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Greenhouse Wireless Monitoring and Control System Based on Sensor Network

نظام لاسلكي لرصد ومراقبة البيوت المحمية بواسطة شبكة المحساسات

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الآية

بسم الله الرحمن الرحيم

قال تعالي:(قلْ لَوْ كَانَ الْبَحْرُ مِدَادًا لِكَلِمَاتِ رَبِّي لَنَفِدَ الْبَحْرُ قَبْلَ أَنْ تَنْفَدَ كَلِمَاتُ رَبِّي وَلَوْ جِئْنَا بِمِثْلِهِ مَدَدًا)

صدق الله العظيم

(سورة الكهف الآية ١٠٩)

DEDICATION

To my family and to them cordial

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ABSTRACT

In this thesis, an embedded system which is closely monitored and controlled the climate parameters such as humidity, temperature, and light of a greenhouses based on wireless sensor network on a regular basis round the clock for cultivation of crops or specific plant species which could maximize their production was presented. The designed system comprises beside the sensors from microcontroller, monitor, wireless communication based on XBee and respondents such as fan, heater and pump. This a low cost and flexible system can be empowered by a reliable management scenario in order to maintain the greenhouses environmental conditions. The designed system shows the importance of using the wireless sensor network in such application, where the installation, power and running cost were minimized. The obtained results show a good management performance to the greenhouse environment where the wireless sensor network can be utilized to form a network from several greenhouses.

المستخلص

هذه الأطروحة تحتوى على تصميم نظام مضمن (مدمج) لرصد ومراقبة بعض المؤشرات البيئية مثل الرطوبة النسبية، ودرجة الحرارة، وكثافة الضوء داخل البيت المحمي بواسطة شبكة الإستشعار اللاسلكية على أساس منتظم على مدار الساعة لتوفير بيئة مناسبة لزراعة المحاصيل أو الأنواع النباتية المحددة لزيادة الإنتاج والإنتاجية. ويتألف النظام المصمم بجانب أجهزة الإستشعار من: المتحكم الدقيق، وشاشة للعرض، وسيط إتصال لاسلكي متوافق مع نظام شبكة الإستشعار اللاسلكية، وأجهزة الإستجابة كالمروحة، والسخان الكهربي ومضخة المياه. هذا النظام قليل التكلفة و المرونة تم تزويده بإجرائية لإدارته بغرض المحافظة على الشروط المناخية بالبيت المحمي. النتائج المتحصل عليها برهنت على جودة إستخدام تقنية شبكة الإستشعار اللاسلكية في إدارة البيوت المحمية حيث يمكن استخدام شبكة الاستشعار اللاسلكية لتشكيل شبكة من عدة بيوت محمية.

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LIST OF ABBREVIATIONS

AC	Alternative Current
ADC	Analog to Digital Converter
API	Application Programming Interface
AVR	Advanced Virtual Risc
BASCOM	BASic COMpiler
CPU	Central Processing Unit
CHS	Capacitive Humidity Sensor
DC	Direct Current
EEPROM	Electrical Erasable Programmable Read Only Memory
GND	Ground
GSM	Global System Mobile
GUI	Graphical User Interface
HS	Humidity Sensor
ISM	Industrial, Scientific & Medical
IT	Information Technology
LCD	Liquid Crystal Display
LDR	Light Dependent Resistor
LMI	Linear Matrix Inequalities
MEMS	Micro Electro Mechanical System
MPPT	Maximum Power Point Tracking
NEST	Network Embedded System Technology
PAR	Photo-synthetically Active Radiation
PC	Personnel Computer
PDA	Personal Digital Assistant
PDC	Parallel Distributed Compensation

PGHS	Paprika GreenHouse System
PIC	Peripheral Interface Controller
PID	Proportional Integral Derivative
RAM	Random Access Memory
ROM	Read Only Memory
RF	Radio Frequency
RH	Relative Humidity
RX	Receiver
SMS	Short Message Service
SIM	Subscriber Identification Module
T-S	Takagi – Sugeno
TX	Transmit
USB	Universal Serial Bus
WSAN	Wireless Sensor Actor Networks
WSN	Wireless Sensor Network
A	Ampere
°C	Degree Celsius
GHz	Gaga Hertz
V	Voltage
W	Watt

CHAPTER ONE

INTRODUCTION

1.1 Background

Greenhouse is a kind of place which can change plant growth environment, create the best conditions for plant growth, and avoid influence on plant growth due to outside changing seasons and severe weather [1, 2]. For greenhouse measurement and control system, in order to increase crop yield, improve quality, regulate the growth period and improve the economic efficiency, the optimum condition of crop growth is obtained on the basis of taking full use of natural resources by changing greenhouse environment factors such as temperature, humidity, light, and CO_2 concentration.

Greenhouse measurement and control system is a complex system，it needs various parameters in greenhouse automatic monitoring, information processing, real-time control and online optimization. The development of greenhouse measurement and control system has made considerable progress in the developed countries, and reached the multi-factors comprehensive control level, but if the foreign existing systems is introduced, the price is very expensive and maintenance is not convenient.

In recent years, Sudan has launched many projects based on greenhouse. The measurement and control system used in these greenhouses is mostly based on cable, so it is not only wiring complex, but also unfavorable to improve the system efficiency. With the rapid development of the low cost, low power sensor and wireless communication technology, the conditions that construct wireless greenhouse measurement and control system becomes mature, and it is important to realize agricultural modernization [3-5].

1.2 Problem Statement

The greenhouse system is a complex system. Any significant changes in one climate parameter could have an adverse effect on another climate parameter as well as the development process of the plants. Therefore, continuous monitoring and control of these climate factors will allow for maximum crop yield. Temperature, humidity and light intensity are the three most common climate variables that most growers generally pay attention to. However, looking at these three climate variables will not give the growers the full picture of the operation of the greenhouse system. Therefore, continuous monitoring and control of these climate factors will allow for maximum crop yield Greenhouse installations require a large amount of wires and cables to distribute sensors and actuators. Therefore, an embedded based solution with wireless techniques can be proposed.

1.3 Objectives

The main objectives of this research are to design and realize a low cost wireless sensor network based technology for monitoring and controlling greenhouse climate.

1.4 Methodology

To achieve the above objectives, the following method/approach is followed:

- The system consists of local station and a central station, where the local station is used to measure the environmental parameters and to control the operation of controlled actuators such as fan, heater, and water pump to maintain climate parameters at predefined set points for the temperature, humidity and light intensity. The central station is used to monitor the environmental parameters. Therefore, a suitable selection for the sensors and their compensation circuit can be achieved.

- An AVR microcontroller is selected to be the processing module for both the local and central unit, when it programmed using Bascom programing language.
- The communication between the local and central stations is achieved via XBee WSN modules in each.
- Test and evaluate the system and its components can be achieved using ISIS Proteus environment.

1.5 Thesis Outline

This thesis is organized as follow: Chapter two introduces the greenhouse and wireless sensor technology. In addition, some of the previous greenhouse designs were reviewed. In chapter three, the design and implementation of the proposed greenhouse monitoring and controlling was demonstrated. In chapter four the results were showed and discussed. In chapter five, the conclusion and recommendations were drawn and presented, respectively.

CHAPTER TWO

MONITORING AND CONTROLLING TECHNIQUES IN GREENHOUSE

2.1 Introduction

As it is well known that greenhouse is a building where plants are grown. Greenhouses are often used for growing flowers, vegetables, fruits, and tobacco plant. Greenhouses are very useful for they provide an optimal temperature around plants, protect them from weather extremes, extends the growing season, allowing you to sow plants earlier and harvest plants later and allows economic crops such as tomatoes, cucumbers, melons and aborigines to crop more successfully [6]. Basic factors affecting plant growth such as sunlight, water content in soil, temperature, CO_2 concentration. These physical factors are hard to control manually inside a greenhouse and there is a need for automated design arises.

i. Temperature effects

Temperature influences most plant development process including: photosynthesis, transpiration, absorption, respiration and flowering [7]. In general, growth is promoted when the temperature rise and inhibited when temperature falls. The growth rate of a plant will not continue to increase with the increasing of temperature. Each species of plant has a different temperature range in which they can grow. Below this range, processes necessary for life stop, ice forms within the tissue, tying up water necessary for life processes. Above this range, enzymes become inactive and again process essential for life stop [8]. Therefore the temperature should be maintained at optimum level whenever possible.

ii. Humidity effects

Humidity is important to plants because it partly controls the moisture loss from the plant [9]. The leaves of plants have tiny pores, CO_2 enters the plants through these pores, and oxygen and water leave through them. Transpiration rates decrease proportionally to the amount of humidity in the air. This is because water diffuses from areas of higher concentration to areas of lower concentration [10]. Due to this phenomenon, plants growing in a dry room will most likely lose its moisture overtime. The damage can be even more severs when the difference in humidity is large. Plants stressed in this way frequently shed flower buds or flowers die soon after opening [11]. High humidity can also affect the development of plant. Under very humid environments, fungal diseases most likely to spread, on top of that air becomes saturated with water vapor which ultimately restricts transpiration. At time of reduced respiration, the water uptake is low, and therefore transport of nutrients from roots to shoots is also restricted. Plants are exposed to high humid environment for a long period of time and may suffer deficiencies.

iii. Light effect

All things need energy to grow, human and animals get energy from food. Plants, on the other hand, get energy from the sun light through a process called photosynthesis. This is how light affects the growth of a plant. Without light, a plant would not be able to produce the energy it needs to grow. Aside from its effect through photosynthesis, light influences the growth of individual organs or of the entire plant in less direct ways. The most striking effect can be seen between a plant grown in normal light and the same kind of plant grown in total darkness. The plant grown in the dark will have a tall and spindling stem, small leaves, and both leaves and stem, lacking chlorophyll, are pale yellow. Plants grown in shade instead of darkness show a different response. Moderate shading tends to reduce transpiration more than it does photosynthesis. Hence, shaded plants may be taller and have larger leaves because the water supply within the growing tissues is better. With heavier shading, photosynthesis is reduced to an ever greater degree and, weak plants result [10].

2.2 Previous Works

There are many previous studies in this area which should be reviewed for helping in proposing a system with solvable problem in greenhouses. Stipanicev and Marasovic [12] have proposed system is an embedded Web server unit system based on TINI board, by collecting data from distributed sensors and activating connected actuators using simple 1-wire local network. On the other side Web server is connected to the Internet through Ethernet or dial-up network [12]. They have claimed that the developed system shows all advantages of Network Embedded System Technology (NEST), like the possibility of changing physical topology and low dimensions and cost in comparison with PC based system, preserving the full functionality at the same time [12].

Nachidi *et al* [13] have proposed system to control of air temperature and humidity concentration in greenhouses is described by means of simultaneous ventilation and heating systems by using Takagi-Sugeno (T-S) fuzzy models and the Parallel Distributed Compensation (PDC) concept**.** And showed that the robust fuzzy controller effectively achieves the desired climate conditions in a greenhouse, using this T-S fuzzy model, the stability analysis and control design problems can be reduced to sufficient conditions expressed as Linear Matrix Inequalities (LMIs) [13].

Qian *et al* [14] have compared the advantages of ZigBee with other two similar wireless networking protocols, Wi-Fi and Bluetooth, and proposed a wireless solution for greenhouse monitoring and control system based on ZigBee technology. As an explorative application of ZigBee technology in Chinese greenhouse, it may promote Chinese protected agriculture. With the capabilities of self-organizing, self-configuring, self-diagnosing and self-healing, the ZigBee based monitoring and control system provides nearly unlimited installation flexibility for transducers, increases network robustness, and considerably reduces costs. Therefore, they concluded that the ZigBee-based monitoring and control system can be a good solution for greenhouse monitoring and control [14].

Elmusrati *et al* [15] have suggested a different approach for implementing WSN in greenhouse environment by making use of a commercial wireless sensing platform provided by Sensinode Inc. The hardware design of the system consists of Sensinode's Micro 2420U100 operates as basic measuring node, with four commercial sensors (*e.g.* humidity, temperature, light and CO_2). The idea behind this development is to test the reliability and feasibility of a prototype wireless environment monitoring system in commercial greenhouse. The experimental result showed that the network can detect local difference in the greenhouse climate caused by various disturbances in the environment [15].

Palaniappan *et al* [16] have proposed an embedded greenhouse monitoring and control system to provide a highly detailed micro-climate data for plants within a greenhouse environment with an innovative method of growing temperate crops in a tropical environment using microclimatic conditions. The greenhouse was equipped with conventional wired sensors that provide readings of the air temperature, light intensity and nutrient solution temperature in the mixing tank. The acidity and concentration of the nutrient solution were manually measured, and adjusted accordingly, and high resolution data, collected with the deployment of a network of wireless sensors to provide sufficient data to develop a model for the growth of these crops under aeroponic conditions. The researcher claimed that the reliability of the star network was relatively high, with many nodes performing with a data transmission rate above 90%, where the minimum data transmission rate for all the nodes was 70% [16].

Abdul Aziz *et al* [17] have proposed system has a measurement which capable of detecting the level of temperature to developed a remote temperature monitoring system using wireless sensor and Short Message Service (SMS) technology. This system also has a mechanism to alert farmers regarding the temperature changes in the greenhouse so that early precaution steps can take and testing several types. This extended to include more environmental variables to be monitored in the agricultural greenhouse which relate to the increment of fruits and vegetables productivity. For example, other than temperature, the soil and water acidity level in the greenhouse also play important role to the quality of fruits, enhanced to produce a system that can trigger automatic actions of related components such as the sprinkler, lighting and air ventilators, rather than just send alert notification message, the proposed system is enhance by implementing artificial intelligent components to enable advanced implementations such as self-learning, predicting, and define ambiguous situation which provide preventive measures [17].

Lee *et al* [18] have suggested the 'Paprika GreenHouse System' (PGHS) which collects paprika growth information and greenhouse information to control the paprika growth at optimum condition. Also controls ventilators, humidifiers, lightings and video-processing through Graphical User Interface (GUI) Application by analyzing the measured data. The system provides with the 'growth environment monitoring service', which is monitoring the paprika growth environment data using sensors measuring temperature, humidity, illuminance, leaf wetness and fruit condition, the 'artificial light-source control service', which is installed to improve the energy efficiency inside greenhouse, and 'growth environment control service', controlling the greenhouse by analyzing and processing of collected data[18].

Song *et al* [19] have proposed system based on AVR Single Chip microcontroller and wireless sensor networks. The monitoring and management center can control the temperature and humidity of the greenhouse, measure the carbon dioxide content, and collect the information about intensity of illumination. In addition, the system adopts multilevel energy memory. It combines energy management with energy transfer, which makes the energy collected by solar energy batteries be used reasonably. Therefore, the self-managing energy supply system is established. The system has advantages of low power consumption, low cost, good robustness, extended flexible as well as an effective tool for monitoring and analysis decision-making of the greenhouse environment is provided [19]**.**

Chiung, Guan and Jwu [20] have utilized Field Point of National Instrument to build the greenhouse environment control system, and Labview as programing language for compiling. They have used smart mobile (or PDA) to control the Personnel Computer (PC) server through the wireless network where the Field Point will adjust environment of greenhouse through controlling the device. Moreover, user can master the status of the greenhouse through web cam, and which use the smart mobile to control greenhouse environment system on anywhere. The result of this proposed system showed that the designed system could be more effective in manpower savings and raising the economic value of products *i.e.* Phalaenopsis [20].

Rahali *et al* [21] have designed and development of an electronic system based on a microcontroller that integrates remote control functions rooted in the GSM network. The system allows the acquisition of different climatic parameters in an agricultural greenhouse. In addition, this electronic system achieves the control and remote monitoring of greenhouse solutions, in particular drip irrigation stations, by sending SMS messages. The system, also, includes a serial cable, a GSM, conditional sensors card, power interfaces and microcontroller. An active SIM card is required to receive and send messages. A graphical user interface using LabVIEW software for the acquisition, monitoring with PC and storage of all data through the PCL812PG card have been developed. This interface encompasses at the same time reliability, flexibility of use, interactivity and processing capability in real-time of the whole data. The proposed system presented several advantages: user friendly, easily implemented, focus main parameters, use GSM phones because of theirs availability, low cost of SMS in Morocco, and network coverage [21].

