-bit timer/counter starts to run and in the second falling edge, it stops. Register R2 is used as an counter to count overflows of timer. Because timer restarts from '0' if reaches to 65536.

Control pin for desired anemometer is set while others are cleared, and waited for pulse coming from anemometer. In the case of exceeding 2 seconds when waiting for interrupt event. Interrupts are disabled and program sends 'nosignal'. Program jumps interrupt service routine (ISR) when first falling edge triggers INT0, and by setting TR0, timer starts to run. If timer overflows R2 is incremented by 1.

On detecting second falling edge, which is shown in figure 4.6, timer stops and all interrupts are disabled.

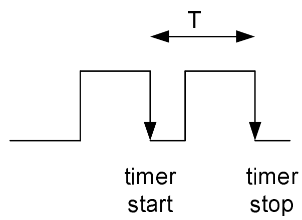


Figure 4.4 Triggering interrupt INT0

The values of timer and register R2 are used to get frequency of signal;

$$f = \frac{1536000}{(R2x65536) + Timer}$$

Wind speed is calculated when frequency is placed in equation of anemometer which is mentioned before.

$$V = axf + b \qquad (4.1)$$

The speed of wind is calculated using the value of R2 and timer value, as follows;

Anemometer 1: $v_1 = 0,765x\left(\frac{1536000}{(R2x65536) + Timer}\right) + 0,409$ (4.2)

Anemometer 2: $v_2 = 0,803x\left(\frac{1536000}{(R2x65536) + Timer}\right) + 0,184$ (4.3)

Anemometer 3: $v_3 = 0,781x\left(\frac{1536000}{(R2x65536) + Timer}\right) + 0,358$ (4.4)

Register R0 and Ram address starting from 30H are used to store speed, date, time, and ADC values. These values are displayed on LCD and are stored into EEPROM.

Wind vane is read by analog to digital converter. CS bit is for chip select, DIO is for digital input – output. Since channel1 (CH1) is used as analog input, with start bit and single ended configuration, the control word should be 7FH.

The first 4 bit are transferred to ADC via DIO pin in order to complete configuration. Then DIO is set as input to read converted digital value of signal. The sum digital value and calibration value is displayed on LCD and is stored in RAM.

Another device that uses i2c protocol is 24LC512 EEPROM. To complete a write operation, device address, memory location address and the data to be written are needed. Device address of EEPROM for write is 0E0H, EEP_CMD_W parameter is assigned to device address and both add_highe and add_lowe are assigned to memory location addresses.

In data logging procedure, to store converted values, date – time values and calculated speed values following RAM location used;

30H – 31H : Speed (Anemometer 1)

32H – 33H: Speed (Anemometer 2)

34H – 35H: Speed (Anemometer 3)

36H: ADC

37H- 38H – 39H – 40H – 41H: Hour, Minute, Day, Month, and Year data of RTC

Starting from 0000H memory location of EEPROM, write_byte subroutine writes the data above into EEPROM, memory location is incremented and memory address is checked if reached to FFFFH which is the maximum address of EEPROM.

A key table for characters assigned to keypad buttons and rows and columns are defined to scan keypad. Port0 pins which are connected to keypad rows are made logic low and the columns are checked to find the pressed key.

In the case of a pressed key, the character assigned to the key is loaded to accumulator. Scan progress jumps to start of subroutine if no key sensed.

Several subroutine has been written to program and to use LCD in the system.

1- Init_LCD: this routine is used to initialize LCD for functions such as determining data pins, initializing cursor, LCD data lines and etc. after definitions, display is cleared.

2- WriteLCD: The text to be displayed is written on data bus using DPTR register with writeLCD. The characters of text should be written one by one, another subroutine which writes only one character, write_LCD, provides this function.

3- WR_INS: this subroutine is used to write LCD commands mentioned before such as cursor commands.

4- Write_LCD: It writes characters value coming from various program using R2 register and accumulator.

RS232 buffering is accomplished through mac232 and a standard DB9 connector connects to the PC. It should be configured SMOD and TMOD registers to set the baud rate of serial port. Serial buffer is checked whether it is busy, after sending the data, and the next byte is sent to serial buffer.

Data coming from sensors and devices are read from EEPROM using block read operation. The difference with byte read and block read operation is to send another data after receiving acknowledge bit instead of stop bit. Thus the master can read up to 127 byte from EEPROM.

All data are stored in a register and following read procedure, program sends them to serial port in the format of RF Modem as <21 A1A1A2A2A3A3VHMDMOY>, where A represents anemometers, V represents vane, H is hour, M is minute, D is day, MO is month and Y is year.

4.3 PC Program

The PC program is developed in Delphi 6.0 and Visual Basic 6.0
A small program code, serial port program, is written in VB 6.0 to read serial port and log data coming from serial port in a file named “wind.dat”.

The main program which is written in delphi, processes the wind data. This program has 3 different forms that 5 tabbed pages. The forms are used for main form, help, and about box whereas tabbed pages are used for detailed data, wind speeds and direction.

The program also includes a menubar to allow the user to load data files, to load data sheets, to display instrument related tabs, to view help and about box forms and to exit.

6 text boxes, 4 buttons, a chart and an image are located in the detailed data tab page to display date, time, speed 1 , speed 2, speed 3 and direction both as text format and as graphical format. This page is shown in figure 4.5.

The tabs of instruments contains a combobox in order to select desired date. When a date is selected from drop-down list. The related speeds (or direction) are shown in graphical format. The form also includes 7 buttons for zooming and scrolling functions of graphic. An anemometer screen is shown in figure 4.6.
Some parts of collected data is given in appendix B.

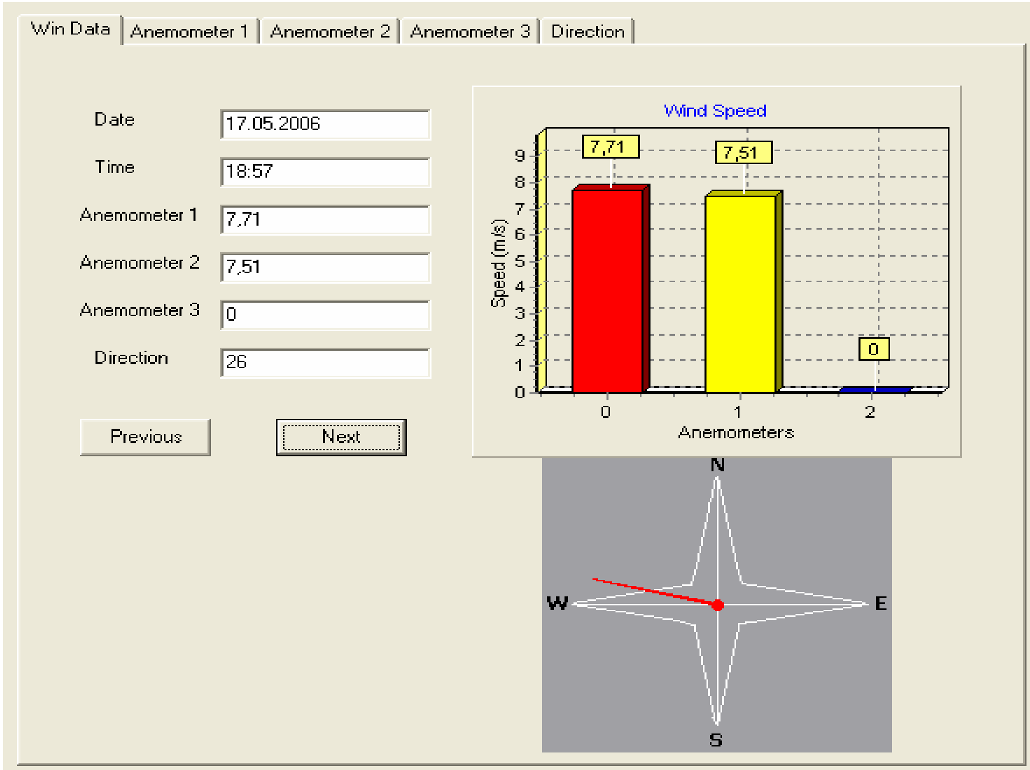


Figure 4.5 Detailed wind data screen of PC program

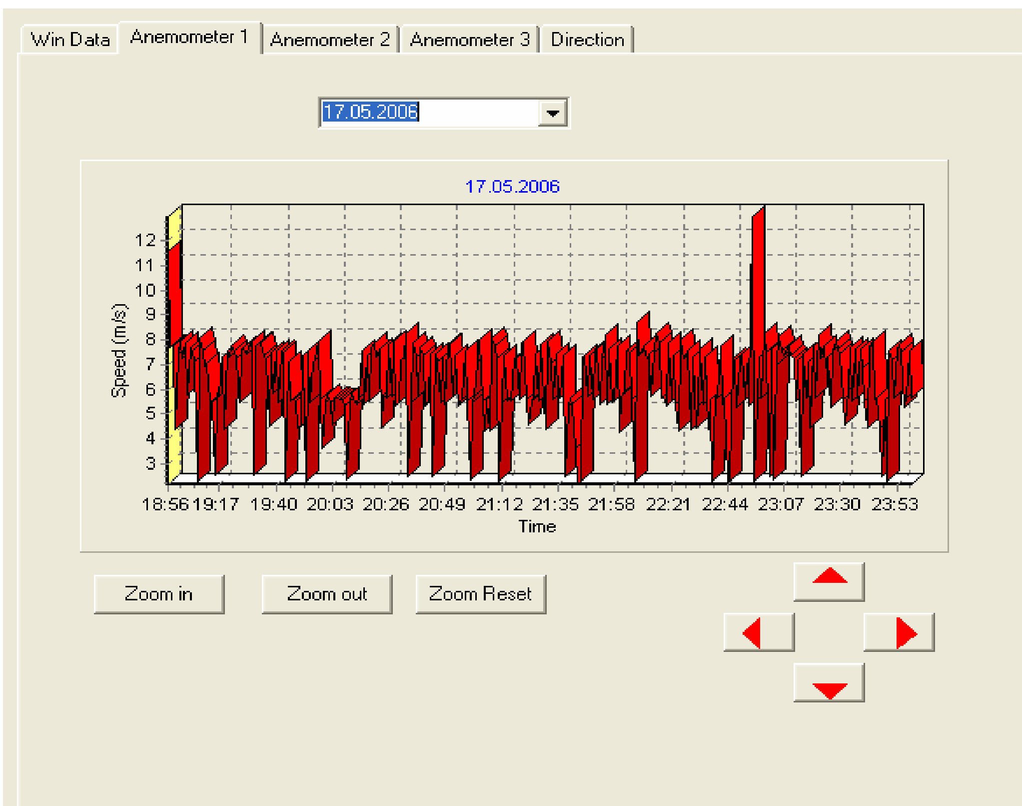
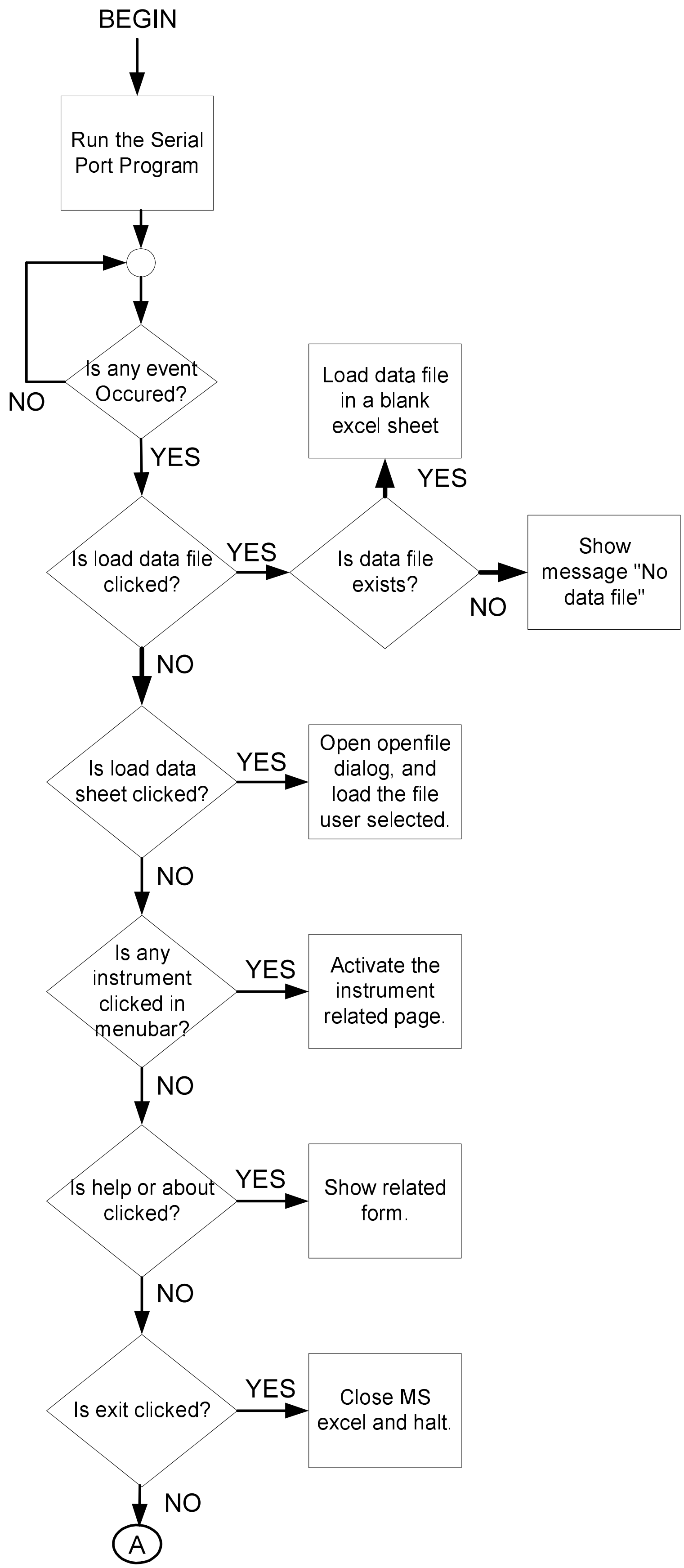