Zagade and Kawitkar [22] designed and implemented of a WSN that can monitor the air temperature, humidity and ambient light intensity in greenhouse. This can help farmers to understand the environmental conditions and they can adopt different methods to increase the crop production. The system is integrated with small size application specific sensors and radio frequency modules. All monitored parameters are transmitted through a wireless link to cellular device for analysis. A cell phone is used instead of computer terminal keeping mind that system will be used by farmers and considering power management [22].

Deore and Umale [23] have given an emphasis on WSN approach for green house monitoring and control. A control system is developed and tested using recent ATmega microcontroller. The farmers in the developing countries can easily use designed for maximizing yield. ATmega microcontrollers are preferred over other microcontrollers due to some important features including 10bit ADC, sleep mode, wide input voltage range and higher memory capacity. The design system considered optimization and functional improvement of the system. The system has several advantages in term of its compact size, low cost and high accuracy [23].

Sagar [24] has developed the monitoring and GSM systems for using in greenhouse applications, where real time data of climate conditions and other environmental properties are sensed and control decisions are taken by monitoring system and they are modified by the automation system and sends SMS that what operation is performed by them to user. The architecture of a greenhouse monitoring system comprises of a set of sensor nodes and a control unit that communicate with each sensor node and collects local information to make necessary decisions about the physical environment. The system is little cost with wireless sensors but it works with more effectively [24].

Song *et al* [25] have proposed system scheme based on wireless sensor network, where they adopted an Atmega128L chip and a low power RF chip from TI *i.e.* CC2530 to design the sink node and sensor nodes in the WSN. The monitoring and management center can control the temperature and humidity of the greenhouse, measure the carbon dioxide content, and collect the information about intensity of illumination, and so on. And the system adopts multilevel energy memory. It combines energy management with energy transfer, which makes the energy collected by solar energy batteries be used reasonably. Therefore, the self-managing energy supply system is established. In addition, the nodes deployment method and time synchronization problem are analyzed in detail. The system can solve the problem of complex cabling with the advantages of low power consumption, low cost, good robustness, extended flexible and high reliability. An effective tool is provided for monitoring and analysis decision-making of the greenhouse environment [25].

Othman and Shazali [26] have discussed and reviewed wireless sensor network applications for environmental monitoring. Development in the technology of sensor such as Micro Electro Mechanical Systems (MEMS), wireless communications, embedded systems, distributed processing and wireless sensor applications have contributed a large transformation in WSN recently. It assists and improves work performance both in the field of industry and our daily life. Wireless sensor network has been widely used in many areas especially for surveillance and monitoring in agriculture and habitat monitoring. Environment monitoring has become an important field of control and protection, providing real-time system and control communication with the physical world. An intelligent and smart Wireless Sensor Network system can gather and process a large amount of data from the beginning of the monitoring and manage air quality, the conditions of traffic, to weather situations in the monitoring system [26].

Mittal *et al* [27] have designed hardware for green house monitoring various sensors are used to control the environment. The parameters *e.g.* temperature, humidity, light intensity for green house and soil wetness for crop growth. The system comprises of sensor, ADC, microcontroller and actuators. When any of the above mentioned climatic parameters cross a safety threshold which has to be maintained to protect the crops, the sensors sense the change and the microcontroller reads this from the data at its input ports after being converted to a digital form by the ADC. The system has successfully overcome quite a few shortcomings of the existing systems by reducing the power consumption, maintenance and complexity, at the same time providing a flexible and precise form of maintaining the environment. The continuously decreasing costs of hardware and software, the wider acceptance of electronic systems in agriculture, and an emerging agricultural control system industry in several areas of agricultural production, will result in reliable control systems that will address several aspects of quality and quantity of production [27].

Berezowski [28] has reviewed the landscape of the application of wireless sensor networking in greenhouse management to make computer engineer more aware about this specific application domain and the space it offers for applying IT and communication infrastructure, as well as to make horticulture researchers more aware of what wireless technologies have to offer and how to optimize their usage in the greenhouse. Also identified, formulated and discussed the design space of a few in opinion most important problems in developing efficient and cost effective WSN deployments for greenhouses. The reasons to propose such an analysis have come from the gap have observed between the results and observations coming from preliminary field experimentation in the greenhouse [28].

Hwang and Yu [29] have proposed design and implementation of a remote monitoring and controlling system using ZigBee networks. This system is targeting the home network. Web service and a smartphone are used for the client system to monitor and control the home. This system can be applied in many areas such as elderly protecting systems, cultural heritage or forest fire monitoring systems, managing systems for agricultural cultivation and so on [29].

Sahu and Mazumdar [30] have designed a simple, easy to install, microcontroller-based (Atmel) circuit to monitor and record the values of temperature, humidity, soil moisture and sunlight of the natural environment that are continuously modified and controlled in order optimize them to achieve maximum plant growth and yield. The microcontroller communicates with the various sensor modules in real-time in order to control the light, aeration and drainage process efficiently inside a greenhouse by actuating a cooler, fogger, dripper and lights respectively according to the necessary condition of the crops. An integrated Liquid Crystal Display (LCD) is also used for real time display of data acquired from the various sensors and the status of the various devices [30].

Alausa Dele and Kolawole [31] have proposed microcontroller based greenhouse control device is used in the automatic control and monitoring of Equipments and quantities such as screening installations, heating, cooling, lighting, temperature, soil Moisture level and other quantities/conditions in a greenhouse, with effective monitoring of all quantities therein, hence eliminating need for Human monitoring. With an enhanceable feature it integrates and automates by turning ON or OFF all monitoring devices in the house as well as provides suggestions for remedies when the need arises. The system has successfully overcome quite a few short comings of the existing systems by reducing the power consumption, maintenance and complexity, at a reduced cost and at the same time providing a flexible and precise form of maintaining the environment [31].

Mohanty and Patil [32] have proposed some important parameters that should be monitored at a greenhouse in order to achieve good results at the end of the agricultural production such as temperature, light and humidity. And have presented a wireless sensor network having several sensor nodes with these commercial sensors to measure the above parameters. The system can efficiently capture greenhouse environmental parameters and it shows normal communication between source and sink node and fine network stability. It also obtains strong adaptability, good confidentiality and high reliability. So will developed greenhouse wireless sensor network monitoring system design based on solar energy. The sensor nodes receive the solar energy and supply it to the wireless sensor network. The design will consume less energy and cost effective [32].

Nikhade and Nalbalwar [33] have summarized an idea that can carry out to provide an efficient control mechanism of microclimate into greenhouses through the implementation of an infrastructure of wireless sensors network to control environmental parameters. This enables a real time action process that aims to atomise the network tasks. Based on the advantage gained from the small size of the network, low cost distributed sensing network that can be employed anywhere and even with harsh environments greenhouse crops are in essential neediness for WSAN system which achieve better monitoring-controlling and hence avoiding damage of the crops due to unstable inside parameters like temperature, humidity, soil moisture, leaf temperature and many other parameters which affects crops growth and may cause of diseases. The design is more focusing on automation jobs, optimizing the response time, and providing instant solution [33].

Gao *et al* [34] have designed a wireless greenhouse monitoring system based on ZigBee and GSM technology to resolve the problems of complicated cabling and costly wired network in the current system. The system consists of two parts: a wireless sensor network and remote control terminal. According to parameter distribution in the monitoring regional, a wireless transmission network was formed, all of the nodes in the network using solar power. In the remote control terminal, the study developed a simplified expert decision system, in which the part of greenhouse control decision adopts the fuzzy decoupling control algorithm to realize the temperature and humidity decoupling control and increase the accuracy of decision-making according to the experimental test. It can realize real-time, accurate monitoring and collecting of parameters data in the greenhouse environment; the remote control terminal can give effective decision management solutions. The system achieves automatic real-time monitoring of environmental parameters and gives correct decision plans, which is of a broad application prospect [34].

Jianjun *et al* [35] have presented system that consists of a data acquisition controller and greenhouse remote monitoring and control software. The system ,monitor temperature ,humidity, soil water content and concentration of carbon dioxide inside the greenhouse which then saved to a database. According to the current indoor temperature, the target temperature and the offset temperature, Proportional Integral and Derivative (PID) control method is used to control temperature control in greenhouse. The system is implemented using low power wireless components, and easy to be installed [35].

In addition, Lambebo and Haghani [36] provided a detailed study and implementation of a WSN for real time and continuous environmental monitoring of greenhouse gases. A tree-topology WSN consisting of two sensor nodes and a base station was successfully built and tested using open source and inexpensive hardware to measure the concentration level of several greenhouse gases. The captured data is made available to the user through a graphing Application Programming Interface (API). The network works within the range of 100 meters for optimum performance [36].

2.3 Wireless Sensor Network in Greenhouse Management

In recent years, environmental monitoring using wireless sensors technology has become more important. Especially in the agriculture industry, wireless sensor technology is very suitable for distributed data collecting and monitoring in tough environments [37]. A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. During the last decade wireless sensor networks are utilized in many civilian applications, including environment and habitat monitoring, healthcare applications, home automation, and traffic control .Several standards are currently either ratified or under development by organizations. Standards are used far less in WSNs than in other computing systems which make most systems incapable of direct communication between different systems. The principal standards commonly used in WSN communications are: Wi-Fi, Bluetooth and ZigBee. All these mentioned technologies work at similar RF frequencies, and their applications sometimes overlap.

In addition, a survey conducted by [38] of the advance in wireless sensor network applications has reviewed a wide range of applications and identified the agriculture industry as a potential area of deployment, together with a review of the factors influencing the design of sensor networks for this application. Intel Corp was found as one of the main players in the early implementation of wireless sensor networks in the agriculture industry [39]. Research and implementation of WSN in greenhouse climate management was carried out all over the world over the last few years. One of such applications was the use of a web based WSN platform for greenhouse climate monitoring and control.

WSN can form a useful part of the automation system architecture in modern greenhouses. Compared to the wired systems, the installation of WSN is fast, cheap and easy. Moreover, it is easy to relocate the measurement points when needed by just moving sensor nodes from one location to another within a communication range of the coordinator device where a greater level of flexibility and mobility at low cost and low power consumption is provided. If the greenhouse's plant is high and dense, the small and light weight nodes can even be hanged up to the plants branches.

However, the overall system cost can be significantly reduced by the employment of ZigBee chip. Data rate, ZigBee is 250 kbps, when Wi-Fi and Bluetooth are 54 Mbps and 1~2 Mbps, respectively. Despite the lowest data rate, ZigBee is sufficient for a greenhouse. Generally, data traffic in a greenhouse is low—usually small messages such as the change of temperature or a command from the controller to an actuator. If lower data rate it will helps for longer battery life. It is also known that the capacity of network is determined by the number of nodes, and ZigBee has up to 254 nodes, the largest among the three. It meets the application demand of more and more sensors and actuators in a greenhouse. The power and current consumption, ZigBee has the lowest current consumption, 30 mA, while Wi-Fi, 350 mA, and Bluetooth, 65~170 mA. It also greatly helps to prolong the battery life [40].

In conclusions regarding which wireless technology is more superior, since the suitability of wireless technology is solely dependent on the application. For example, ZigBee wireless technology cannot be applied to high data implementations applications such as audio/video streaming and graphic web browsing because of their high bandwidth requirements. Bluetooth and Wi-Fi on the other hand are not suitable for battery powered applications of their high power consumption characteristics. For this particular thesis ZigBee wireless technology was chosen for a number of reasons: ZigBee has very low power consumption, Low network complexity, it is designed for remote monitoring and control applications, and ZigBee networks can scale to hundreds and thousands of devices.

2.4 ZigBee Technology

ZigBee is new short range wireless communication technology, representing a wireless sensor network which is highly reliable, secure, low data rate, low power consumption, low cost and fast reaction with a Radio Frequency (RF) communications standard based on IEEE 802.15.4. There are three kinds of device types in ZigBee. Every ZigBee network will have a single coordinator device. You cannot call anything a network until you have at least two things connected. So every ZigBee network will also have at least one other device, either a router device or an end device. Many networks will have both, and most will be much larger than just two or three radios:

i. ZigBee coordinator

ZigBee networks always have a single coordinator device. This radio is responsible for forming the network, handing out addresses, and managing the other functions that define the network, secure it, and keep it healthy. Remember that each network must be formed by a coordinator where there is one coordinator in the network.

ii. ZigBee router

A router is a full-featured ZigBee node. It can join existing networks, send information, receive information, and route information. Routing means acting as a messenger for communications between other devices that are too far apart to convey information on their own. Routers are typically plugged into an electrical outlet because they must be turned on all the time. A network may have multiple router radios.

iii. ZigBee end device

There are many situations where the hardware and full-time power of a router are excessive for what a particular radio node needs to do. End devices are essentially stripped-down versions of a router. They can join networks and send and receive information, but that's about it. They don't act as messengers between any other devices, so they can use less expensive hardware and can power themselves down intermittently, saving energy by going temporarily into a nonresponsive sleep mode. End devices always need a router or the coordinator to be their parent device. The parent helps end devices join the network, and stores messages for them when they are asleep. ZigBee networks may have any number of end devices. In fact, a network can be composed of one coordinator, multiple end devices, and no routers at all. There are four major ZigBee topologies: star, mesh, pair, and cluster tree as in Figure 2.1. Each has its own advantage and disadvantages. Mostly star and mesh topologies are used frequently [41].

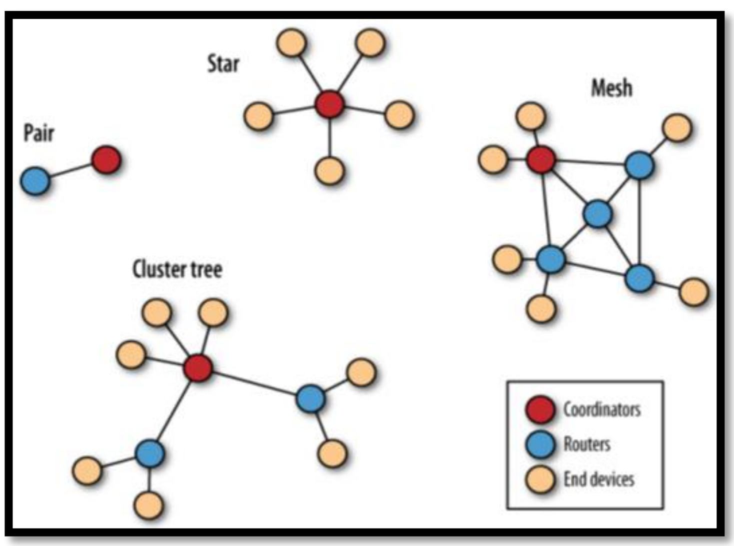

Figure 2.1: ZigBee pair, star, mesh, and cluster tree topologies

CHAPTER THREE

DESIGN, INTEGRATION AND IMPLEMENTATION OF EMBEDDED-BASED GREENHOUSE SYSTEM

3.1 An Overview of the Greenhouse Design

The proposed green house system is presented in Figure 3.1. As can be grasped, the system has the following units: sensing unit, processing and storing unit, displaying and indicating unit, communication unit, power supply unit, and derivers and actautors unit. In the following, the units of the proposed greenhouse system were designed, simulated, implemented, tuned and integrated. A Proteus ISIS environment simulator was utilized to simulate the proposed system as shown in Figure 3.2, where the implemented system was achieved by using the breadboard.