Figure 4.6 Anemometer screen



BEGIN
Run the Serial Port Program
Is any event Occured?
NO
YES
Is load data file clicked?
YES
Is data file exists?
YES
Load data file in a blank excel sheet
NO
Show message "No data file"
NO
Is load data sheet clicked?
YES
Open openfile dialog, and load the file user selected.
NO
Is any instrument clicked in menubar?
YES
Activate the instrument related page.
NO
Is help or about clicked?
YES
Show related form.
NO
Is exit clicked?
YES
Close MS excel and halt.
NO
A

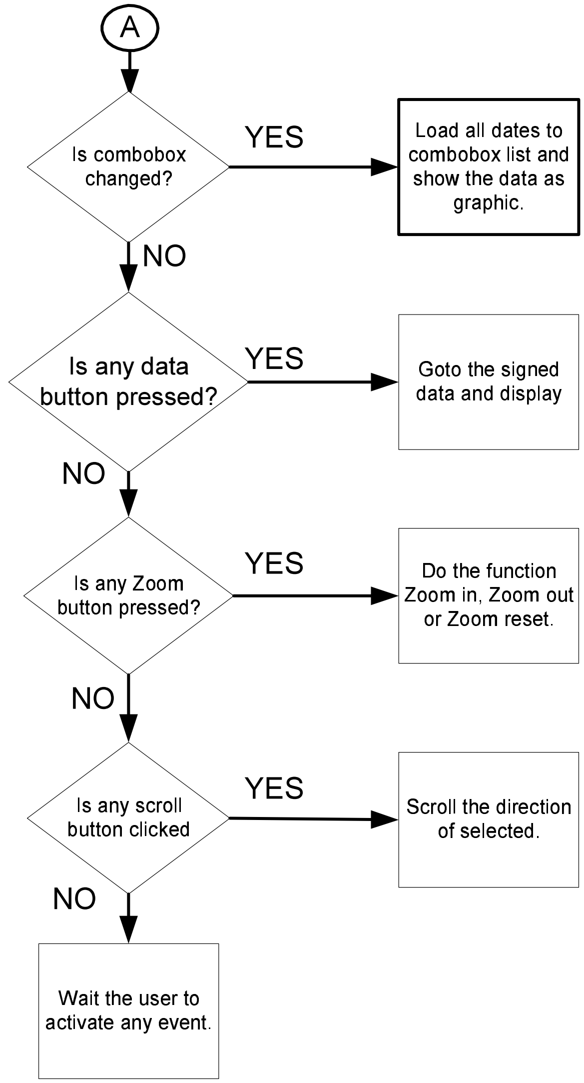


Figure 4.7 Flowchart of PC program

At start of the main program, it runs the serial port program to log any data in the serial buffer. The program code is as follow;

```
Private Sub Form_Load()
MSComm1.PortOpen = True            'open port
MSComm1.Output = "<>"              'trigger the modem
End Sub

Private Sub Form_Unload(Cancel As Integer)
MSComm1.PortOpen = False    ' close the port
End Sub
```

```
Private Sub MSComm1_OnComm()
Dim okunan As String

Open "c:\wind.dat" For Append As #1     ' open data file in insert mode
If MSComm1.InBufferCount > 0 Then       ' is there any data in buffer?
okunan = MSComm1.Input
Text1.Text = okunan                           ' write data in textbox
 Print #1, okunan                       ' write data into data file
End If

Close #1                                ' close data file.
End Sub
```

The serial port program initializes the port as 9600, 8N1, selects com1 and checks the serial port. On sensing any data in serial buffer, program writes it into data file and continues to checking the port.

4.4 I2C Protocol

I2C bus is an abbreviation for Inter Integrated Circuit bus. It is also known as IIC. I2C is a serial and synchronous bus protocol**.** There are just two wires, called SCL and SDA. SCL is the serial clock line, as shown in figure 4.8. SDA is the serial data line. The SCL & SDA lines are connected to all devices on the I2C bus. There needs to be a third wire which is just the ground or 0 volts. There may also be a 5 volt wire is power is being distributed to the devices [22].

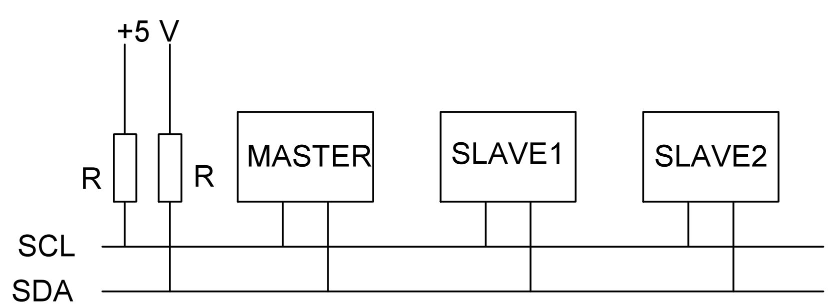


Figure 4.8 Connection of devices in i2c protocol

In a simple I2C system there can only be one master, but multiple slaves. The master is always the device that drives the SCL clock line. The master also defines when communication should occur. A slave cannot initiate a transfer over the I2C bus.

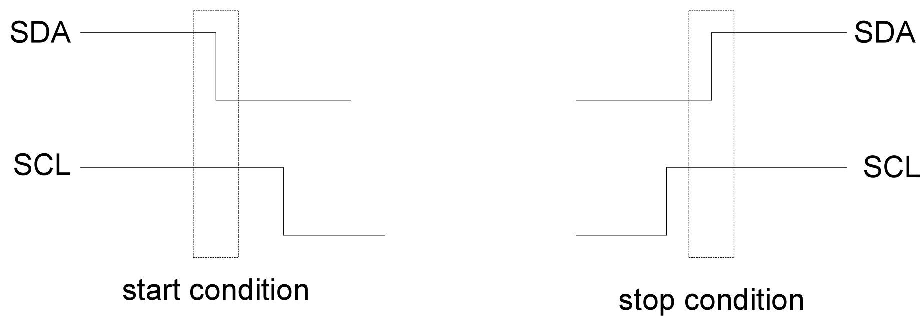


Figure 4.9 Start and stop conditions

Data can only occur after the master generates a start condition. A start condition is a high-to-low transition of the SDA line while SCL remains high. After each data transfer a stop condition is generated. A stop condition is a low-to-high transition of the SDA line while SCL remains high. These conditions are shown in figure 4.9. When data is being transferred, SDA must remain stable and not change whilst SCL is high. The length of transferred data is 8 bits. The bits are placed on the SDA line starting with the MSB (Most Significant Bit). The SCL line is then pulsed high, then low. For each byte transferred, the device receiving the data must generate an acknowledge bit. After an acknowledge there can be a stop condition, if the master wishes to leave the bus idle. Or a repeated start condition. When the master reads from a slave it should acknowledge after each byte received. There are two reasons for the master not to acknowledge. The master sends a not acknowledge if data was not received correctly or if the master wishes the stop receiving.

All I2C addresses are either 7 bits or 10 bits. This means that up to 128 devices can be connected on the I2C bus, since a 7bit number can be from 0 to 127. After sending 7 bits address, a read/write direction bit is sent also as LSB of byte. If the R/W bit is zero the master is writing to the slave. If the R/W bit is 1 the master is reading from the slave.

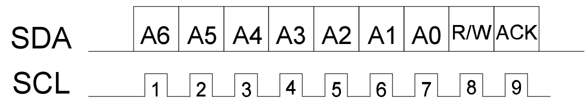


Figure 4.10 SDA and SCL pulses for a typical operation

In order to write data to a slave, following steps needs to be applied;

1- Send a start condition
2- Send the I2C address of the slave with the R/W bit low
3- Send the internal register number that the data will be written
4- Send the data byte
5- Send any further data bytes
6- Send the stop condition.

Reading from slaves is more complicated;

1- Send a start sequence
2- Send the I2C address of the slave with the R/W bit low
3- Send the internal register number that the data will be read from
4- Send a start condition again (repeated start)
5- Send the I2C address of the slave with the R/W bit high
6- Read data byte from slave
7- Send the stop condition.

I2c protocol can be used in various circuits such as LCD drivers, remote I/O ports, RAM, EEPROM or data converters. In this study, i2c protocol used to establish the communication between microcontroller and both 24LC512 serial EEPROM and DS1307 serial real time clock. The subroutines of microcontroller program, writing to/reading from EEPROM or writing to/reading from RTC, can help to understand the operation of i2c protocol. It must be noted that pin P2.5 is determined as SCL, and pin P2.6 is determined as SDA.

4.5 Summary

The microcontroller program was written in assembly and hexadecimal code was loaded into flash memory. The program reads wind sensors, stores speed and direction values into EEPROM with time stamp and sends all data to central unit. PC program, in central unit, logs coming data and saves as spreadsheets into hard disk. All collected data can be displayed in graphical format.

CHAPTER 5

DISCUSSIONS, CONCLUSIONS AND FUTURE WORK

A portable, 8051 based wind speed data logger is designed to measure and log the wind speed and direction information from three anemometers and a wind vane. NRG maximum #40 anemometers, and #200P wind vane are used to measure the wind.

The anemometers are calibrated at the Mechanical Engineering department before installation. Depending on our experimental results, the anemometers response curves are obtained and the constants are obtained to get the actual wind speeds.

Because of difficulty of reading the instruments by microcontroller directly, an interface circuit is designed. The unit uses an analog to digital converter for direction measurement and three zero cross detectors to read anemometers via microcontroller interrupts.

The collected data is sent from remote unit to base unit using RF modems, UDEA Electronics' UMD-B12. A PC program in base unit reads the serial port and log all data coming from remote unit in a data file and displays the data in graphical format. However, there are many data loggers available in the markets. They are expensive and not as flexible as the realized data logger. The designed data logger can easily compete with the commercial data loggers with a better presentation. By adding a few page assembly code and a little more hardware, this device may be used in weather stations as remote unit to measure the wind speed, direction, humidity, temperature and for more. Another important feature of this device is the ability of wireless transferring data to base unit. The system allows up to 5 km distance between remote unit and base unit. The distance can be extended by using proper modems.

For investigation of two or more sites, the base unit can be located in the center of sites, so two or more sites' wind data are measured at the same time. Using GSM modules and only one base unit, the wind measurement of all regions of Turkey can be gathered to construct a Wind map of Turkey.

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APPENDIX A

The Basics of 8051 Based Microcontrollers

8051 Pins

P0: P0 is an 8-bit open drain bi-directional I/O port. P0 can also be used as multiplexed low-level (AD7-AD0) address/data bus.

P1: P1 is an 8-bit bi-directional I/O port with internal pull-ups.

P2: P2 is an 8-bit bi-directional I/O port with internal pull-ups. P2 can also be used as high-level (AD15-AD8) address/data bus.

P3: P3 is an 8-bit bi-directional I/O port with internal pull-ups. Port 3 pins have alternate functions as seen in the table.

Table AA.1 Alternate functions of Port 3 pins

Port Pin	Alternate Functions
P3.0	RXD (Serial input port)
P3.1	TXD (Serial output port)
P3.2	INT0 (External interrupt 0)
P3.3	INT1 (External interrupt 1)
P3.4	T0 (Timer 0 external input)
P3.5	T1 (Timer 1 external input)
P3.6	WR (External data memory write strobe)
P3.7	RD (External data memory read strobe)

RST: Reset input. A high pulse on this pin for two machine cycles while oscillator is running resets the device.

ALE/PROG: Address latch enable is an output pulse for latching the low byte of address during accesses to external memory. This pin is also the program pulse input during flash programming.

/PSEN: Program store enable is the read strobe to external program memory.

EA/ VPP: External Access Enable. EA must be connected to GND in order to enable the device to fetch code from external program memory locations starting at

0000H up to FFFFH. This pin also receives the 12-volt programming enable voltage (VPP) during Flash programming when 12-volt programming is selected.

XTAL1 and XTAL2: Inputs for oscillator.

VCC and GND: Supply voltage and ground [16].

Memory map

8051-based microcontrollers have three types of memory, which are On-chip memory, external code memory, and external RAM. The memories is shown in figure AA.1

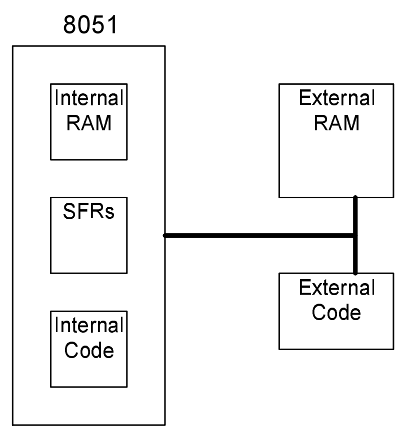

Figure AA.1 8051 memory map

Code memory is limited to 64K and holds the 8051 program. It can be found on-chip as an EPROM or off-chip as an external EPROM. When user loads the program into 8051, the program locates in code memory and become ready to run.

The 8051 also supports external RAM, whereas it has on-chip RAM. But this type of memory is rarely used because of the difficult of accessing the data.

On-chip memory consists of two memories called internal RAM and special function registers memory. Internal RAM includes 80 byte RAM, register banks and bit memory.

80 byte RAM is used for variables and as storage of stack. Bit memory has 128 bit variables, these bits may be either 1 or 0.

8051 microcontroller has 4 register banks. Each bank consists of 8 registers. These register are numbered from 0 through 7 (R0, R1…R7), and are generally used to assist in manipulating values and moving data from one memory location to another .

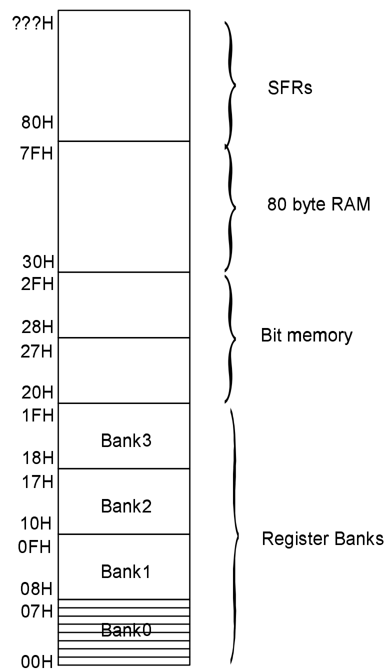

Figure AA.2 Internal RAM of 8051

Special Function Register memory is used to store data and control registers such as timers, interrupts and serial port control registers. SFRs are accessed as if they were normal internal RAM. Each SFR has a name and an address [17].

Table AA.2 SFR Memory Map

F8									FF
F0	B								F7
E8									EF
E0	ACC								E7
D8									DF
D0	PSW								D7
C8									CF
C0									C7
B8	IP								BF
B0	P3								B7
A8	IE								AF
A0	P2								A7
98	SCON	SBUF							9F
90	P1								97
88	TCON	TMOD	TL0	TL1	TH0	TH1			8F
80	P0	SP	DPL	DPH				PCON	87

SFR descriptions

P0 (Port 0, Address 80h, Bit-Addressable): This is input/output port 0. Each bit of this SFR corresponds to one of the pins on the microcontroller. Writing a value of 1 to a bit of this SFR will send a high level on the corresponding I/O pin whereas a value of 0 will bring it to a low level.

SP (Stack Pointer, Address 81h): This is the stack pointer of the microcontroller. If a value is pushed onto the stack, the value will be written to the address of SP + 1. That is to say, if SP holds the value 07h, a PUSH instruction will push the value onto the stack at address 08h.

DPL/DPH (Data Pointer Low/High, Addresses 82h/83h): The SFRs DPL and DPH work together to represent a 16-bit value called the Data Pointer. The data pointer is used in operations regarding external RAM and some instructions involving code memory. Since it is a two-byte integer value, it can represent values from 0000h to FFFFh.

PCON (Power Control, Addresses 87h): The Power Control SFR is used to control the 8051's power control modes. Certain operation modes of the 8051 allow the 8051 to go into a type of "sleep" mode which requires much less power. These modes of operation are controlled through PCON.

TCON (Timer Control, Addresses 88h, Bit-Addressable): The Timer Control SFR is used to configure and modify the 8051's two timers. This SFR controls whether each of the two timers is running or stopped and contains a flag to indicate that each timer has overflowed. Additionally, some bits are located in the TCON SFR.

TF1	TR1	TF0	TR0	IE0	IT1	IE0	IT0

Figure AA.3 TCON register bits

These bits are used to configure the external interrupts and also contain the external interrupt flags which are set when an external interrupt has occurred.

TMOD (Timer Mode, Addresses 89h): The Timer Mode SFR is used to configure the mode of operation of each of the two timers. Using this SFR program may configure each timer to be a 16-bit timer, an 8-bit auto reload timer, a 13-bit timer, or two separate timers. Additionally, the timers can be configured to only count when an external pin is activated or to count "events".

GATE	C / T	M1	M0	GATE	C / T	M1	M0

M1	M0	Mod	
0	0	0	13-bit
0	1	1	16-bit
1	0	2	8-bit autoreload
1	1	3	8-bit
1	1	3	timer1 stops

Figure AA.4 TMOD register

TL0/TH0 (Timer 0 Low/High, Addresses 8Ah/8Ch): These two SFRs, represent timer 0. Their behavior depends on how the timer is configured in the TMOD SFR; however, these timers always count up.

TL1/TH1 (Timer 1 Low/High, Addresses 8Bh/8Dh): These two SFRs, represent timer 1. Their behavior depends on how the timer is configured in the TMOD SFR; however, these timers always count up.

P1 (Port 1, Address 90h, Bit-Addressable): This is input/output port 1. Each bit of this SFR corresponds to one of the pins on the microcontroller. Writing a value of 1 to a bit of this SFR will send a high level on the corresponding I/O pin.

SCON (Serial Control, Addresses 98h, Bit-Addressable): The Serial Control SFR is used to configure the 8051's on-board serial port. This SFR controls the baud rate of the serial port, whether the serial port is activated to receive data, and also contains flags that are set when a byte is successfully sent or received.

SM0	SM1	SM2	REN	TB8	RB8	TI	RI

SM0	SM1	MOD	
0	0	0	shift register
0	1	1	8-bit uart
1	0	2	9-bit uart
1	1	3	9-bit uart

Figure AA.5 SCON register

Baud rate of system is depends on timer 1. if timer 1 is programmed in mod 2, the baud rate of system is calculated as;

$$baud = \frac{2^{SMOD} x(osc.freq)}{384x(256-TH1)} \tag{AA.1}$$

SBUF (Serial Control, Addresses 99h): The Serial Buffer SFR is used to send and receive data via the on-board serial port. Any value written to SBUF will be sent out the serial port's TXD pin. Any value which the 8051 receives via the serial port's RXD pin will be delivered to the user program via SBUF. SBUF serves as the output port when written to and as an input port when read from.

P2 (Port 2, Address A0h, Bit-Addressable): This is input/output port 2. Each bit of this SFR corresponds to one of the pins on the microcontroller. Writing a value of 1 to a bit of this SFR will send a high level on the corresponding I/O pin.

IE (Interrupt Enable, Addresses A8h): The Interrupt Enable SFR is used to enable and disable specific interrupts. The low 7 bits of the SFR are used to enable/disable the specific interrupts, where as the highest bit is used to enable or disable ALL interrupts.

EA			ES	ET1	EX1	ET0	EX0

Figure AA.6 IE register

Thus, if the high bit of IE is 0 all interrupts are disabled even if an individual interrupt is enabled by setting a lower bit.

P3 (Port 3, Address B0h, Bit-Addressable): This is input/output port 3. Each bit of this SFR corresponds to one of the pins on the microcontroller. Writing a value of 1 to a bit of this SFR will send a high level on the corresponding I/O pin.

IP (Interrupt Priority, Addresses B8h, Bit-Addressable): The Interrupt Priority SFR is used to specify priority of each interrupt. On the 8051, an interrupt may either be of low (0) priority or high (1) priority.

			PS	PT1	PX1	PT0	PX0

Figure AA.7 IP register

For example, if we configure the 8051 so that all interrupts are of low priority except the serial interrupt, the serial interrupt will always be able to interrupt the system, even if another interrupt is currently executing.

PSW (Program Status Word, Addresses D0h, Bit-Addressable): The Program Status Word is used to store a number of important bits that are set and cleared by 8051 instructions. The PSW SFR contains the carry flag, the auxiliary carry flag, the overflow flag, and the parity flag.

CY	AC	F0	RS1	RS0	OV		P

Figure AA.8 PSW register

Additionally, the PSW register contains the register bank select flags which are used to select which of the "R" register banks are currently selected.