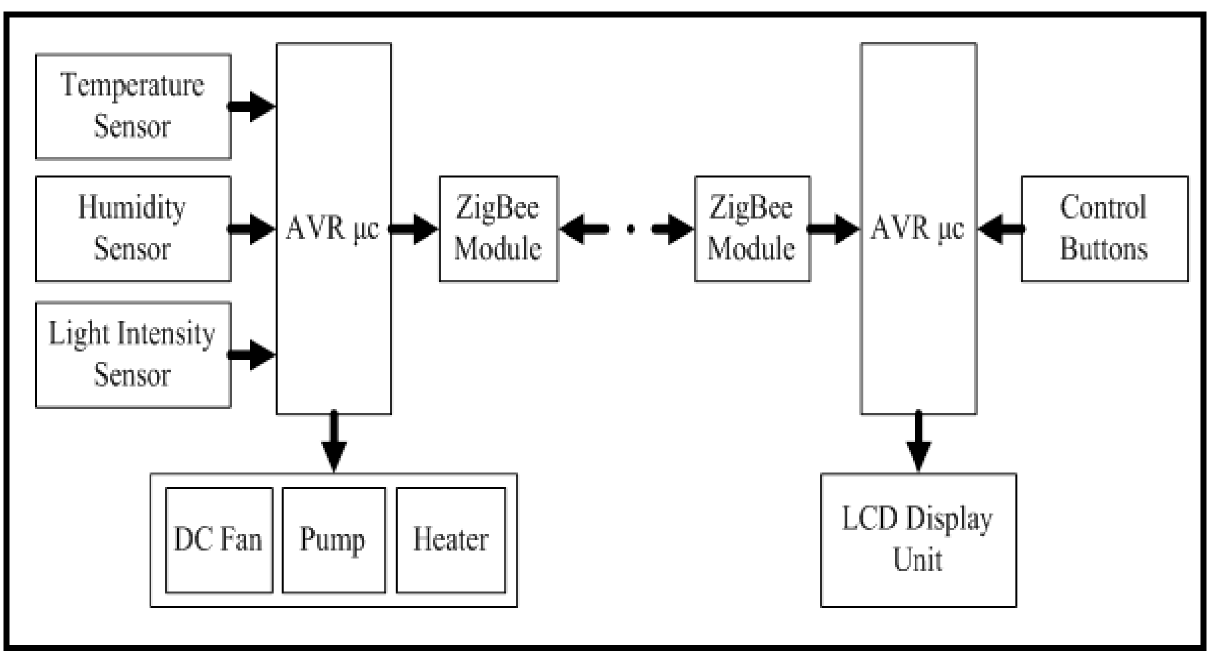

Figure 3.1: The proposed greenhouse block diagram

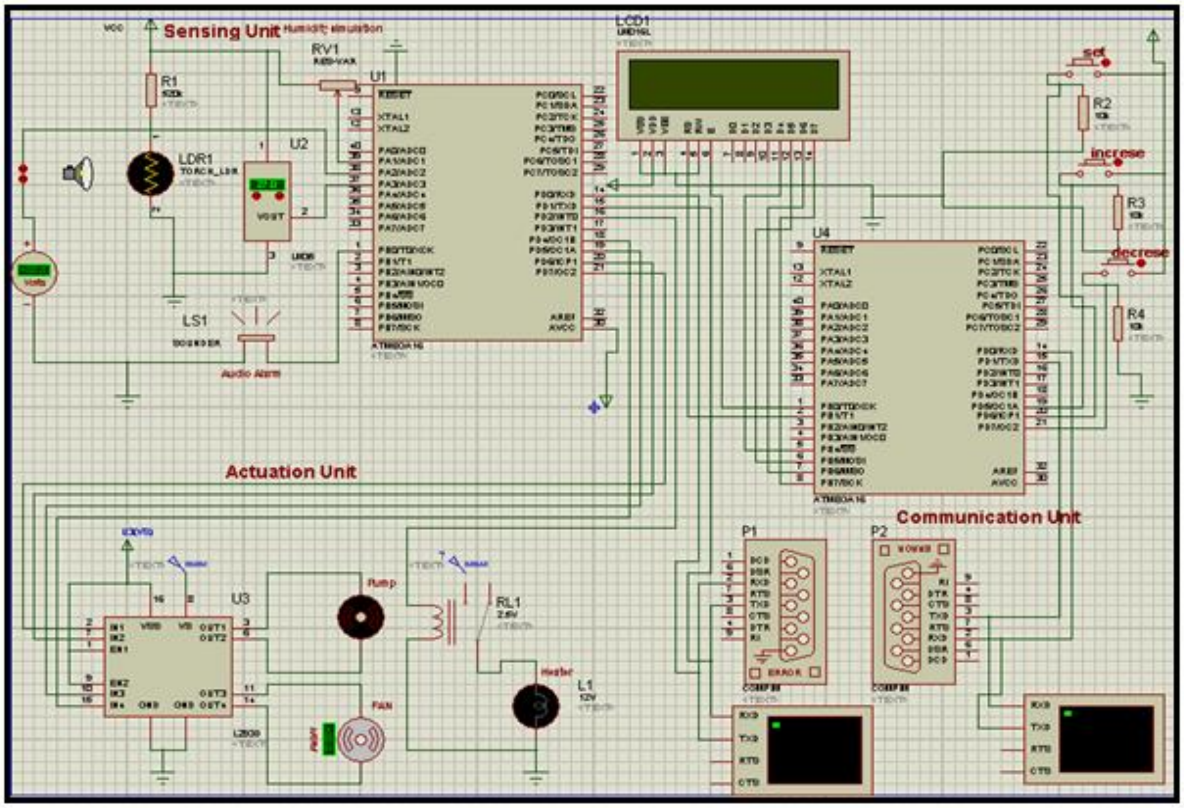

Figure 3.2: The complete schematic diagram of the proposed greenhouse system

3.2 Sensing Unit

A sensor is a device, which responds to an input quantity (physical quantity) by generating a functionally related output usually in the form of an electrical or optical signal. A sensor's sensitivity indicates how much the sensor's output changes when the measured quantity changes. For instance, if the mercury in a thermometer moves 1 cm when the temperature changes by 1°C, the sensitivity is 1cm/°C (it is basically the slope dy/dx assuming a linear characteristic). Sensors also have an impact on what they measure; for instance, a room temperature thermometer inserted into a hot cup of liquid cools the liquid while the liquid heats the thermometer. Sensors need to be designed to have a small effect on what is measured; making the sensor smaller often improves this and may introduce other advantages.

The following factors must be consider when choosing sensor

- Rang and span: This reprent the range a limits heater which the input can vary. The span is the maximum value of the input minus the minimum value.
- Errors: Is the different between the result of the measurement and the free value of the quantity being measured.

Error = measured value – free value

- Accuracy: is the extent to which the value indicated by measurement system might be varying. It is the summation all possible error that to accuracy.
- Sensitivity: it is relationship indicating how much output you get per unit input.
- Stability: it is the ability to give the same output when used to measure a constant input over a period of time.
- Resolution: when input varies continuously over the range the output signals for the some seasons may change in srrall steps.

In this thesis the sensors used to measure environmental parameters are: temperature sensor (*i.e.* LM35), light sensor (*i.e.* LDR), and humidity sensor (*i.e.* HS1101).

3.2.1 Temperature Sensor

Temperature sensing technology is one of the most widely used sensing technologies in the modern world. It allows for the detection of temperature in various applications and provides protection from excessive temperature excursions. The LM35 shown in Figure 3.3 was selected in this application. The LM35 is a precision integrated circuit temperature sensor, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature, thus it has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1/4°C at room temperature and ±3⁄4°C over a full -55 to +150°C temperature range. Low cost is assured by trimming and calibration at the water level. Table 3.1 shows the technical specification of this model. (Appendix B).

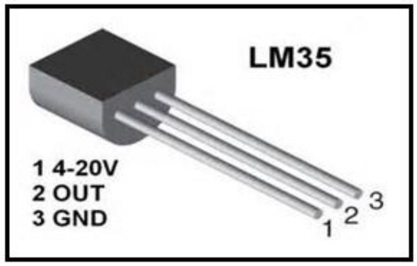

Figure 3.3: The LM35 temperature sensor

Table 3.1: Technical specification of LM35

Specification	**Value**
Power Supply:	4 to 20 voltages
Temperature Measuring Range	-55 to 150°C
Output Voltage	+6V to −1.0V
Output Current	10mA

3.2.2 Light Sensor

Plants use light in the range of 400 to 700 nanometers which is most commonly referred to as PAR (Photo-synthetically Active Radiation). Monitoring PAR is important to ensure their plants are receiving adequate light for photosynthesis.

Light Dependent Resistors (LDR) shown in Figure 3.4 was selected in this application. LDR is basically a resistor that has internal resistance increases or decreases dependent on the level of light intensity impinging on the surface of the sensor where it measures visible light as seen by the human eye with fast response, and small in size. Table 3.2 shows technical specification of LDR. (Appendix C).

Figure 3.4: The Light dependent resistors sensor

Table 3.2: Technical specification of LDR

Specification	Value
Voltage ,AC or DC peak	320V
Current	75mA
Power Dissipation at 30°C	250mW
Operating temperature range	-60°C to 75°C

Because LDR give variable resistor it must connected to voltage divider circuit as shown in Figure 3.5, where the equation of V_{out} from the voltage divider is:

$$Vout = \frac{LDR \times Vin}{LDR+R1} \quad (3.1)$$

Then,

$$LDR = \frac{Vout \times R1}{Vin - Vout} \quad (3.2)$$

To calculate the intensity of light uses this equation:

$$R_l = \frac{500}{Lux} \quad (3.3)$$

$$Lux = \frac{500}{R_l} \quad (3.4)$$

where:

Vout : Output Voltage

Vin : Input Voltage

R_l : Resistor of voltage divider

Lux : Light Intensity

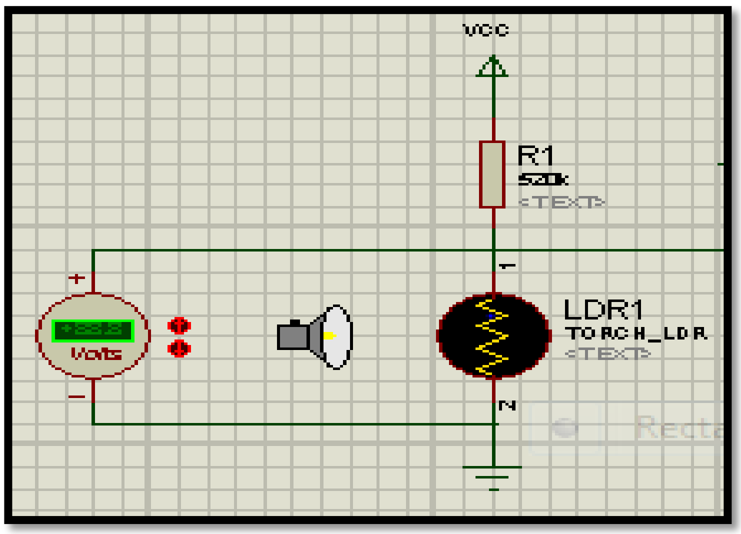

Figure 3.5: Schematic of signal conditioning circuit for LDR sensor

3.2.3 Humidity Sensor

A humidity sensor measures and regularly reports the humidity in the air. When it comes to humidity sensing technology, there are three types of humidity sensors: capacitive, resistive and thermal conductivity humidity sensors. The sensor that used in this thesis is the relative humidity sensor HS1101 as shown in Figure 3.6. This HS1101 is based on a unique capacitive cell; therefore, by using simple RC circuit wiring it is easy to interface with any microcontroller, which is widely used in industrial, home and office automation, and weather telemetry applications.

Figure 3.6: The HS1101 humidity sensor

The changes in the dielectric constant of a Capacitive Humidity Sensor (CHS) are nearly directly proportional to the relative humidity of the surrounding environment. HS1101 have analog output of varying capacitance in response to change in relative humidity. Table 3.3 shows technical Specification of this HS1101 sensor. (Appendix D).

Table 3.3: Technical specification of HS1101

Specification	**Value**
Power Supply:	5 to 10 V
Humidity Measuring Range	1 to 99% RH
Operating Temperature	40 to 100 °C

The HS1101, which is used as variable capacitor, is connected to the TRIG and THRES pin at the 555 timer (See Appendix E) as can be shown in Figure 3.7. The duty cycle of is determined by:

$$T_{high} = \frac{C}{RH}*(R2+R4)*\ln 2 \quad (3.5)$$

$$T_{low} = \frac{C}{RH}*R2*\ln 2 \quad (3.6)$$

$$F = \frac{1}{(T_{high} + T_{low})} = \frac{1}{(\frac{C}{RH}*(R4+2*R2)*\ln 2)} \quad (3.7)$$

$$\text{Output duty cycle} \;= T_{high} * F = \frac{R2}{(R4+2*R2)} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \;(3.\,8)$$

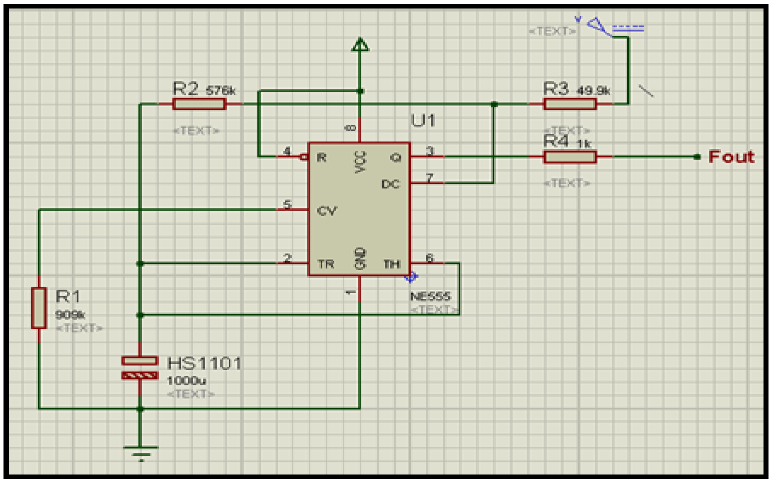

Figure 3.7: Schematic of the condition circuit of the humidity sensor using 555 timer

3.3 Processing Unit:

Both the sensor station and coordinator station require a Central Processing Unit (CPU) in order to perform various tasks as data acquisition, and data processing. Therefore a microcontroller was integrated into each transmit and receive stations. It is an integrated chip that has a CPU, Random Access Memory (RAM), Read Only Memory (ROM), on chip timers, Digital to Analog Converter (DAC) and many other components that are also presented on a computer. There are a large number of commercially available microcontrollers on the market today. Depending on the type application, each microcontroller has its advantages and disadvantages. The AVR ATmega16 microcontroller shown in Figure 3.8 was selected. This particular microcontroller was chosen for several reasons, including its ease of programming, reliability, low power and high performance. (Appendix F)

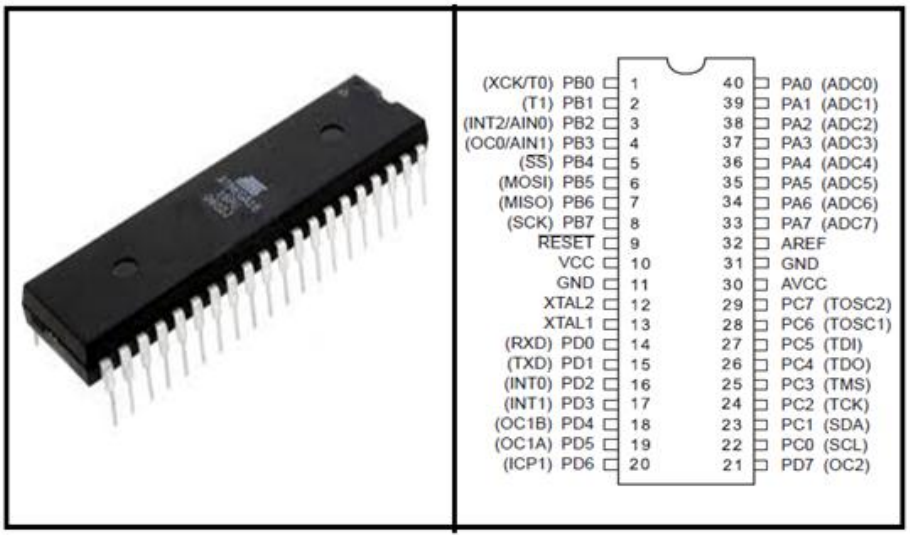

Figure 3.8: AVR ATmega16 microcontroller and its pin out

The BASCOM language was selected to programming the ATmaga16 microcontroller for its simplicity. The BASCOM was invented in 1995 for personal usage only. Since that time, a lot of options and extensions were added. Without the help and patience of the many users, BASCOM would not be what it is today: "the best and most affordable tool for fast proto typing".