ACC (Accumulator, Addresses E0h, Bit-Addressable): The Accumulator is one of the most-used SFRs on the 8051 since it is involved in so many instructions. The Accumulator is located as an SFR at E0h, which means the instruction MOV A,#20h is really the same as MOV E0h,#20h.

B (B Register, Addresses F0h, Bit-Addressable): The "B" register is used in two instructions: the multiply and divide operations. The B register is also commonly used by programmers as an auxiliary register to temporarily store values.

Interrupts

The 8051 has 5 interrupt sources which are external interrupt 0, external interrupt 1, timer 0, timer 1, serial port. Interrupts and their vector addresses are shown in table AA.3.

If an interrupt occurs the program completes executing the last code line and jumps to interrupt service routine. If timer 0 or timer 1 overflows TF0 or TF1 bits of TCON triggers an interrupt event. INT0 and INT1 are external interrupts, if a low signal is applied to the related pin, an interrupt occurs. RI and TI bits of SCON are source of interrupt also.

Table AA.3 Interrupt vector addresses

Interrupt	ISR Address	Priority
IE0	0003H	1
TF0	000BH	2
IE1	0013H	3
TF1	001BH	4
RI or TI	0023H	5

Addressing modes

Addressing mode means how a given memory is addressed. 8051 addressing modes can be divided into 6 categories [16]. They are;

- Immediate Addressing
- Direct Addressing
- Register Addressing
- Register Specific
- Register Indirect
- Register Indexed

Immediate addressing is so-named because the value to be stored in memory immediately follows the operation code in memory.

Direct addressing is so-named because the value to be stored in memory is obtained by directly retrieving it from another memory location.

In Register addressing mode source or destination byte is always a register such as R0,R1 etc.

Some instructions are specific for a register so that it doesn't need any addressing mode. MOV A,#1 is an example for register specific addressing.

Register indirect is the most powerful addressing mode of 8051. In this mode, neither source nor destination address is not given. For example MOV @DPTR, A.

If source or destination address is the sum of a base address and accumulator, this type of addressing mode is called register indexed addressing. It is generally used when working with look-up tables.

Cpu timing

All 8051 microcontrollers has an on-board oscillator, xtal1 and xtal2 pins are connected to an crystal and two external capacitor. One machine cycle consists of 12 oscillator cycles. To provide high baud rates, Many 8051-based systems uses 11.0592 Mhz crystals. 18,432,000 hz crystal is connected to xtal pins of microcontroller in this project.

APPENDIX B

Measured Wind Speeds and Direction Data

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
03.05.2006	13:00	2,54	2,7	0	16
04.05.2006	14:00	2,35	1,88	0	19
04.05.2006	14:00	4,11	3,79	0	16
05.05.2006	15:00	4,1	4,4	0	19

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
08.05.2006	14:00	5,31	4,83	0,02	24
08.05.2006	15:00	5,83	5,79	0,01	23
08.05.2006	16:00	6,51	6,44	0,01	23
08.05.2006	17:00	9,26	9,12	0,01	22
08.05.2006	18:00	7,78	7,59	0,01	22
08.05.2006	19:00	5,85	5,68	0,00	25
08.05.2006	20:00	6,17	5,72	0,00	26
08.05.2006	21:00	7,43	6,32	0,00	27
08.05.2006	22:00	6,03	4,13	0,00	27
08.05.2006	23:00	3,90	3,84	0,00	27

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
09.05.2006	00:00	5,86	4,55	0,00	26
09.05.2006	01:00	6,85	6,32	0,00	26
09.05.2006	02:00	6,45	6,40	0,00	26
09.05.2006	03:00	6,22	5,54	0,00	26
09.05.2006	04:00	5,75	4,64	0,00	26
09.05.2006	05:00	5,82	5,10	0,00	27
09.05.2006	06:00	5,20	4,03	0,00	26
09.05.2006	07:00	4,26	4,08	0,00	26
09.05.2006	08:00	4,74	4,82	0,00	25
09.05.2006	09:00	6,33	6,00	0,00	27
09.05.2006	10:00	5,44	5,12	0,00	25
09.05.2006	11:00	4,94	4,75	0,00	23
09.05.2006	12:00	4,41	4,15	0,00	27
09.05.2006	13:00	4,80	4,46	0,00	24
09.05.2006	14:00	5,60	5,20	0,00	24
09.05.2006	15:00	4,09	4,21	0,00	25
09.05.2006	16:00	5,49	4,86	0,00	26
09.05.2006	17:00	5,50	4,85	0,00	27
09.05.2006	18:00	3,83	3,37	0,00	27
09.05.2006	19:00	4,60	3,82	0,00	27
09.05.2006	20:00	5,33	4,95	0,00	26
09.05.2006	21:00	5,89	5,46	0,00	26
09.05.2006	22:00	5,22	4,48	0,00	27
09.05.2006	23:00	4,18	3,25	0,00	26

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
10.05.2006	00:00	4,45	3,57	0,00	28
10.05.2006	01:00	4,63	3,83	0,00	29
10.05.2006	02:00	4,21	3,10	0,00	29
10.05.2006	03:00	4,51	3,61	0,00	29
10.05.2006	04:00	3,64	3,03	0,00	29
10.05.2006	05:00	3,74	3,35	0,00	26
10.05.2006	06:00	2,75	2,29	0,00	17
10.05.2006	07:00	3,98	2,16	0,00	22
10.05.2006	08:00	3,40	3,08	0,00	19
10.05.2006	09:00	4,46	3,79	0,00	22
10.05.2006	10:00	4,23	3,79	0,00	22
10.05.2006	11:00	3,21	3,33	0,00	24
10.05.2006	12:00	4,08	4,18	0,00	25
10.05.2006	13:00	4,22	3,90	0,00	24
10.05.2006	14:00	4,04	4,07	0,00	25
10.05.2006	15:00	4,60	4,07	0,00	25
10.05.2006	16:00	4,89	4,13	0,00	26
10.05.2006	17:00	4,83	4,00	0,00	26
10.05.2006	18:00	8,94	2,98	0,00	25
10.05.2006	19:00	4,30	3,22	0,00	27
10.05.2006	20:00	2,90	2,56	0,00	15
10.05.2006	21:00	2,87	2,63	0,00	27
10.05.2006	22:00	3,04	2,75	0,00	30
10.05.2006	23:00	3,15	2,72	0,00	31

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
11.05.2006	00:00	1,10	1,07	0,00	20
11.05.2006	01:00	5,10	5,24	0,00	6
11.05.2006	02:00	2,98	2,53	0,00	30
11.05.2006	03:00	3,16	2,82	0,00	30
11.05.2006	04:00	2,99	2,60	0,00	31
11.05.2006	05:00	1,75	1,25	0,00	30
11.05.2006	06:00	1,23	1,01	0,00	14
11.05.2006	07:00	3,23	2,39	0,00	17
11.05.2006	08:00	3,05	3,63	0,00	18

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
12.05.2006	00:00	3,30	2,86	0,00	30
12.05.2006	01:00	4,61	4,05	0,00	30
12.05.2006	02:00	4,17	3,03	0,00	29
12.05.2006	03:00	3,66	2,96	0,00	25
12.05.2006	04:00	3,69	3,01	0,00	30
12.05.2006	05:00	3,37	2,45	0,00	30
12.05.2006	06:00	9,93	0,72	0,00	12
12.05.2006	07:00	3,64	2,10	0,00	6
12.05.2006	08:00	2,18	5,81	0,00	13

11.05.2006	09:00	4,60	5,12	0,00	19
11.05.2006	10:00	4,43	4,66	0,00	21
11.05.2006	11:00	3,94	4,44	0,00	21
11.05.2006	12:00	5,04	4,85	0,00	20
11.05.2006	13:00	4,38	4,19	0,00	20
11.05.2006	14:00	4,46	4,49	0,00	22
11.05.2006	15:00	4,47	3,99	0,00	22
11.05.2006	16:00	4,98	4,94	0,00	21
11.05.2006	17:00	5,21	4,30	0,00	24
11.05.2006	18:00	4,09	3,10	0,00	25
11.05.2006	19:00	3,90	3,25	0,00	27
11.05.2006	20:00	4,09	2,56	0,00	29
11.05.2006	21:00	4,09	3,81	0,00	31
11.05.2006	22:00	4,73	3,88	0,00	30
11.05.2006	23:00	3,54	2,51	0,00	26

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
13.05.2006	00:00	3,84	4,87	0,00	29
13.05.2006	01:00	3,09	6,62	0,00	30
13.05.2006	02:00	3,09	2,92	0,00	28
13.05.2006	03:00	2,93	2,80	0,00	26
13.05.2006	04:00	2,36	2,31	0,00	25
13.05.2006	05:00	1,67	4,91	0,00	15
13.05.2006	06:00	1,31	0,21	0,00	21
13.05.2006	07:00	8,46	0,36	0,00	18
13.05.2006	08:00	8,99	1,25	0,00	13
13.05.2006	09:00	2,45	2,20	0,00	18
13.05.2006	10:00	3,57	3,47	0,00	20
13.05.2006	11:00	4,83	4,49	0,00	23
13.05.2006	12:00	5,42	4,60	0,00	24
13.05.2006	13:00	7,59	6,98	0,00	26
13.05.2006	14:00	6,43	6,14	0,00	26
13.05.2006	15:00	6,91	6,75	0,00	25
13.05.2006	16:00	6,77	6,00	0,00	25
13.05.2006	17:00	6,79	5,44	0,00	26
13.05.2006	18:00	5,79	5,38	0,00	27
13.05.2006	19:00	5,83	5,29	0,00	27
13.05.2006	20:00	6,91	6,00	0,00	28
13.05.2006	21:00	2,63	2,32	0,00	23
13.05.2006	22:00	4,42	3,62	0,00	27
13.05.2006	23:00	5,12	4,43	0,00	26

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
14.05.2006	00:00	6,50	6,00	0,00	26
14.05.2006	01:00	6,15	5,06	0,00	27
14.05.2006	02:00	4,98	4,10	0,00	28
14.05.2006	03:00	5,11	4,16	0,00	29
14.05.2006	04:00	6,49	5,12	0,00	28
14.05.2006	05:00	6,16	5,28	0,00	27
14.05.2006	06:00	5,35	4,47	0,00	27

12.05.2006	09:00	3,64	3,54	0,00	17
12.05.2006	10:00	4,89	4,66	0,00	18
12.05.2006	11:00	5,86	6,14	0,00	20
12.05.2006	12:00	5,64	5,74	0,00	21
12.05.2006	13:00	6,46	6,09	0,00	22
12.05.2006	14:00	4,67	4,34	0,00	22
12.05.2006	15:00	5,19	4,80	0,00	22
12.05.2006	16:00	4,64	3,78	0,00	26
12.05.2006	17:00	4,74	4,39	0,00	26
12.05.2006	18:00	4,06	3,77	0,00	26
12.05.2006	19:00	4,28	4,03	0,00	28
12.05.2006	20:00	2,73	2,56	0,00	28
12.05.2006	21:00	3,50	3,12	0,00	29
12.05.2006	22:00	3,18	6,04	0,00	30
12.05.2006	23:00	3,31	4,63	0,00	29

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
17.05.2006	18:00	6,62	6,42	0,00	26
17.05.2006	19:00	6,40	5,47	0,00	25
17.05.2006	20:00	6,09	5,58	0,00	25
17.05.2006	21:00	6,06	5,23	0,00	25
17.05.2006	22:00	6,24	5,54	0,00	24
17.05.2006	23:00	6,38	6,18	0,00	25

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
18.05.2006	00:00	8,16	6,97	0,00	25
18.05.2006	01:00	7,09	6,26	0,00	25
18.05.2006	02:00	6,98	5,77	0,00	25
18.05.2006	03:00	8,68	7,67	0,00	26
18.05.2006	04:00	7,47	6,72	0,00	26
18.05.2006	05:00	7,12	4,12	0,00	26
18.05.2006	06:00	4,52	4,05	0,00	25
18.05.2006	07:00	5,12	6,30	0,00	27
18.05.2006	08:00	5,52	0,96	0,00	27
18.05.2006	09:00	5,62	5,42	0,00	27
18.05.2006	10:00	5,81	5,18	0,00	26
18.05.2006	11:00	4,99	4,95	0,00	25
18.05.2006	12:00	5,11	5,36	0,00	25
18.05.2006	13:00	4,75	4,54	0,00	26
18.05.2006	14:00	6,44	5,69	0,00	25
18.05.2006	15:00	7,32	6,73	0,00	24
18.05.2006	16:00	6,11	5,68	0,00	24
18.05.2006	17:00	5,44	5,12	0,00	25
18.05.2006	18:00	4,56	4,07	0,00	26
18.05.2006	19:00	4,76	4,11	0,00	27
18.05.2006	20:00	4,24	3,91	0,00	25
18.05.2006	21:00	4,57	3,83	0,00	28
18.05.2006	22:00	3,35	2,90	0,00	23
18.05.2006	23:00	4,36	4,00	0,00	29

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
19.05.2006	00:00	4,94	4,64	0,00	30
19.05.2006	01:00	5,94	3,88	0,00	29
19.05.2006	02:00	3,56	3,04	0,00	10
19.05.2006	03:00	4,44	3,70	0,00	28
19.05.2006	04:00	4,72	3,90	0,00	30
19.05.2006	05:00	4,73	3,95	0,00	29
19.05.2006	06:00	3,65	3,15	0,00	9
19.05.2006	07:00	4,14	3,71	0,00	2
19.05.2006	08:00	4,25	4,08	0,00	3
19.05.2006	09:00	3,62	3,55	0,00	5
19.05.2006	10:00	3,28	2,62	0,00	8
19.05.2006	11:00	2,56	2,11	0,00	12
19.05.2006	12:00	2,42	1,98	0,00	9
19.05.2006	13:00	3,11	2,56	0,00	12
19.05.2006	14:00	2,78	2,74	0,00	9
19.05.2006	15:00	3,19	2,76	0,00	17
19.05.2006	16:00	1,38	0,67	0,00	13
19.05.2006	17:00	1,84	1,10	0,00	11
19.05.2006	18:00	2,88	1,68	0,00	11
19.05.2006	19:00	2,26	3,41	0,00	14
19.05.2006	20:00	3,01	2,85	0,00	12
19.05.2006	21:00	3,14	3,67	0,00	2
19.05.2006	22:00	1,64	2,59	0,00	18
19.05.2006	23:00	1,17	2,19	0,00	13

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
20.05.2006	00:00	2,96	6,14	0,00	31
20.05.2006	01:00	2,97	6,53	0,00	30
20.05.2006	02:00	3,80	3,43	0,00	30
20.05.2006	03:00	4,66	3,46	0,00	31
20.05.2006	04:00	4,79	3,49	0,00	30
20.05.2006	05:00	4,10	3,05	0,00	30
20.05.2006	06:00	2,91	1,78	0,00	27
20.05.2006	07:00	2,72	1,11	0,00	4
20.05.2006	08:00	2,23	1,83	0,00	5
20.05.2006	09:00	2,22	2,34	0,00	7
20.05.2006	10:00	2,66	2,48	0,00	8
20.05.2006	11:00	2,32	1,80	0,00	11
20.05.2006	12:00	3,40	3,12	0,00	21
20.05.2006	13:00	2,83	2,55	0,00	18
20.05.2006	14:00	2,91	2,31	0,00	13
20.05.2006	15:00	3,40	2,73	0,00	21
20.05.2006	16:00	4,30	4,01	0,00	28
20.05.2006	17:00	5,04	5,14	0,00	26
20.05.2006	18:00	4,93	4,52	0,00	26
20.05.2006	19:00	6,51	5,22	0,00	26
20.05.2006	20:00	5,84	5,28	0,00	26
20.05.2006	21:00	6,61	6,19	0,00	27
20.05.2006	22:00	6,90	6,07	0,00	27
20.05.2006	23:00	5,48	4,66	0,00	28

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
21.05.2006	00:00	5,59	4,67	0,00	28
21.05.2006	01:00	6,16	5,08	0,00	28
21.05.2006	02:00	6,02	5,24	0,00	28
21.05.2006	03:00	6,16	4,88	0,00	28
21.05.2006	04:00	6,68	4,46	0,00	28
21.05.2006	05:00	6,86	5,48	0,00	28
21.05.2006	06:00	4,86	4,26	0,00	28
21.05.2006	07:00	4,22	3,53	0,00	29
21.05.2006	08:00	4,44	3,81	0,00	28
21.05.2006	09:00	5,23	4,73	0,00	24
21.05.2006	10:00	7,51	6,73	0,00	28
21.05.2006	11:00	5,33	4,37	0,00	20
21.05.2006	12:00	4,21	4,17	0,00	23
21.05.2006	13:00	4,47	4,02	0,00	17
21.05.2006	14:00	2,89	2,89	0,00	21
21.05.2006	15:00	3,39	3,27	0,00	25
21.05.2006	16:00	5,78	5,13	0,00	28
21.05.2006	17:00	6,48	5,92	0,00	27
21.05.2006	18:00	5,10	4,81	0,00	29
21.05.2006	19:00	3,89	4,59	0,00	28
21.05.2006	20:00	5,50	5,24	0,00	28
21.05.2006	21:00	7,80	6,97	0,00	29
21.05.2006	22:00	4,51	4,09	0,00	28
21.05.2006	23:00	5,29	4,27	0,00	28

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
22.05.2006	00:00	5,13	4,26	0,00	28
22.05.2006	01:00	4,52	3,51	0,00	28
22.05.2006	02:00	4,99	4,27	0,00	29
22.05.2006	03:00	4,94	4,07	0,00	29
22.05.2006	04:00	4,90	3,19	0,00	29
22.05.2006	05:00	4,20	3,48	0,00	30
22.05.2006	06:00	4,72	3,96	0,00	30
22.05.2006	07:00	5,15	4,61	0,00	21
22.05.2006	08:00	4,98	4,53	0,00	11
22.05.2006	09:00	5,98	5,31	0,00	10
22.05.2006	10:00	5,63	5,19	0,00	5
22.05.2006	11:00	3,92	3,84	0,00	4
22.05.2006	12:00	4,00	3,25	0,00	12
22.05.2006	13:00	3,48	3,24	0,00	19
22.05.2006	14:00	4,93	4,49	0,00	13
22.05.2006	15:00	5,17	4,19	0,00	8
22.05.2006	16:00	4,87	4,19	0,00	11
22.05.2006	17:00	4,19	3,38	0,00	16
22.05.2006	18:00	3,56	2,38	0,00	29
22.05.2006	19:00	8,86	4,34	5,60	27
22.05.2006	20:00	2,81	4,46	5,56	29
22.05.2006	21:00	3,23	4,51	4,56	29
22.05.2006	22:00	5,29	5,87	5,83	29
22.05.2006	23:00	4,68	3,70	5,63	31

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
23.05.2006	00:00	2,29	4,35	3,67	31
23.05.2006	01:00	2,83	4,36	5,57	31
23.05.2006	02:00	5,75	5,41	5,88	31
23.05.2006	03:00	3,21	4,36	5,84	31
23.05.2006	04:00	1,10	5,71	5,57	31
23.05.2006	05:00	3,21	4,21	5,42	31
23.05.2006	06:00	3,17	5,49	7,55	31
23.05.2006	07:00	5,33	5,48	7,54	1
23.05.2006	08:00	4,37	5,53	6,98	31
23.05.2006	09:00	5,41	8,08	7,48	0
23.05.2006	10:00	4,32	5,51	5,51	1
23.05.2006	11:00	4,55	5,52	5,53	2
23.05.2006	12:00	3,27	2,68	2,52	31
23.05.2006	13:00	0,11	1,02	2,77	3
23.05.2006	14:00	5,38	7,28	4,45	4
23.05.2006	15:00	7,92	7,97	7,91	1
23.05.2006	16:00	4,37	4,26	5,48	2
23.05.2006	17:00	5,60	7,51	7,11	1
23.05.2006	18:00	3,68	4,50	3,75	2
23.05.2006	19:00	3,19	1,84	2,14	2
23.05.2006	20:00	2,29	1,41	2,52	2
23.05.2006	21:00	3,21	4,34	4,59	30
23.05.2006	22:00	3,22	3,59	3,15	1
23.05.2006	23:00	3,12	4,34	4,46	31

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
24.05.2006	00:00	5,81	3,15	4,64	31
24.05.2006	01:00	4,55	5,71	5,68	31
24.05.2006	02:00	4,62	4,31	5,45	31
24.05.2006	03:00	3,72	4,45	5,59	31
24.05.2006	04:00	4,46	3,12	5,49	31
24.05.2006	05:00	4,47	3,64	5,61	31
24.05.2006	06:00	2,58	4,32	5,46	31
24.05.2006	07:00	1,04	2,16	1,02	0
24.05.2006	08:00	3,14	3,06	2,12	3
24.05.2006	09:00	3,16	4,43	5,48	7
24.05.2006	10:00	5,40	5,53	5,60	6
24.05.2006	11:00	4,45	5,42	5,57	6
24.05.2006	12:00	1,31	1,83	1,08	4
24.05.2006	13:00	0,00	0,01	1,10	12
24.05.2006	14:00	3,15	4,29	3,74	2
24.05.2006	15:00	3,11	5,36	3,68	9
24.05.2006	16:00	2,54	2,01	1,07	2
24.05.2006	17:00	3,21	4,45	3,20	8
24.05.2006	18:00	3,65	3,09	4,47	1
24.05.2006	19:00	3,71	3,16	3,77	4
24.05.2006	20:00	0,00	0,01	0,30	2
24.05.2006	21:00	0,00	0,10	1,33	5
24.05.2006	22:00	0,00	0,01	0,00	10
24.05.2006	23:00	0,00	2,00	1,53	0

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
25.05.2006	00:00	1,00	1,41	2,54	2
25.05.2006	01:00	0,00	2,74	3,79	0
25.05.2006	02:00	0,00	2,72	2,28	31
25.05.2006	03:00	1,10	2,75	2,30	31
25.05.2006	04:00	1,43	2,71	2,77	0
25.05.2006	05:00	0,00	1,02	0,30	3
25.05.2006	06:00	4,47	3,60	3,71	31
25.05.2006	07:00	0,11	1,01	2,52	31
25.05.2006	08:00	3,71	3,05	1,34	1
25.05.2006	09:00	4,36	4,47	3,70	5
25.05.2006	10:00	5,28	4,40	5,44	5
25.05.2006	11:00	2,85	2,17	3,12	5
25.05.2006	12:00	0,11	2,19	3,25	5
25.05.2006	13:00	3,22	2,70	3,18	12
25.05.2006	14:00	3,84	2,74	2,52	28
25.05.2006	15:00	5,71	5,87	5,57	4
25.05.2006	16:00	0,10	2,35	2,31	10
25.05.2006	17:00	2,11	5,77	4,45	4
25.05.2006	18:00	3,82	1,70	3,62	4
25.05.2006	19:00	3,22	1,02	3,56	1
25.05.2006	20:00	0,00	0,01	0,00	3
25.05.2006	21:00	0,00	0,01	1,14	8
25.05.2006	22:00	0,00	0,01	0,00	30
25.05.2006	23:00	0,00	1,32	2,33	31