3.4 Wireless Communication Unit

To collect data from sensing unit and are monitored in the control unit to provide the appropriate conditions for the plant is a wireless communication where XBee ZigBee wireless modules were selected. The XBee as shown in Figure 3.9 is a device used to send and receive data wirelessly base on ZigBee/IEEE 802.15.4 network standard and support the unique needs of low-cost, low-power wireless sensor networks. The XBee module requires minimal power and provides reliable delivery of critical data between devices where some of its specifications were presented in Table 3.4. The XBee could be configured by using XCTU programming as shown in Figure 3.10 to function as coordinator, router and end device. There are several types of XBee module, the very popular XBee type is series 1 and series 2. (See Appendix G)

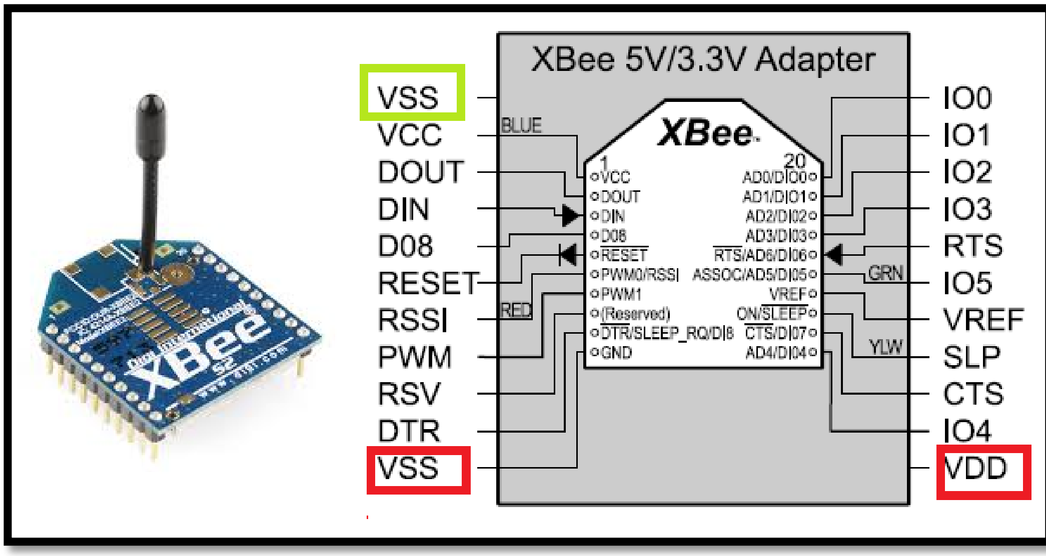

Figure 3.9: The XBee module and its pin description

Table 3.4: Technical specifications of the XBee module

Specification	Value
Radio Frequency Band	ISM 2.4GHz
RF Data Rate	250,000 bps
Indoor/Urban	up to 100ft/30 m
Outdoor Line-of-Sight	up to 300ft(100 m)
Transmit Power	1 mW (0 dBm)
Receiver Sensitivity	-92 dBm
TX Current/RX Current	45 mA (3.3 V)/ 50 mA (3.3 V)
Power-Down Current	< 10 µA

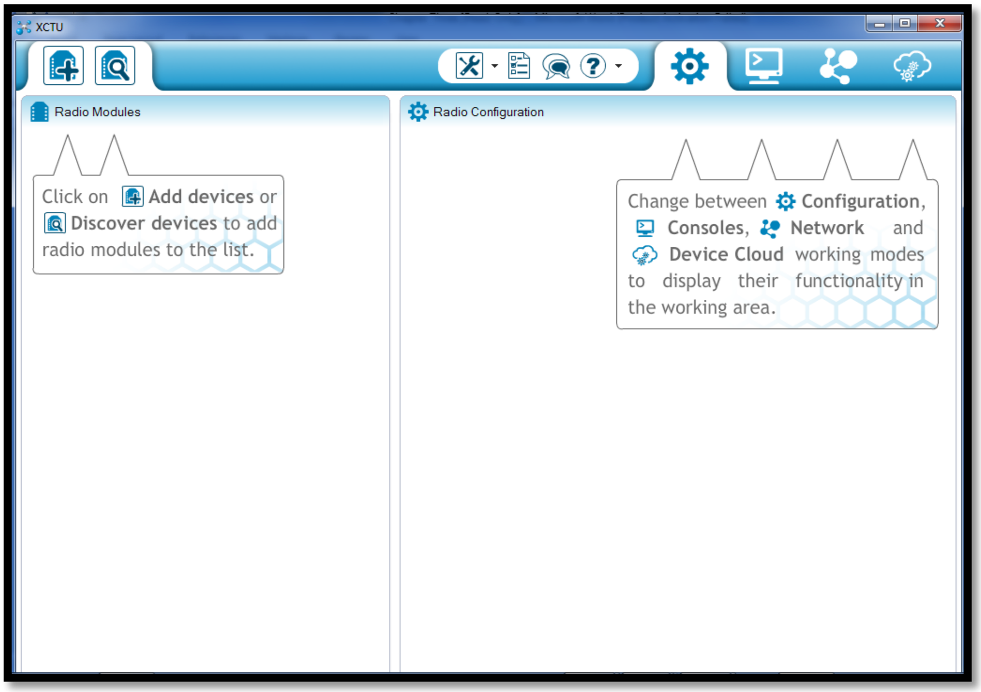

Figure 3.10: The XCTU configuration environment for XBee module

3.5 Display Unit

The collected and processed data may need to be displayed. A LCD is a thin, flat display device made up of any number of color or monochrome pixels arrayed in front of a light source or reflector. It is often utilized in battery-powered electronic devices because it uses very small amounts of electric power. For this purpose an LCD 2×16 shown in Figure 3.11 and Table 3.5 was used for simplicity and cost efficient.

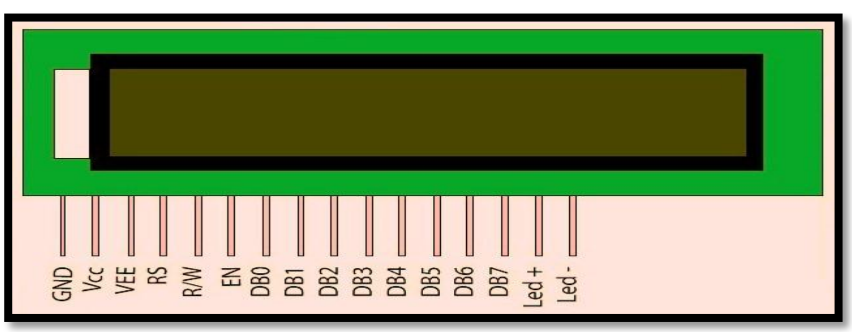

Figure 3.11: LCD and its pin out

Table 3.5: Technical specifications of the JHD 162A LCD

Specification	Value
Number of characters	16 characters*2 lines.
Module dimension	80.0mm*36.0mm*9.7mm.
Area	66.0mm*16.0mm.
Active area	56.2mm*11.5mm.
Dot size	0.55mm*0.65mm.
Dot pitch	0.60mm*0.70mm.
Character size	2.95mm*5.55mm.
Character pitch	3.55mm*5.95mm.
LCD Type	Positive, Reflective, Yellow Green.

3.6 Actuation Unit

An actuator is a piece of equipment which will produce a movement when signal is given. Actuators are used in the computer control of an environment, industrial automation and in robotics or, more generally, actuators are the machines used for output in control applications. For the situation in a computer controlled greenhouse, the actuators receive their control signal from the microcontroller to control the inside climate variables of the greenhouse. The designed unit includes the following actuators:

i. A ventilation fan: its speed determines the exchange between inside and outside air, thus causing natural ventilation.

ii. Heating system: consists of heater is distributed in the greenhouse.

- DC Fan: have developed for applications with demanding environmental requirements, signal speed, alarm with limit speed, external temperature sensor, analogue control input, and moisture protection. Table 3.6 shows the technical specification of this model.

Table 3.6: Technical Specification of DC Fan

Specification	Value
Nominal Voltage Range	6-15 V
Power Input	1.8 W
Speed	5900 min-1

- Water Pump: Pumps provide the means for moving water through the system at usable working pressures. The operation and maintenance of these pumps are some of the most important duties for many water utility operators. There are two basic types of pumps used in water and wastewater systems. The most common type of pump is the centrifugal pump. The other type is the positive displacement pump
- Heater: Each plant species has an optimum temperature range. Heating devices will maintain the temperature within that range during periods of cold weather. Important do not undersize the heating capacity. You may not need all your heaters much of the year, but if you undersize your system you may lose your entire crop during the coldest nights of winter

3.7 Power Supply Unit

The limitation of the wireless sensor unit can be discussed in term of the power, which is to be considered as crucial in the deployment of the sensor section. The sensor section needs to have low power consumption, and be portable and flexible. To meet these requirements a portable source of power is proposed. Monitoring of the environmental behavior should be done for duration of complete season. Power supply to sensor node is provided with 3.3VDC/220mA. After determine the output voltage and current of all components of the system that supported by the electrical characteristics for them to make a simple linear power supply in Figure 3.12, use a transformer to step down the 120V AC to a lower voltage needed. Next, send the low voltage AC through a bridge rectifier to make it DC and use filter capacitors that limit the rectifier ripple to a reasonable value. Finally, add a linear regulator (Appendix H) with that can handle the required current to regulate the output voltage.

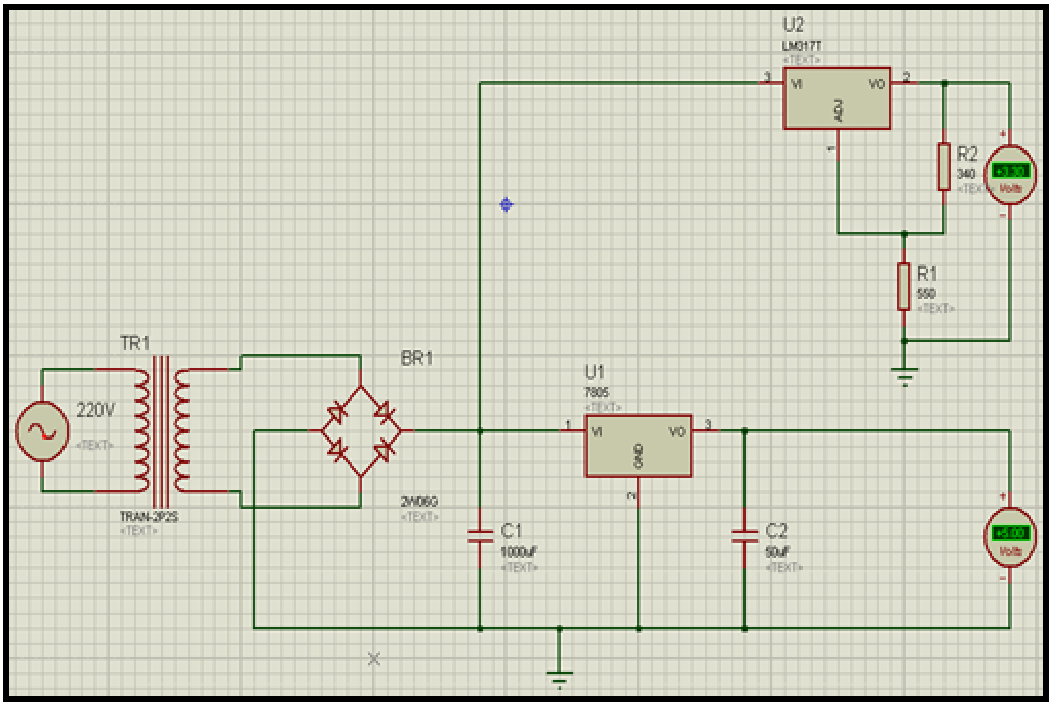

Figure 3.12: Design of power supply unit

3.8 Monitoring and Control Unit

The transmission unit connected as shown in Figure 3.13. It contains several electronic elements: microcontroller (Atmega16), LCD for display, three push button switches for entering the data of set the system and increase or decrease the data, and ZigBee module for receive or transmit which replaced by serial communication for simulation (serial com1). The proposed microcontroller was utilized as follow:

- Port B is used to interface the LCD.

- Port D is used as follow: PD5, PD6, PD7 respectively are used as connected to the push button switches with three pull up resistors (10kΩ). PD0 (RXD) and PD1 (TXD) connected for serial communication and virtual terminal.

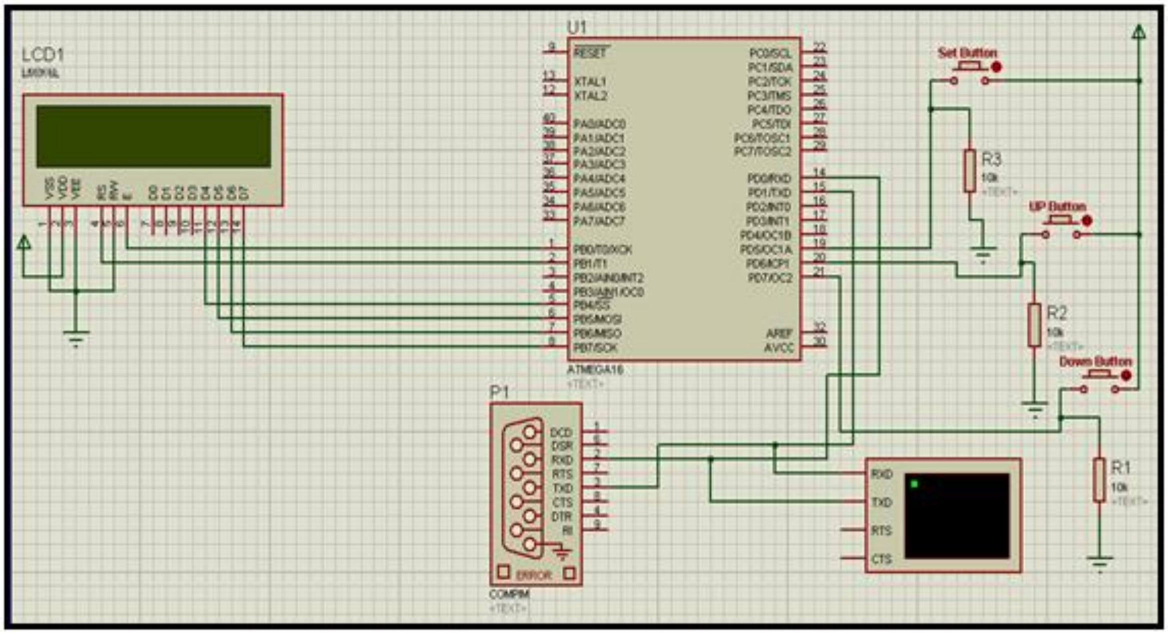

Figure 3.13: Monitoring and control unit

3.9 Sensing and Response Unit

The receiving unit connected as shown in Figure 3.14. It contains several electronic elements as follows:

- Microcontroller (Atmega16), LM35 temperature sensor, HS1101 humidity sensor, LDR light sensor, DC fan, DC motor, heater and ZigBee module for receive or transmit which replaced by serial communication (serial com2).
- LM35 sensor: Have needed for reading the temperature in the Greenhouse.
- HS1101 sensor: Have needed for reading the relative humidity in the Greenhouse which replaced by variable resistor.