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
26.05.2006	00:00	0,00	0,01	0,00	15
26.05.2006	01:00	1,10	2,43	2,48	1
26.05.2006	02:00	1,03	2,18	3,70	31
26.05.2006	03:00	3,71	3,13	4,60	31
26.05.2006	04:00	2,32	4,44	2,00	31
26.05.2006	05:00	3,75	3,09	3,22	1
26.05.2006	06:00	2,09	4,46	5,26	0
26.05.2006	07:00	4,57	2,71	3,65	2
26.05.2006	08:00	5,69	4,37	3,70	6
26.05.2006	09:00	1,03	3,58	4,37	7
26.05.2006	10:00	4,38	4,28	4,43	8
26.05.2006	11:00	2,79	1,82	4,49	13
26.05.2006	12:00	2,77	3,06	4,45	6
26.05.2006	13:00	1,04	1,42	2,79	20
26.05.2006	14:00	3,13	3,63	3,14	20
26.05.2006	15:00	2,83	4,39	5,40	22
26.05.2006	16:00	3,68	4,37	4,48	13
26.05.2006	17:00	5,63	5,53	7,76	31
26.05.2006	18:00	3,69	3,63	5,55	2
26.05.2006	19:00	5,60	3,61	5,61	2
26.05.2006	20:00	2,82	3,73	4,31	31
26.05.2006	21:00	2,54	3,78	3,72	0
26.05.2006	22:00	1,00	3,12	2,81	31

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
29.05.2006	16:00	3,73	4,27	3,17	28
29.05.2006	17:00	3,77	2,71	3,20	21
29.05.2006	18:00	3,18	3,04	4,38	23
29.05.2006	19:00	5,97	4,23	4,39	27
29.05.2006	20:00	4,49	3,56	3,74	29
29.05.2006	21:00	4,36	4,42	5,54	28
29.05.2006	22:00	4,50	5,39	5,61	27
29.05.2006	23:00	5,82	4,29	5,65	27

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
30.05.2006	00:00	0,00	0,01	1,08	27
30.05.2006	01:00	3,75	4,28	4,77	31
30.05.2006	02:00	3,84	4,25	2,84	30
30.05.2006	03:00	4,43	5,76	4,45	31
30.05.2006	04:00	7,66	7,78	4,55	31
30.05.2006	05:00	0,00	3,67	3,83	31
30.05.2006	06:00	1,10	1,33	3,63	31
30.05.2006	07:00	0,00	0,01	0,00	31
30.05.2006	08:00	0,00	0,10	0,11	14
30.05.2006	09:00	2,83	3,17	2,79	17
30.05.2006	10:00	3,14	3,70	3,70	16
30.05.2006	11:00	3,66	5,56	5,65	14
30.05.2006	12:00	3,61	5,48	5,71	20
30.05.2006	13:00	5,43	7,36	4,48	16
30.05.2006	14:00	3,73	3,63	2,12	17
30.05.2006	15:00	4,28	5,67	5,57	20
30.05.2006	16:00	4,48	5,50	5,69	21
30.05.2006	17:00	4,46	3,73	3,75	21
30.05.2006	18:00	2,86	3,05	3,14	17
30.05.2006	19:00	3,79	3,63	4,42	20
30.05.2006	20:00	5,84	4,20	5,74	26
30.05.2006	21:00	1,33	2,16	3,16	31
30.05.2006	22:00	0,00	0,01	0,00	31
30.05.2006	23:00	0,00	0,01	2,37	31

DATE	TIME	SPEED 1	SPEED 2	SPEED 3	DIR.
31.05.2006	00:00	0,00	0,01	3,27	31
31.05.2006	01:00	0,00	0,01	0,00	29
31.05.2006	02:00	0,00	0,01	0,00	29
31.05.2006	03:00	0,00	0,01	0,00	30
31.05.2006	04:00	5,97	5,51	4,34	0
31.05.2006	05:00	1,20	1,10	2,80	31
31.05.2006	06:00	0,00	0,01	2,32	31
31.05.2006	07:00	0,00	1,40	2,79	31
31.05.2006	08:00	2,86	1,81	2,50	4
31.05.2006	09:00	2,76	1,02	1,40	5
31.05.2006	10:00	0,00	1,40	1,30	14
31.05.2006	11:00	2,82	3,73	3,67	16
31.05.2006	12:00	7,64	7,23	7,69	14
31.05.2006	13:00	3,78	4,40	5,51	17
31.05.2006	14:00	2,79	4,42	3,79	22
31.05.2006	15:00	5,63	7,36	7,43	22
31.05.2006	16:00	7,04	7,98	7,35	18
31.05.2006	17:00	3,11	3,63	4,44	26
31.05.2006	18:00	1,00	2,62	3,13	25
31.05.2006	19:00	2,60	2,71	4,43	24
31.05.2006	20:00	0,10	3,05	3,14	27
31.05.2006	21:00	5,64	4,39	5,43	27
31.05.2006	22:00	0,00	0,01	3,19	27
31.05.2006	23:00	5,72	4,34	5,74	27

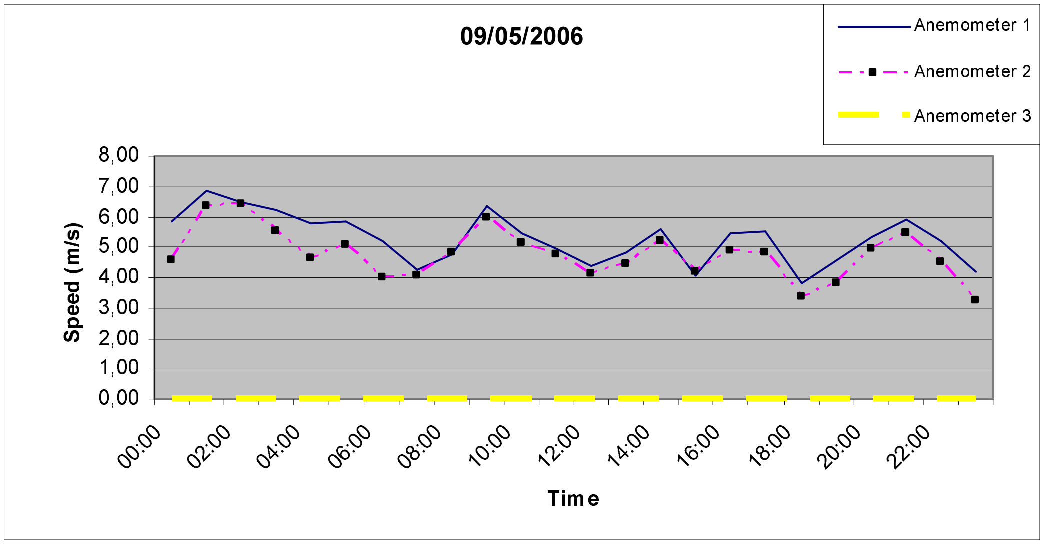

Figure AB.1 Measured speed (09.05.2006)

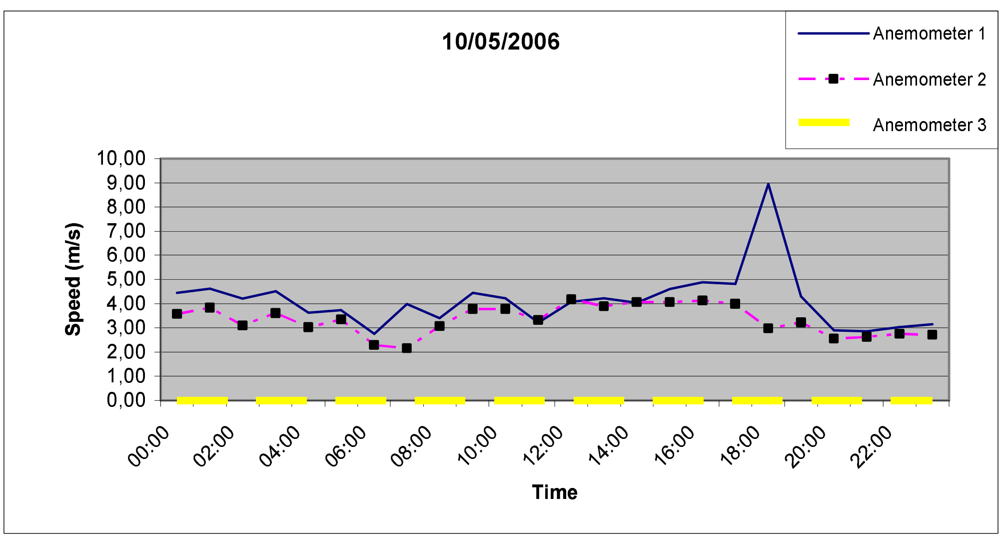

Figure AB.2 Measured speed (10.05.2006)

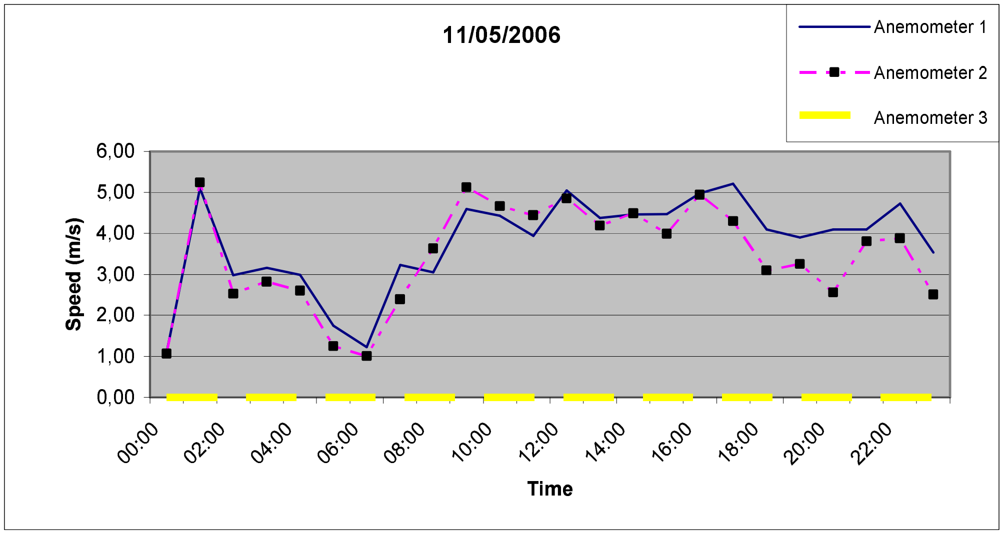

Figure AB.3 Measured speed (11.05.2006)

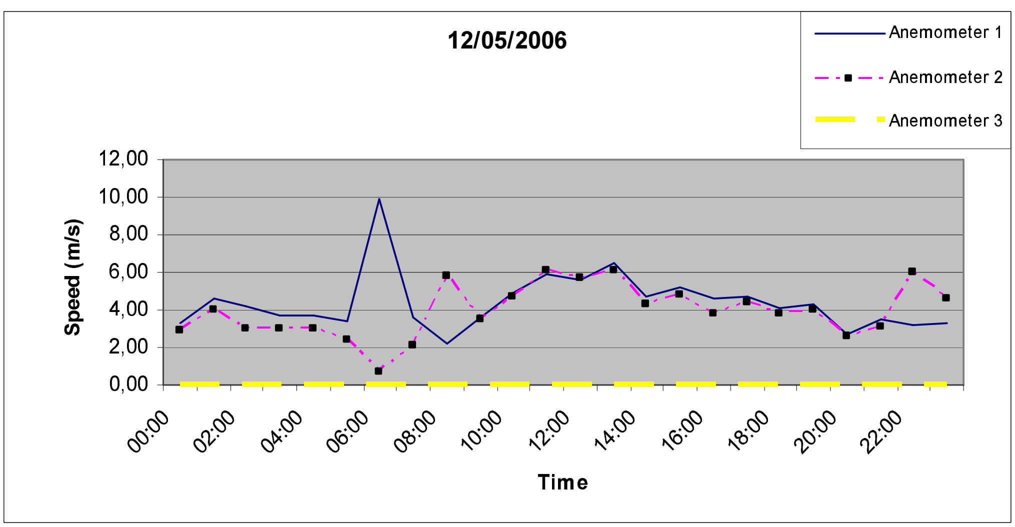

Figure AB.4 Measured speed (12.05.2006)

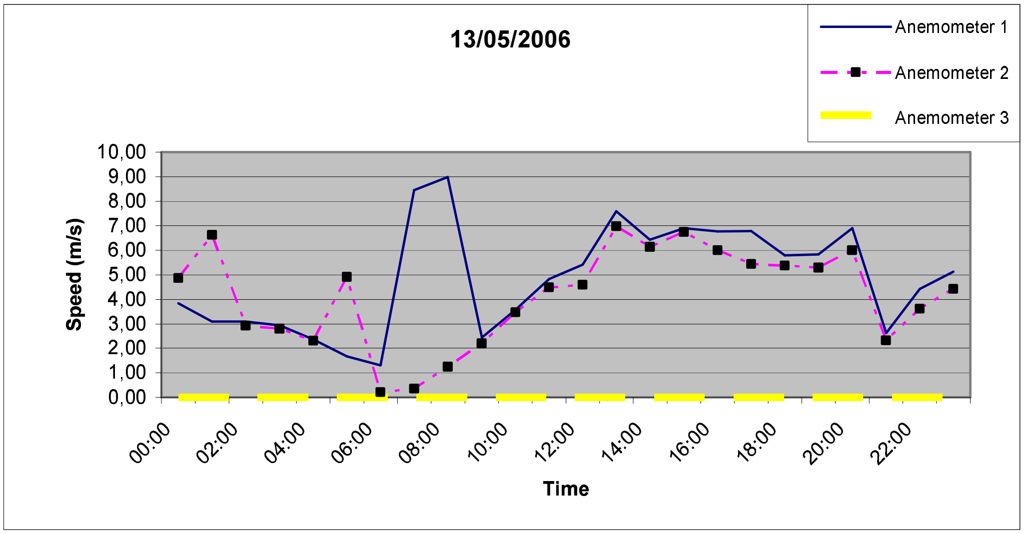

Figure AB.5 Measured speed (13.05.2006)

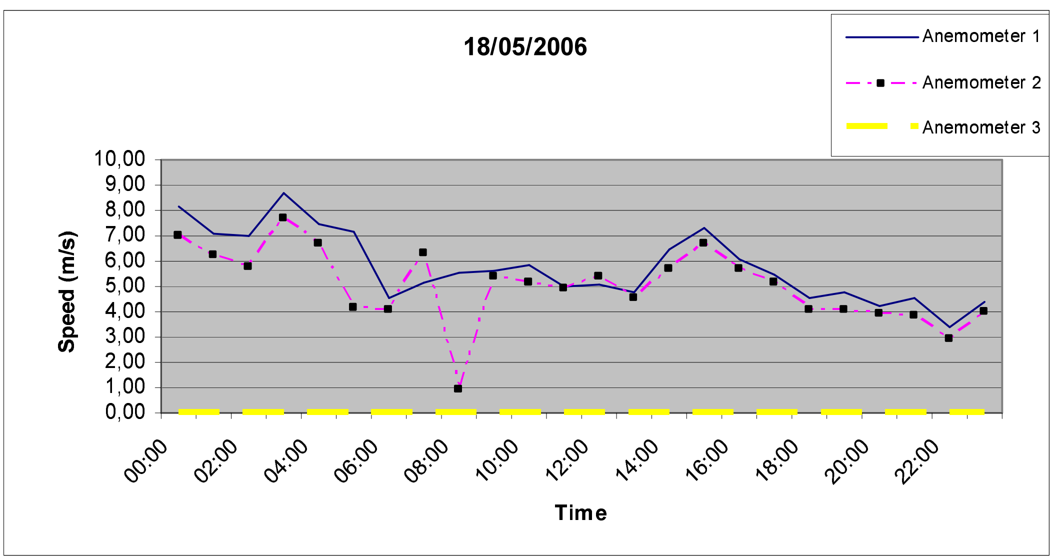

Figure AB.6 Measured speed (18.05.2006)

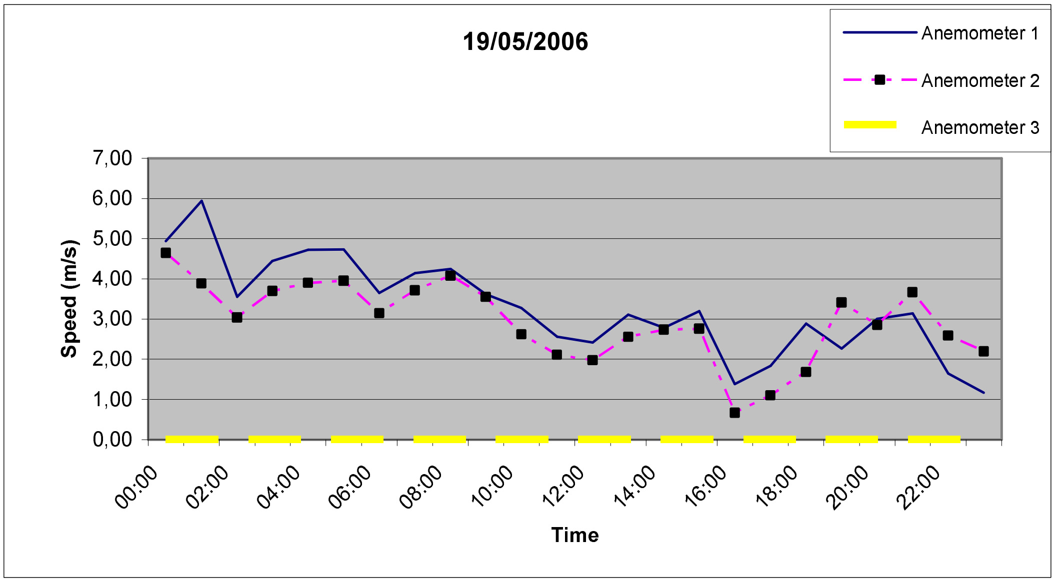

Figure AB.7 Measured speed (19.05.2006)

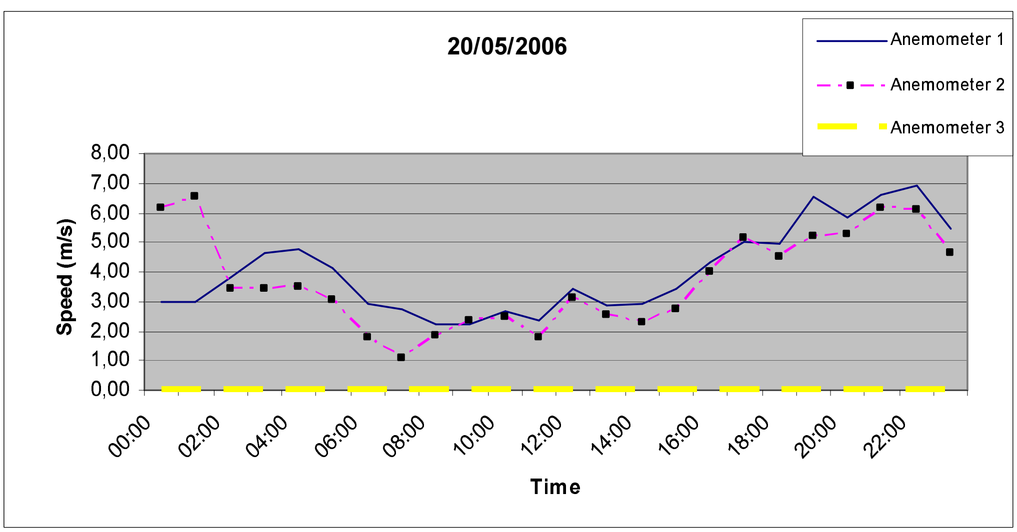

Figure AB.8 Measured speed (20.05.2006)

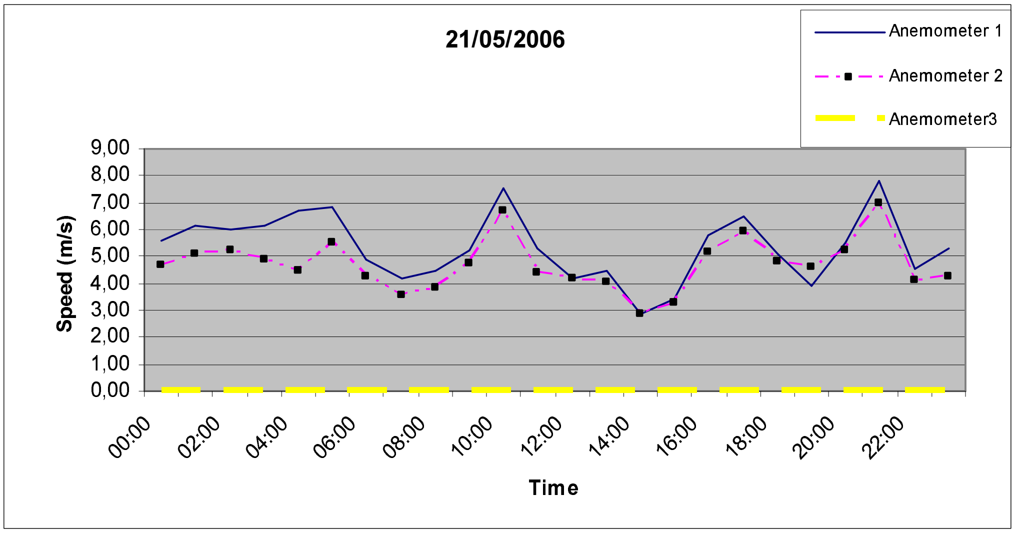

Figure AB.9 Measured speed (21.05.2006)

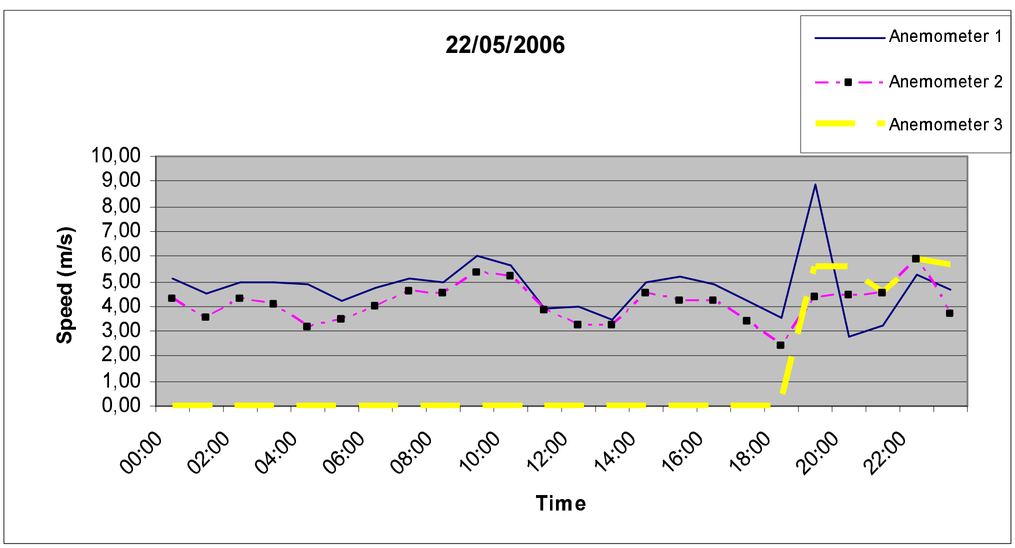

Figure AB.10 Measured speed (22.05.2006)