- LDR sensor: Have needed for reading the light density in the Greenhouse.
- DC fan: Have needed for ventilation in greenhouse if the temperature is increase above and humidity is increase the needed of the plant
- Water pump: Have needed for pumping water in Greenhouse if the relative humidity is decrease the needed of the plant.
- Heater: Have needed for heating in greenhouse if the temperature is decreasing and humidity decreasing the needed of the plant.
- Relay: The relay driver is used to isolate both the controlling and the controlled device. The relay is an electromagnetic device, which consists of solenoid, moving contacts (switch) and restoring spring and consumes comparatively large amount of power. Hence it is possible for the interface IC to drive the relay satisfactorily. To enable this, a driver circuitry, which will act as a buffer circuit, is to be incorporated between them. The driver circuitry senses the presence of a “high” level at the input and drives the relay from another voltage source. Hence the relay is used to switch the electrical supply to the appliances (Appendix I).
- L293D Driver: The L293D is quadruple high-current half-H driver. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. The device is designed to drive inductive loads such as relays, solenoids, DC and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications (Appendix J).
- Port A is used as follow: PA1 is used as connected to the HS1101 replaced as variable resistor, PA2 is used as connected to the LDR with resistor 520K̀Ω, and PA3 is used as connected to the LM35.
- Port B is used as follow: PB0 is connected to the audio alarm.

- Port D is used as follow: PD2 is used as connected to the heater with realy, PD4, PD5, PD6, PD7 respectively are used as connected to the L293D driver with DC motor and DC fan, PD0 (RXD), PD1 (TXD) connected for serial communication (com2) and virtual terminal.

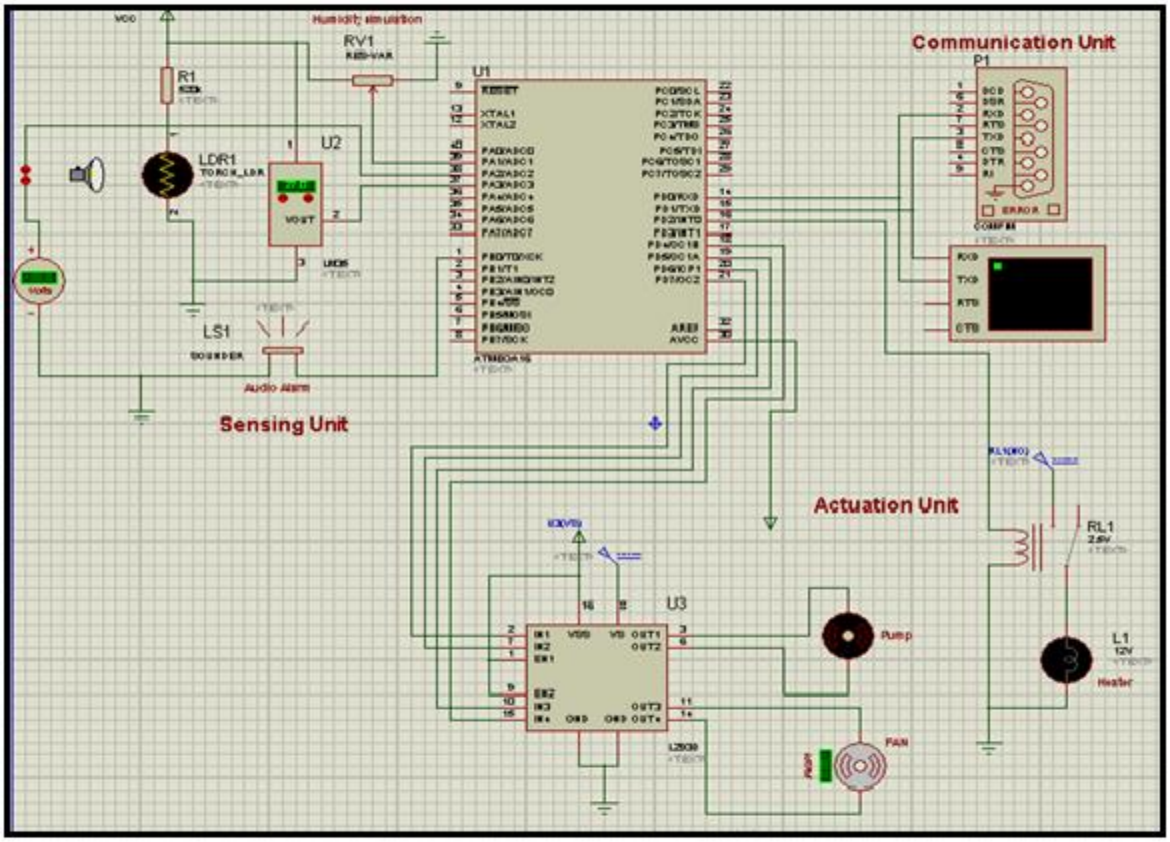

Figure 3.14: Sensing and response unit

3.10 System Operation Flow Chart

The system is clarified using the flowchart; it is illustrate comparing the set values with the acquiring values as shown in Figure 3.15.

Firstly enter the values of the greenhouse parameters and upload these values into sensing and response unit to comparing with acquiring values. If the set temperature greater than the acquired temperature the microcontroller send signal to run the fan in blower mode and the heater else run the fan in blower mode. If the set humidity greater than the acquired humidity the microcontroller send signal to run the pump, fan in blower mode and the heater else run the fan in sucker mode. If the set light greater than the acquired humidity the microcontroller send signal to run the alarm else no action.

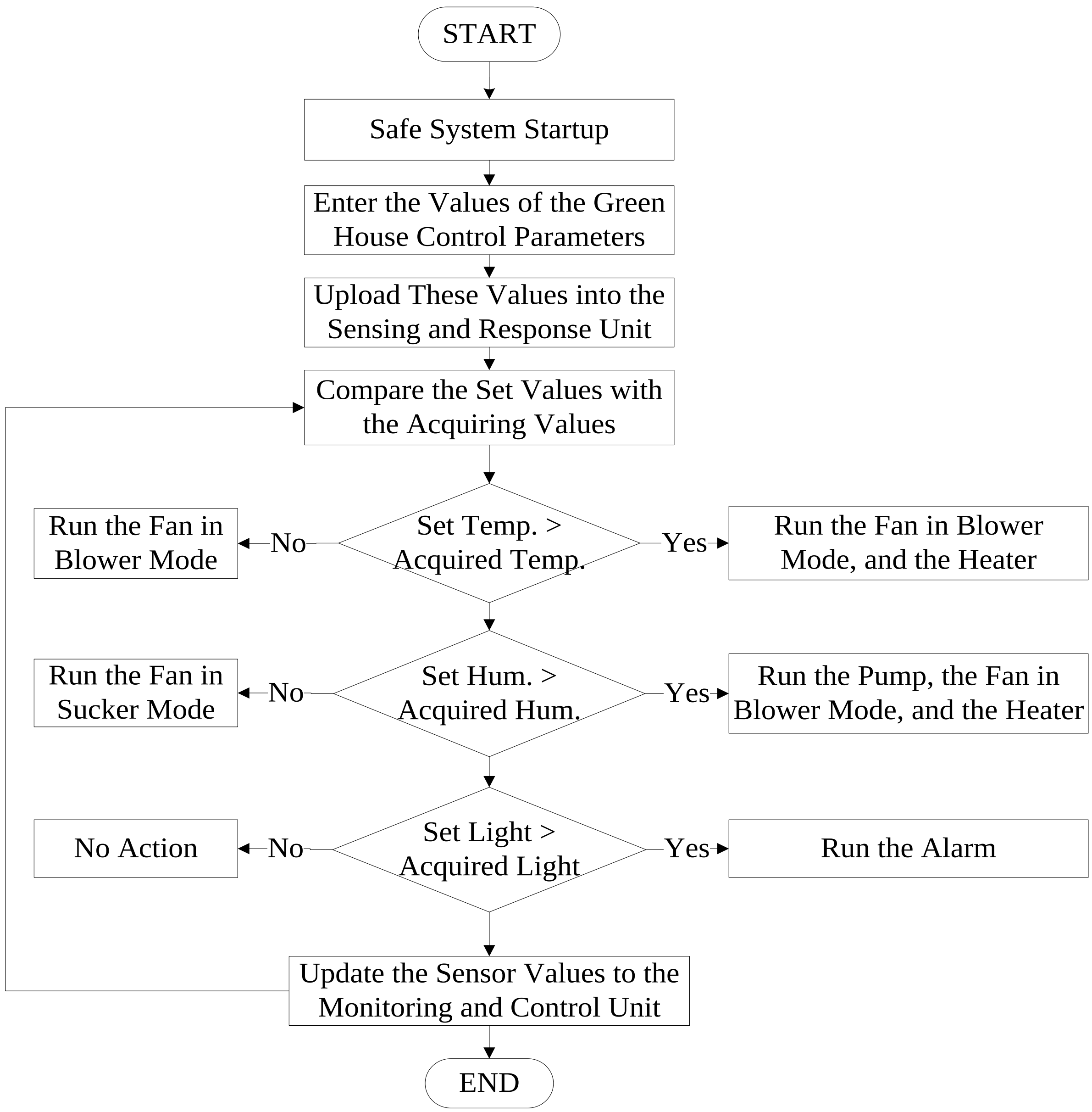

Figure 3.15: The flow chart

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

As mentioned in chapter three, the monitoring and controlling unit and sensing and response unit based on wireless sensor network can be there got different result based on effective management of greenhouse environment. In this chapter, these different responses were discussed based on the greenhouse management.

4.2 The Monitoring and Control Unit

After safe system booting, a welcome and guidance message on the LDC can be recognized as shown in Figure 4.1. Three navigation buttons: set, up and down can be selected according to the operation mode: start, increase and decrease the environmental parameters respectively. As shown in Figure 4.1, a set button can be used to start using the system.

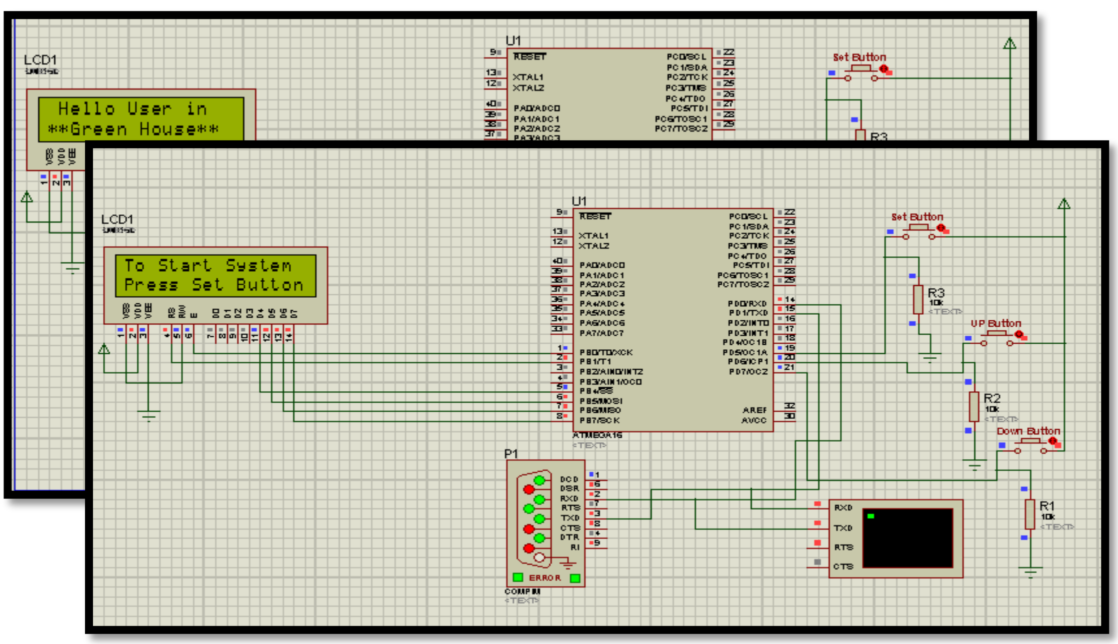

Figure 4.1: Guidance message to start the system by pressing the set button

However, to manipulate and read sensors valves, a set and up/down buttons can be exploited through following the instructions on the attached LCD as shown in Figure 4.2.

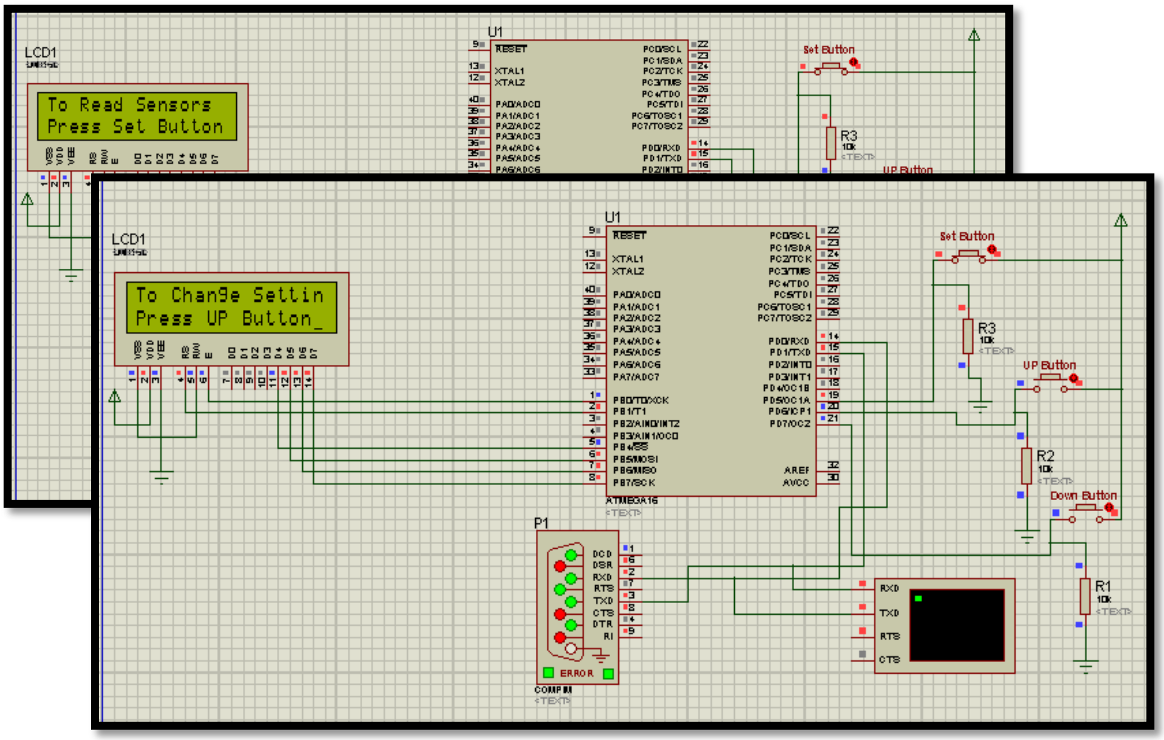

Figure 4.2: Manipulation and reading of the sensors values

The set sensors values at the monitor and control unit were uploaded through the XBee module to the sensing and response unit.

4.3 The Sensing and Response Unit

The sensing and response unit receives the preset sensor values at the monitoring and control unit through its associated XBee module. Then these values were stored at the microcontroller memory to maintain the environmental conditions of the greenhouse accordingly. Three environmental conditions can be maintained: temperature, humidity and light. In the following, the associated response to the change of each parameter can be explored.