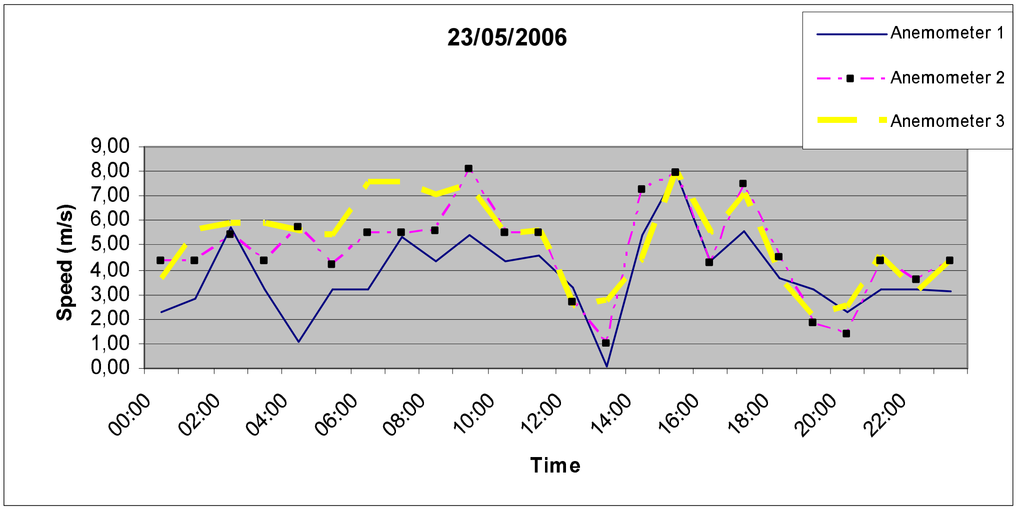

Figure AB.11 Measured speed (23.05.2006)

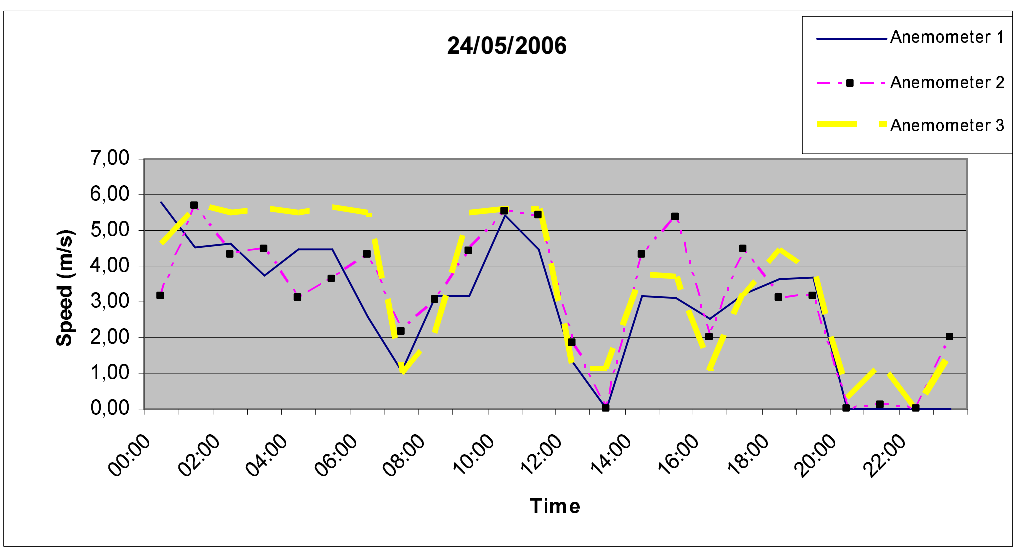

Figure AB.12 Measured speed (24.05.2006)

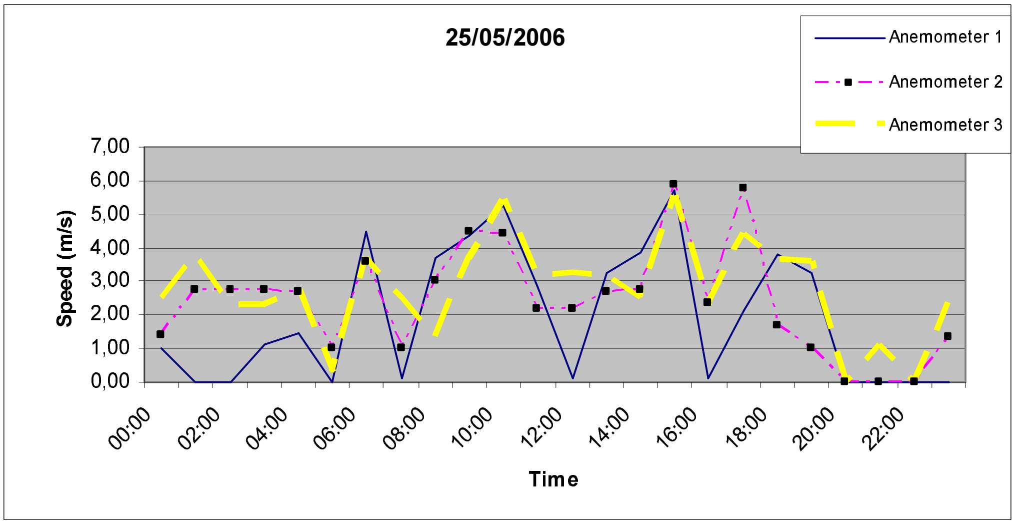

Figure AB.13 Measured speed (25.05.2006)

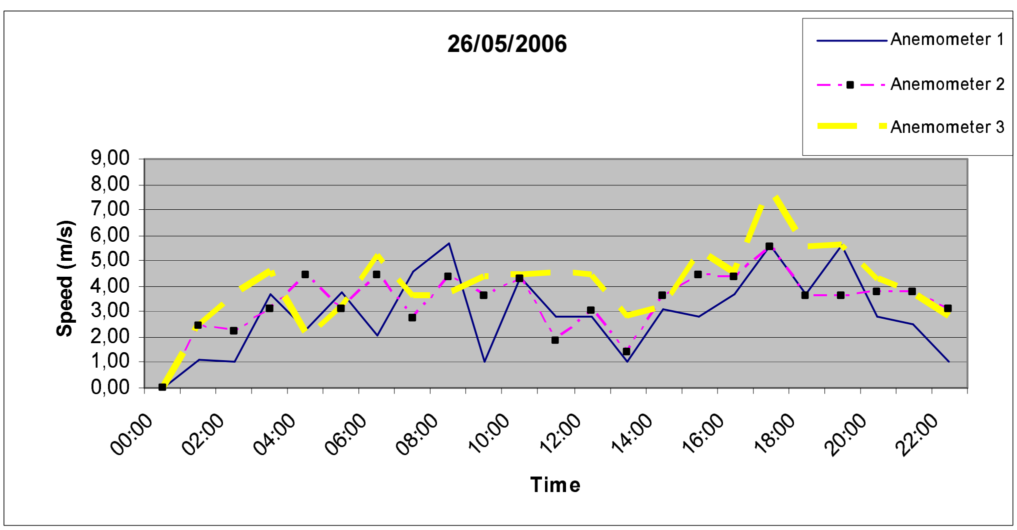

Figure AB.14 Measured speed (26.05.2006)

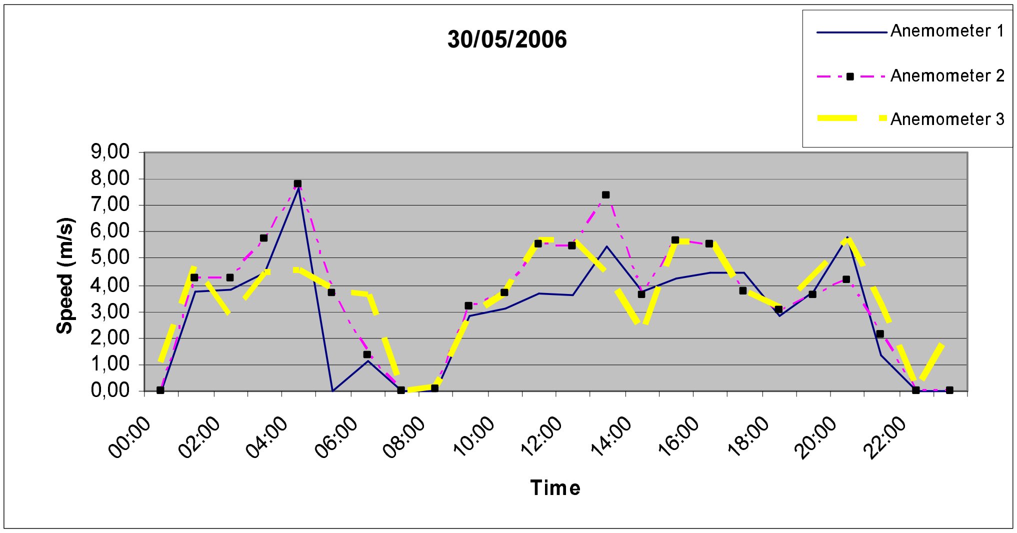

Figure AB.15 Measured speed (30.05.2006)

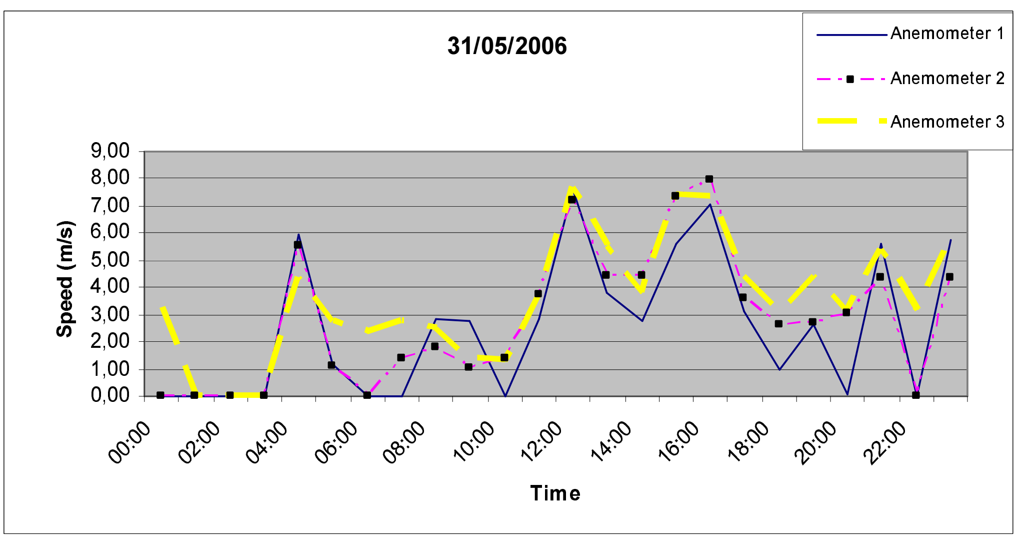

Figure AB.16 Measured speed (31.05.2006)

APPENDIX C

Installation of Mast

Figure AC.1 Erection of Mast (part 1)

Figure AC.2 Erection of Mast (part 2)

Figure AC.3 Erection of Mast (part 3)