4.3.1 Temperature control

To decrease the acquired temperature in the green house to meet the required one, a ventilating fan can be turned on as in Figure 4.3. A continuous tracking to the temperature can be achieved. In addition, while the acquired temperature in the green house was decreasing comparable to the set one, a heater with the circulation fan can be turned on as shown in Figure 4.4.

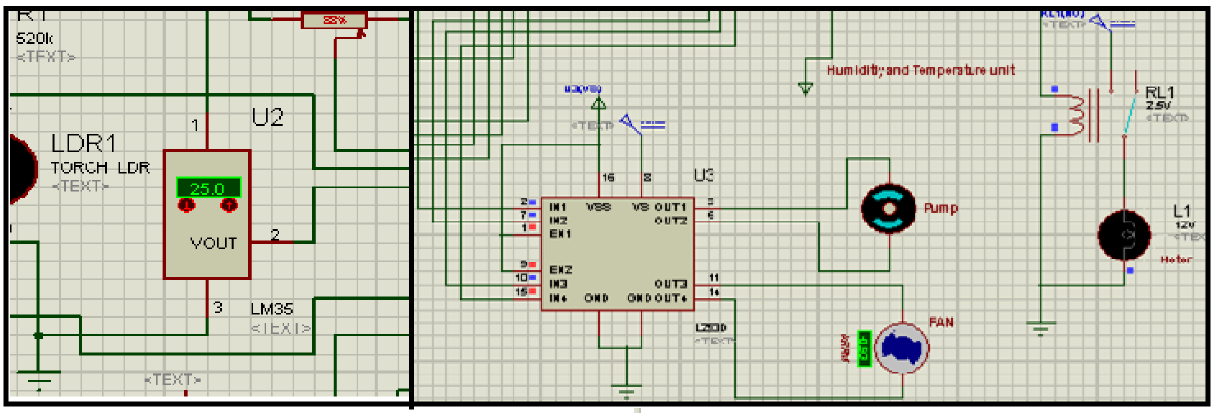

Figure 4.3: The decreasing temperature

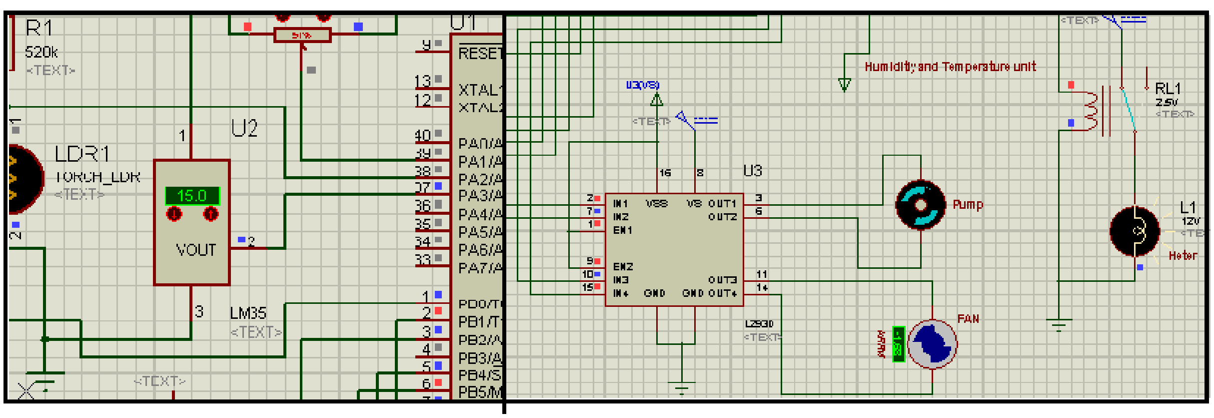

Figure 4.4: The increasing temperature

4.3.2 Humidity Control:

The H1101 humidity sensor can track the percentage of the humidity at the green house atmosphere. While the humidity shows decrement percentage, the water pump, heater and circulation fan can be turned on to inject vapored water to the environment of the green house as can be shown in Figure 4.5. In contrast, when the humidity recorded a higher percentage than the set one, the sucker fan can be turned on to evacuate the excessive percentage of humidity as shown in Figure 4.6.

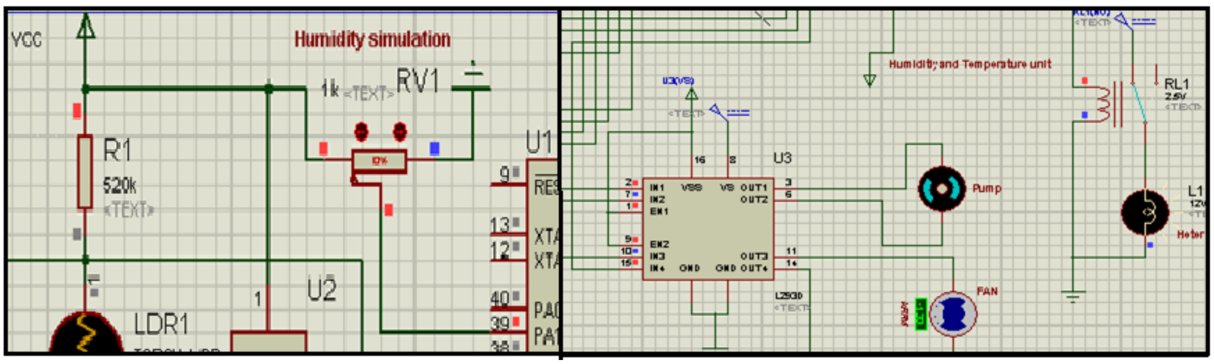

Figure 4.5: The decreasing humidity

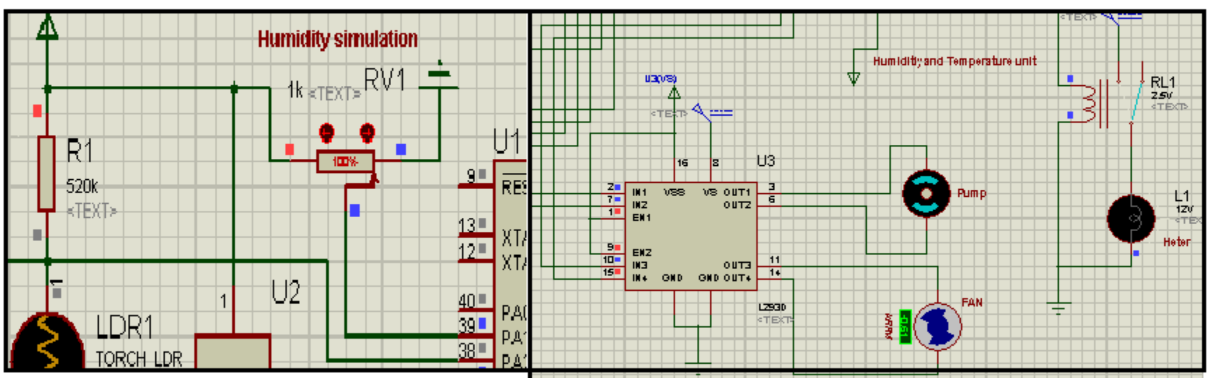

Figure 4.6: The increasing humidity

4.3.2 Light Control:

Most of the crop needs a natural sun light to grow. The green house can provide this direct sun light through its transparent roof. After while this transparent roof become darker by the accumulated dust, therefore the light intensity sensor can be used to monitor and note when the received light is less than the required amount. An audio alarm can be recognized to indicate the low light intensity inside the greenhouse as shown in Figure 4.7.

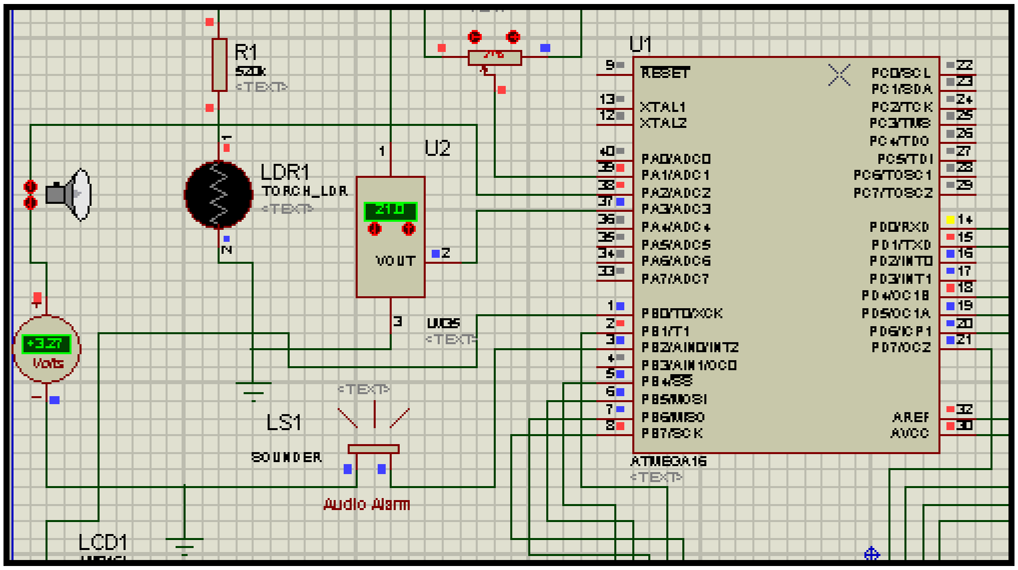

Figure 4.7: The light control

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This thesis presents a design of a simple and low cost monitoring and control greenhouse system based on a ZigBee technology. A temperature, humidity and light sensors were integrated with fan, heater and pump to figure out the sensing and responding unit. The microcontroller and XBee module were utilized to be the processing and communication units respectively.

The proposed WSN i.e. XBee is one of the promising solution lower installation and running costs, and increase flexibility and reliability in a greenhouse management system. Compatibility, compactness, portability and low power consumption is some of important key elements in the design of wireless system. Therefore a carefully selection of sensing devices and circuitry components is also very important especially when interfaced to the microcontroller. The management scenario of the entire environment of the greenhouse has a crucial importance in utilizing the attached responding elements, where the logical relation between them should be studies firstly. In conclusion, greenhouse climate monitoring and controlling is one attractive application field to create a wireless automation system.

5.2 Recommendations

This thesis has provided a comprehensive report on the design process and implementation of a ZigBee based wireless greenhouse management system. Certainly, there is a need for further study to improve the system reliability and capability. The following improvements can be recommended for possible future work:

- More sensors can be added to the sensing unit to monitor other environmental parameters such as soil moisture, soil pH level, air flow, carbon monoxide and oxygen level.
- The reliability of the designed system can be exploited to build a network of such monitor and control system for several greenhouses.
- Global system for mobile communication and SMS can also be integrated into the system. These extra features will allow the system to directly alert the user of any abnormal changes in the green house environment through the transmission of a simple short texts message.

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A. Appendix A

Bascom code

```
$regfile "m16def.dat"
$crystal = 4000000
Config Com1 = 9600 , Parity = None , Stopbits = 1 , Databits = 8
Config Lcdpin = Pin , Db4 = Portb.4 , Db5 = Portb.5 , Db6 = Portb.6 , Db7 = Portb.7 , E =
Portb.0 , Rs = Portb.1
Config Lcd = 16 * 2
Config Portd = Input
Dim X As Byte
Dim I As Byte
Dim Y As Byte
Dim Xx As Word
Dim Yy As Word
Dim Z As Word
Dim Var1 As Word
'**************************************************
Do
Welcom:
X = 0
Y = 0
I = 0
Xx = 0
Yy = 0
Z = 0
Var1 = 0
Cls
Lcd " Hello User in "
Lowerline
Lcd "**Green House** "
Wait 2
Cls
Lcd "To Start System"
Lowerline
Lcd "Press Set Button"
Wait 2
Cls
If Pind.5 = 1 Then
Goto Startsysem
End If
Wait 2
Loop
'***********************************************
Startsysem:
Do
Lcd "To Read Sensors"
```

```
Lowerline
Lcd "Press Set Button"
Wait 3
Cls
Lcd "To Change Setting"
Lowerline
Lcd "Press UP Button"
Wait 3
Cls
Wait 2
If Pind.5 = 1 Then
Goto Readsensors
End If
If Pind.6 = 1 Then
Goto Changesetting
End If
Wait 1
Loop
'*******************************************************
Readsensors:
Lcd "sensor:"
Wait 3
Cls
Goto Welcom
'******************************************************
Changesetting:
Do
Lcd "If need steps of"
Lowerline
Lcd "Enter New Values"
Wait 3
Cls
Lcd "Press Set Button"
Lowerline
Lcd "Else Press UP"
Wait 3
Cls
Wait 2
If Pind.5 = 1 Then
Goto Steps
End If
If Pind.6 = 1 Then
Goto Enternewdata
End If
Wait 1
Loop
'********************************************************
Steps:
```

```
Lcd "Use The UP & DWN"
Lowerline
Lcd "Button To Enter"
Wait 2
Cls
Lcd "Values And use"
Lowerline
Lcd "Set But.To Select"
Wait 3
Cls
Lcd "Press UP Button"
Lowerline
Lcd "To incrse Value"
Wait 3
Cls
Lcd "Press DWN Button"
Lowerline
Lcd "To decres Value"
Wait 3
Cls
Lcd "initial Value=0"
Wait 3
Cls
Goto Enternewdata
'*************************************************************
'****************tem tem tem tem tem
*************************************************
Enternewdata:
Do
Lcd "Enter Tem:"
Wait 2
Lowerline
Lcd "Firest enter MSB"
Wait 2
Cls
Lcd "After that Enter"
Wait 2
Lowerline
Lcd " enter LSB"
Wait 2
Cls
If Pind.6 = 1 Then
Lcd "Value:  "
Wait 2
Lowerline
Goto Increse
End If
Wait 1
```

```
If Pind.7 = 1 Then
Lcd "Value:"
Wait 2
Goto Decrese
End If
Loop
'************************************************************
Increse:
'X = 0
Do
If Pind.6 = 1 Then
Incr X
Lcd X
Wait 2
Cls
End If
If Pind.7 = 1 Then
Goto Decrese
End If
If Pind.5 = 1 Then
Lcd "X="
Lowerline
Lcd X
Wait 2
Cls
Goto Lsb
End If
If X = 9 Then
Lcd X
Wait 2
Cls
Goto Lsb
End If
Loop
'************
Lsb:
Lcd " enter LSB"
Wait 2
Cls
Do
If Pind.6 = 1 Then
Incr Y
Lcd Y
Wait 2
Cls
End If
If Pind.7 = 1 Then
Goto Decreselsb
```

```
End If
If Pind.5 = 1 Then
Lcd "y="
Lowerline
Lcd Y
Wait 2
Cls
Goto Lsb&Msb
End If
If Y = 9 Then
Lcd Y
Wait 2
Cls
Goto Lsb&Msb
End If
Loop
'********************************************************
Lsb&Msb:
X = X * 10
Var1 = X + Y
Lcd Var1
Wait 3
Cls
Goto Senddata

'************************************************************
Decrese:
Do
If Pind.7 = 1 Then
Decr X
Lcd X
Wait 2
Cls
End If
If Pind.6 = 1 Then
Goto Increse
End If
If Pind.5 = 1 Then
Lcd "X="
Lowerline
Lcd X
Wait 2
Cls
Goto Lsb
End If
If X = 0 Then
Lcd X
Wait 2
```

```
Cls
Goto Lsb
End If
Loop
'***********************************************
Decreselsb:
Do
If Pind.7 = 1 Then
Decr Y
Lcd Y
Wait 2
Cls
End If
If Pind.6 = 1 Then
Goto Lsb
End If
If Pind.5 = 1 Then
Lcd "y="
Lowerline
Lcd Y
Wait 2
Cls
Goto Lsb&Msb
End If
If Y = 0 Then
Lcd Y
Wait 2
Cls
Goto Lsb&Msb
End If
Loop
'********************************************
'************************* tem tem tem tem tem *************************
Senddata:
Print Var1
Wait 2
Print Var1

Print "A"
Print "22"

If I = 0 Then
I = 1
Goto Hum
End If
If I = 1 Then
I = 2
Goto Light
```

```
End If
If I = 2 Then
Goto Welcom
End If

'**********************************************************************
Hum:
Do
X = 0
Y = 0
Var1 = 0
Lcd "Enter Hum:"
Wait 2
Lowerline
Lcd "Firest enter MSB"
Wait 2
Cls
Lcd "After that Enter"
Wait 2
Lowerline
Lcd " enter LSB"
Wait 2
Cls
If Pind.6 = 1 Then
Lcd "Value:  "
Wait 2
Lowerline
Goto Increse
End If
Wait 1
If Pind.7 = 1 Then
Lcd "Value:"
Wait 2
Goto Decrese
End If
Loop
'*****************************************************************************
********
Light:
Do
Xx = 0
Yy = 0
Z = 0
Var1 = 0
Lcd "Enter Light:"
Wait 2
Lowerline
Lcd "Firest enter 3thd"
```

```
Wait 2
Cls
Lcd "After that Enter"
Wait 2
Lowerline
Lcd " enter 2nd"
Wait 2
Cls
Lcd "After that Enter"
Wait 2
Lowerline
Lcd " enter 1st"
Wait 2
Cls
If Pind.6 = 1 Then
Lcd "Value:  "
Wait 2
Lowerline
Goto Increselight
End If
Wait 1
If Pind.7 = 1 Then
Lcd "Value:"
Wait 2
Goto Decreselight
End If
Loop
'*********************************************************
Decreselight:
Do
If Pind.7 = 1 Then
Decr Xx
Lcd Xx
Wait 2
Cls
End If
If Pind.6 = 1 Then
Goto Increselight
End If
If Pind.5 = 1 Then
Lcd "Xx="
Lowerline
Lcd Xx
Wait 2
Cls
Goto 2nd
End If
If Xx = 0 Then
```

```
Lcd Xx
Wait 2
Cls
Goto 2nd
End If
Loop
'*******************************************************
Increselight:
'X = 0
Do
If Pind.6 = 1 Then
Incr Xx
Lcd Xx
Wait 2
Cls
End If
If Pind.7 = 1 Then
Goto Decreselight
End If
If Pind.5 = 1 Then
Lcd "Xx="
Lowerline
Lcd Xx
Wait 2
Cls
Goto 2nd
End If
If Xx = 9 Then
Lcd Xx
Wait 2
Cls
Goto 2nd
End If
Loop
'******************************************************
2nd:
Lcd " enter  2nd"
Wait 2
Cls
Do
If Pind.6 = 1 Then
Incr Yy
Lcd Yy
Wait 2
Cls
End If
If Pind.7 = 1 Then
Goto Decrese2nd
```

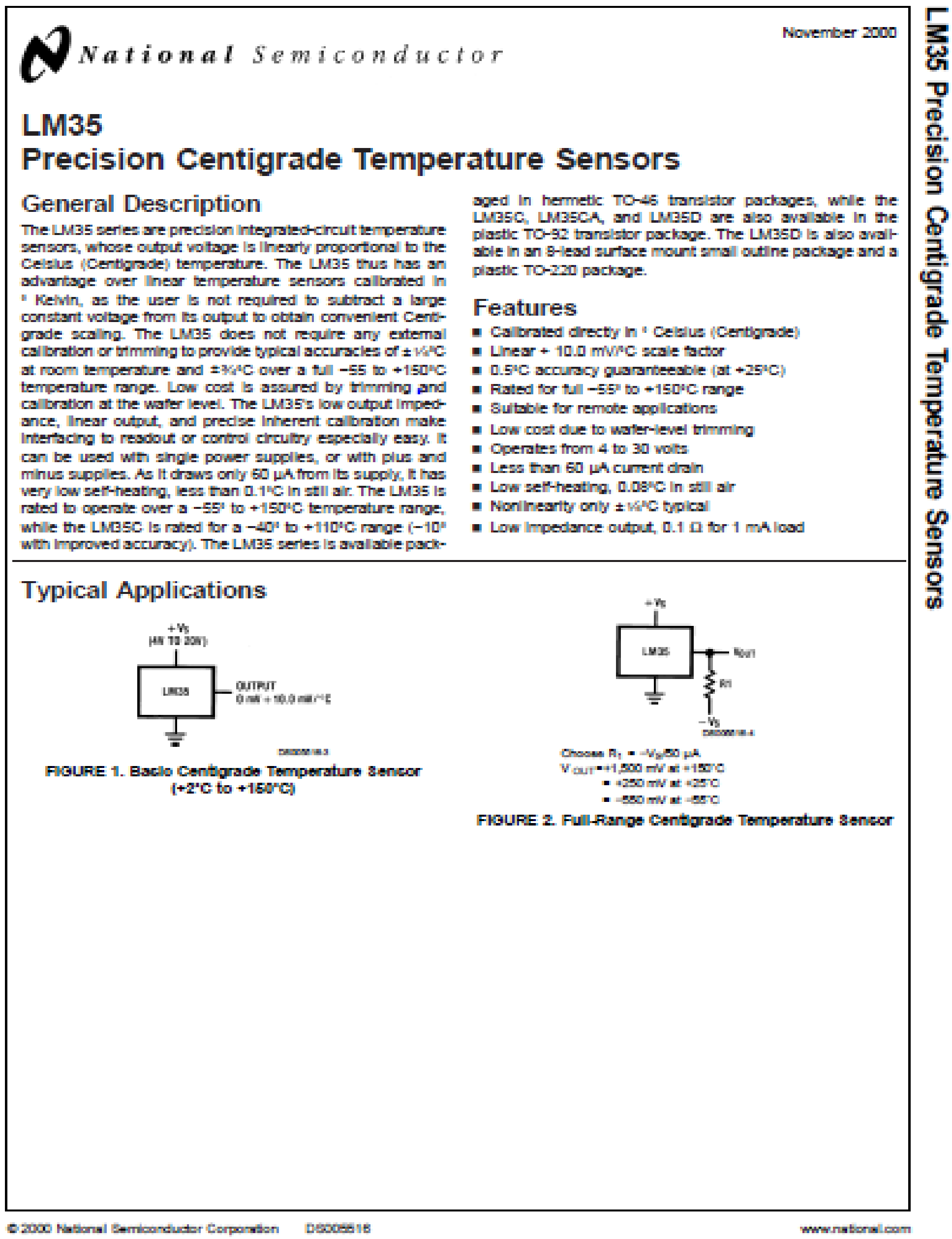
```
End If
If Pind.5 = 1 Then
Lcd "yy="
Lowerline
Lcd Yy
Wait 2
Cls
Goto 1st
End If
If Yy = 9 Then
Lcd Yy
Wait 2
Cls
Goto 1st
End If
Loop
'*****************************************************
Decrese2nd:
Do
If Pind.7 = 1 Then
Decr Yy
Lcd Yy
Wait 2
Cls
End If
If Pind.6 = 1 Then
Goto 2nd
End If
If Pind.5 = 1 Then
Lcd "yy="
Lowerline
Lcd Yy
Wait 2
Cls
Goto 1st
End If
If Yy = 0 Then
Lcd Yy
Wait 2
Cls
Goto 1st
End If
Loop
'*****************************************************
1st:
Lcd " enter  1st"
Wait 2
Cls
```

```
Do
If Pind.6 = 1 Then
Incr Z
Lcd Z
Wait 2
Cls
End If
If Pind.7 = 1 Then
Goto Decrese1st
End If
If Pind.5 = 1 Then
Lcd "z="
Lowerline
Lcd Z
Wait 2
Cls
Goto 1st&2nd&3thd
End If
If Z = 9 Then
Lcd Z
Wait 2
Cls
Goto 1st&2nd&3thd
End If
Loop
'*******************************************************
Decrese1st:
Do
If Pind.7 = 1 Then
Decr Z
Lcd Z
Wait 2
Cls
End If
If Pind.6 = 1 Then
Goto 1st
End If
If Pind.5 = 1 Then
Lcd "z="
Lowerline
Lcd Z
Wait 2
Cls
Goto 1st&2nd&3thd
End If
If Z = 0 Then
Lcd Z
Wait 2
```

```
Cls
Goto 1st&2nd&3thd
End If
Loop
'******************************************************
1st&2nd&3thd:
Xx = Xx * 100
Yy = Yy * 10
Var1 = Xx + Yy
Var1 = Var1 + Z
Lcd Var1
Wait 3
Cls
Goto Senddata
```

B. Appendix B

LM35 Precision Centigrade Temperature Sensors Data Sheet



National Semiconductor

November 2000

LM35 Precision Centigrade Temperature Sensors

LM35
Precision Centigrade Temperature Sensors

General Description

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in ° Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55 to +150°C temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

- Calibrated directly in ° Celsius (Centigrade)
- Linear + 10.0 mV/°C scale factor
- 0.5°C accuracy guaranteeable (at +25°C)
- Rated for full −55° to +150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 µA current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only ±¼°C typical
- Low impedance output, 0.1 Ω for 1 mA load

Typical Applications

+Vs (4V TO 20V)
LM35
OUTPUT 0 mV + 10.0 mV/°C

FIGURE 1. Basic Centigrade Temperature Sensor (+2°C to +150°C)

+Vs
LM35
V_{OUT}
R1
−Vs

Choose $R_1 = -V_S/50\ \mu A$
V_{OUT} = +1,500 mV at +150°C
= +250 mV at +25°C
= −550 mV at −55°C

FIGURE 2. Full-Range Centigrade Temperature Sensor

 www.national.com

All data sheet downloading available:

http://www.ece.usu.edu/ece_store/spec/lm35dt-3p.pdf

C. Appendix C

LDR Light Dependent Resistors Data Sheet

Data pack F — *Issued March 1997* **232-3816**

RS Data Sheet

Light dependent resistors

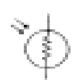
NORP12 RS stock number 651-507
NSL19-M51 RS stock number 596-141

Two cadmium sulphide (cdS) photoconductive cells with spectral responses similar to that of the human eye. The cell resistance falls with increasing light intensity. Applications include smoke detection, automatic lighting control, batch counting and burglar alarm systems.

Guide to source illuminations

Light source	Illumination (Lux)
Moonlight	0.1
60W bulb at 1m	50
1W MES bulb at 0.1m	100
Fluorescent lighting	500
Bright sunlight	30,000

Circuit symbol



Light memory characteristics

Light dependent resistors have a particular property in that they remember the lighting conditions in which they have been stored. This memory effect can be minimised by storing the LDRs in light prior to use. Light storage reduces equilibrium time to reach steady resistance values.

NORP12 (RS stock no. 651-507)

Absolute maximum ratings

Voltage, ac or dc peak	320V
Current	75mA
Power dissipation at 30°C	250mW
Operating temperature range	-60°C to +75°C

Electrical characteristics

T_A = 25°C. 2854°K tungsten light source

Parameter	Conditions	Min.	Typ.	Max.	Units
Cell resistance	1000 lux	-	400	-	Ω
	10 lux	-	9	-	kΩ
Dark resistance	-	1.0	-	-	MΩ
Dark capacitance	-	-	3.5	-	pF
Rise time 1	1000 lux	-	2.8	-	ms
	10 lux	-	18	-	ms
Fall time 2	1000 lux	-	48	-	ms
	10 lux	-	120	-	ms

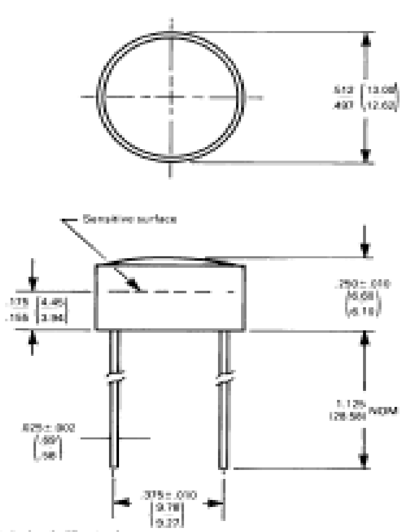
1. Dark to 110% R_L
2. To 10 × R_L

R_L = photocell resistance under given illumination.

Features

- Wide spectral response
- Low cost
- Wide ambient temperature range.

Dimensions



All data sheet downloading available:

www.biltek.tubitak.gov.tr/.../40/**LDR**_NSL19_M51.**pdf**

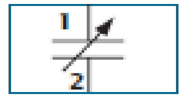
D. Appendix D

HS1101 Relative Humidity Sensor Data Sheet

HUMIREL — TECHNICAL DATA

RELATIVE HUMIDITY SENSOR — HS 1100 / HS 1101

Based on a unique capacitive cell, these relative humidity sensors are designed for high volume, cost sensitive applications such as ***office automation, automotive cabin air control, home appliances, and industrial process control systems.*** *They are also useful in all applications where humidity compensation is needed.*



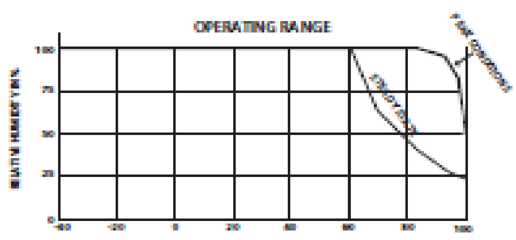
Features

- **Full interchangeability** with no calibration required in standard conditions
- **Instantaneous desaturation** after long periods in saturation phase
- Compatible with automatized assembly processes, **including wave soldering, reflow and water immersion** (1)
- High reliability and long term stability
- Patented solid polymer structure
- Suitable for linear voltage or frequency output circuitry
- Fast response time
- Individual marking for compliance to stringent traceability requirements

(1) soldering temperature profiles available on request

Maximum Ratings (Ta = 25°C unless otherwise noted)

Ratings	Symbol	Value	Unit
Operating Temperature	Ta	-40 to 100	°C
Storage Temperature	Tstg	-40 to 125	°C
Supply Voltage	Vs	10	Vac
Humidity Operating Range	RH	0 to 100	% RH
Soldering @ T = 260°C	t	10	s



Characteristics

(Ta = 25°C, measurement frequency @ 10kHz unless otherwise noted)

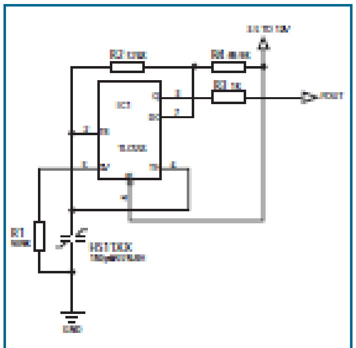
Characteristics	Symbol	Min.	Typ.	Max.	Unit.
Humidity measuring range	RH	1		99	%
Supply voltage	Vs		5	10	V
Nominal capacitance @ 55% RH*	C	177	180	183	pF
Temperature coefficient	Tc		0.04		pF/°C
Averaged Sensitivity from 33% to 75% RH	ΔC/%RH		0.34		pF/%RH
Leakage current (Vcc = 5 Volts)	Ix		1		nA
Recovery time after 150 hours of condensation	tr		10		s
Humidity Hysteresis			+/-1.5		%
Long term stability			0.5		%RH/yr
Response time (33 to 76 % RH, still air @ 63%)	ta		5		s
Deviation to typical response curve (10% to 90% RH)			+/-2		% RH

* *Tighter specification available on request*

HPC001 Rev. 7 June 2002

HUMIREL TECHNICAL DATA

FREQUENCY OUTPUT CIRCUITS



BILL OF MATERIAL AVAILABLE ON REQUEST

COMMENTS

This circuit is the typical astable design for 555. The HS1100/HS1101, used as variable capacitor, is connected to the TRIG and THRES pin. Pin 7 is used as a short circuit pin for resistor R4.
The HS1100/HS1101 equivalent capacitor is charged through R2 and R4 to the threshold voltage (approximately 0.67Vcc) and discharged through R2 only to the trigger level (approximately 0.33Vcc) since R4 is shorten to ground by pin 7.
Since the charge and discharge of the sensor run through different resistors, R2 and R4, the duty cycle is determined by :

$$t_{high} = C@\%RH*(R2+R4)*\ln 2$$
$$t_{low} = C@\%RH*R2*\ln 2$$
$$F = 1/(t_{high}+t_{low}) = 1/(C@\%RH*(R4+2*R2)*\ln 2)$$
$$Output\ duty\ cycle = t_{high}*F = R2/(R4+2*R2)$$

To provide an output duty cycle close to 50%, R4 should be very low compared to R2 but never under a minimum value.
Resistor R3 is a short circuit protection. 555 must be a CMOS version.

REMARK

R1 unbalances the internal temperature compensation scheme of the 555 in order to introduce a temperature coefficient that matches the HS1100/HS1101 temperature coefficient. In all cases, R1 should be a 1% resistor with a maximum of 100ppm coefficient temperature like all other R-C timer resistors. Since 555 internal temperature compensation changes from one trademark to one other, R1 value should be adapted to the specific chip. To keep the nominal frequency of 6660Hz at 55%RH, R2 also needs slight adjustment as shown in the table.

555 Type	R1	R2
TLC555 (Texas)	909kΩ	576kΩ
TS555 (STM)	100nF capacitor	523kΩ
7555 (Harris)	1732kΩ	549kΩ
LMC555 (National)	1238kΩ	562kΩ

For a frequency of 6660Hz at 55%RH

Typical Characteristics for Frequency Output Circuits

REFERENCE POINT AT 6660Hz FOR 55%RH / 25°C

RH	0	10	20	30	40	50	60	70	80	90	100
Frequency	7351	7224	7100	6976	6853	6728	6600	6468	6330	6186	6033

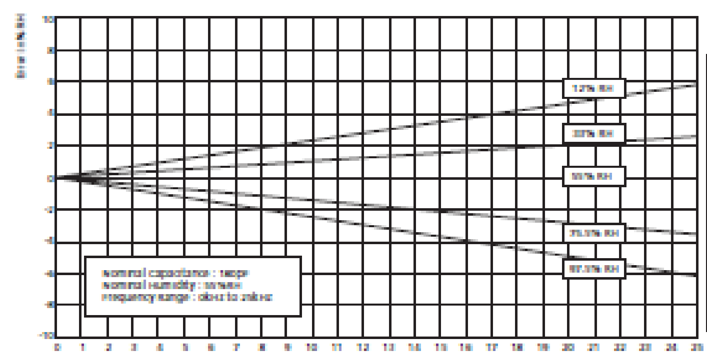
Typical for a 555 Cmos type. TLC555 (RH : Relative Humidity in %, F : Frequency in Hz)

Polynomial response :

$$F_{mes(Hz)} = F55_{(Hz)}(1.1038-1.9368 10^{-3}*RH+3.0114 10^{-6}*RH^{2}-3.4403 10^{-8}*RH^{3})$$

Measurement Error vs Stray Capacitance

A special attention is required in order to minimize stray capacitance in the layout. The added capacitance will act as a parallel capacitance with the sensor and create a measurement error.



HPC001 Rev. 7 June 2002

All data sheet downloading available:

www.jameco.com/jameco/products/prodds/2082901.pdf

E. Appendix E

NE555 General Purpose Single Bipolar Timers

NE555
SA555 - SE555

GENERAL PURPOSE SINGLE BIPOLAR TIMERS

- LOW TURN OFF TIME
- MAXIMUM OPERATING FREQUENCY GREATER THAN 500kHz
- TIMING FROM MICROSECONDS TO HOURS
- OPERATES IN BOTH ASTABLE AND MONOSTABLE MODES
- HIGH OUTPUT CURRENT CAN SOURCE OR SINK 200mA
- ADJUSTABLE DUTY CYCLE
- TTL COMPATIBLE
- TEMPERATURE STABILITY OF 0.005% PER°C

N
DIP8
(Plastic Package)

D
SO8
(Plastic Micropackage)

DESCRIPTION

The NE555 monolithic timing circuit is a highly stable controller capable of producing accurate time delays or oscillation. In the time delay mode of operation, the time is precisely controlled by one external resistor and capacitor. For a stable operation as an oscillator, the free running frequency and the duty cycle are both accurately controlled with two external resistors and one capacitor.

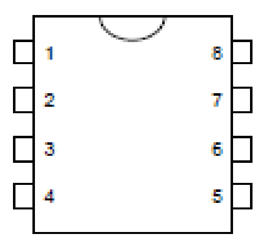
The circuit may be triggered and reset on falling waveforms, and the output structure can source or sink up to 200mA.

ORDER CODE

Part Number	Temperature Range	Package	
		N	D
NE555	0°C, 70°C	•	•
SA555	-40°C, 105°C	•	•
SE555	-55°C, 125°C	•	•

N = Dual In Line Package (DIP)
D = [illegible] - also available in Tape & Reel (DT)

PIN CONNECTIONS (top view)



1 - GND
2 - Trigger
3 - Output
4 - Reset
5 - Control voltage
6 - Threshold
7 - Discharge
8 - Vcc

June 2003 1/9

All data sheet downloading available:

[www.doctronics.co.uk/**pdf**_files/**ne555.pdf**](www.doctronics.co.uk/pdf_files/ne555.pdf)

F. Appendix F

ATMEGA16 Microcontroller Data Sheet

Features

- High-performance, Low-power AVR® 8-bit Microcontroller
- Advanced RISC Architecture
  - 131 Powerful Instructions – Most Single-clock Cycle Execution
  - 32 x 8 General Purpose Working Registers
  - Fully Static Operation
  - Up to 16 MIPS Throughput at 16 MHz
  - On-chip 2-cycle Multiplier
- Nonvolatile Program and Data Memories
  - 16K Bytes of In-System Self-Programmable Flash
    Endurance: 10,000 Write/Erase Cycles
  - Optional Boot Code Section with Independent Lock Bits
    In-System Programming by On-chip Boot Program
    True Read-While-Write Operation
  - 512 Bytes EEPROM
    Endurance: 100,000 Write/Erase Cycles
  - 1K Byte Internal SRAM
  - Programming Lock for Software Security
- JTAG (IEEE std. 1149.1 Compliant) Interface
  - Boundary-scan Capabilities According to the JTAG Standard
  - Extensive On-chip Debug Support
  - Programming of Flash, EEPROM, Fuses, and Lock Bits through the JTAG Interface
- Peripheral Features
  - Two 8-bit Timer/Counters with Separate Prescalers and Compare Modes
  - One 16-bit Timer/Counter with Separate Prescaler, Compare Mode, and Capture Mode
  - Real Time Counter with Separate Oscillator
  - Four PWM Channels
  - 8-channel, 10-bit ADC
    8 Single-ended Channels
    7 Differential Channels in TQFP Package Only
    2 Differential Channels with Programmable Gain at 1x, 10x, or 200x
  - Byte-oriented Two-wire Serial Interface
  - Programmable Serial USART
  - Master/Slave SPI Serial Interface
  - Programmable Watchdog Timer with Separate On-chip Oscillator
  - On-chip Analog Comparator
- Special Microcontroller Features
  - Power-on Reset and Programmable Brown-out Detection
  - Internal Calibrated RC Oscillator
  - External and Internal Interrupt Sources
  - Six Sleep Modes: Idle, ADC Noise Reduction, Power-save, Power-down, Standby and Extended Standby
- I/O and Packages
  - 32 Programmable I/O Lines
  - 40-pin PDIP, 44-lead TQFP, and 44-pad QFN/MLF
- Operating Voltages
  - 2.7 - 5.5V for ATmega16L
  - 4.5 - 5.5V for ATmega16
- Speed Grades
  - 0 - 8 MHz for ATmega16L
  - 0 - 16 MHz for ATmega16
- Power Consumption @ 1 MHz, 3V, and 25°C for ATmega16L
  - Active: 1.1 mA
  - Idle Mode: 0.35 mA
  - Power-down Mode: < 1 µA

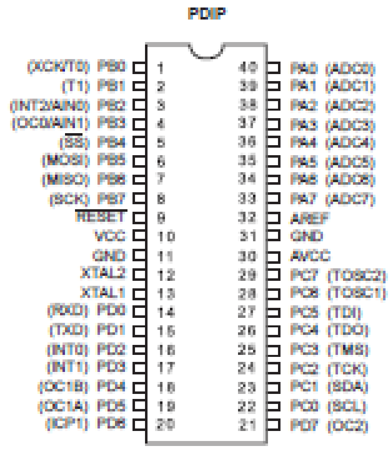
8-bit AVR® Microcontroller with 16K Bytes In-System Programmable Flash

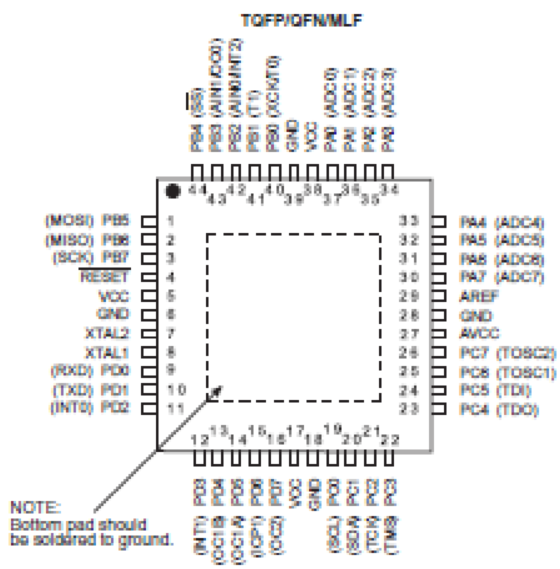
ATmega16
ATmega16L

2466M–AVR–04/06

Pin Configurations

Figure 1. Pinout ATmega16





Disclaimer

Typical values contained in this datasheet are based on simulations and characterization of other AVR microcontrollers manufactured on the same process technology. Min and Max values will be available after the device is characterized.

A full data sheet can be downloading available:

www.atmel.com/images/doc2503.pdf.

G. Appendix G

XBee XBee™/XBee-PRO™ OEM RF Modules Datasheet

XBee™/XBee-PRO™ OEM RF Modules

Product Manual v1.06

For OEM RF Module Part Numbers: XB24-...-001, XB24-...-002
XBP24-...-001, XBP24-...-002

ZigBee™/IEEE® 802.15.4 OEM RF Modules by MaxStream, Inc.

MaxStream®

355 South 520 West, Suite 180
Lindon, UT 84042
Phone: (801) 765-9885
Fax: (801) 765-9895

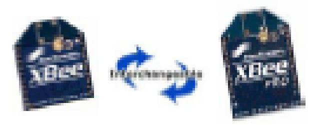
rf-xperts@maxstream.net
www.MaxStream.net (live chat suport)

M100232
2005.10.28

1. XBee/XBee-PRO OEM RF Modules

XBee and XBee-PRO Modules were engineered to meet ZigBee/IEEE 802.15.4 standards and support the unique needs of low-cost, low-power wireless sensor networks. The modules require minimal power and provide reliable delivery of critical data between devices.

The modules operate within the ISM 2.4 GHz frequency band and are pin-for-pin compatible with each other.



1.1. Key Features

High Performance, Low Cost

XBee

- Indoor/Urban: up to 100' (30 m)
- Outdoor line-of-sight: up to 300' (100 m)
- Transmit Power: 1 mW (0 dBm)
- Receiver Sensitivity: -92 dBm

XBee-PRO

- Indoor/Urban: up to 300' (100 m)
- Outdoor line-of-sight: up to 1 mile (1500 m)
- Transmit Power: 100 mW (20 dBm) EIRP
- Receiver Sensitivity: -100 dBm

RF Data Rate: 250,000 bps

Advanced Networking & Security

Retries and Acknowledgements

DSSS (Direct Sequence Spread Spectrum)

Each direct sequence channels has over 65,000 unique network addresses available

Point-to-point, point-to-multipoint and peer-to-peer topologies supported

128-bit Encryption (downloadable firmware version coming soon)

Self-routing/Self-healing mesh networking (downloadable firmware version coming soon)

Low Power

XBee

- TX Current: 45 mA (@3.3 V)
- RX Current: 50 mA (@3.3 V)
- Power-down Current: < 10 µA

XBee-PRO

- TX Current: 270 mA (@3.3 V)
- RX Current: 55 mA (@3.3 V)
- Power-down Current: < 10 µA

Easy-to-Use

No configuration necessary for out-of box RF communications

Free X-CTU Software (Testing and configuration software)

AT Command Mode for simple configuration of module parameters

Small form factor

Network compatible with other ZigBee/802.15.4 devices

Free & Unlimited Technical Support

1.1.1. Worldwide Acceptance

FCC Approval (USA) Refer to Appendix A [p23] for FCC Requirements. Systems that include XBee/XBee-PRO Modules inherit MaxStream's Certifications.

ISM (Industrial, Scientific & Medical) 2.4 GHz frequency band

Manufactured under **ISO 9001:2000** registered standards

XBee/XBee-PRO RF Modules are optimized for use in **US, Canada, Australia, Israel and Europe** (contact MaxStream for complete list of approvals).

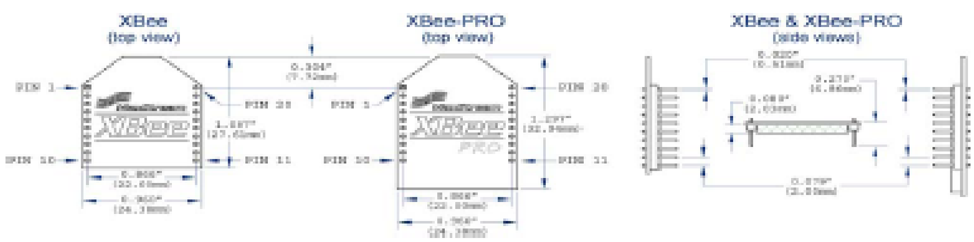
1.2. Specifications

Table 1-01. Specifications of the XBee/XBee-PRO OEM RF Modules

Specification	XBee	XBee-PRO
Performance		
Indoor/Urban Range	up to 100 ft. (30 m)	Up to 300' (100 m)
Outdoor RF line-of-sight Range	up to 300 ft. (100 m)	Up to 1 mile (1500 m)
Transmit Power Output	1mW (0 dBm)	60 mW (18 dBm) conducted, 100 mW (20 dBm) EIRP
RF Data Rate	250,000 bps	250,000 bps
Interface Data Rate (software selectable)	1200 - 115200 bps (non-standard baud rates also supported)	1200 - 115200 bps (non-standard baud rates also supported)
Receiver Sensitivity	-92 dBm (1% packet error rate)	-100 dBm (1% packet error rate)
Power Requirements		
Supply Voltage	2.8 – 3.4 V	2.8 – 3.4 V
Transmit Current (typical)	45 mA (@ 3.3 V)	270 mA (@ 3.3 V)
Receive Current (typical)	50 mA (@ 3.3 V)	55 mA (@ 3.3 V)
Power-down Current	< 10 µA	< 10 µA
General		
Operating Frequency	ISM 2.4 GHz	ISM 2.4 GHz
Dimensions	0.960" x 1.087" (2.438cm x 2.761cm)	0.960" x 1.297" (2.438cm x 3.294cm)
Operating Temperature	-40 to 85° C (industrial)	-40 to 85° C (industrial)
Antenna Options	U.FL Connector, Chip Antenna or Whip Antenna	U.FL Connector, Chip Antenna or Whip Antenna
Networking & Security		
Supported Network Topologies	Point-to-Point, Point-to-Multipoint, Peer-to-Peer and Mesh (coming soon)	Point-to-Point, Point-to-Multipoint, Peer-to-Peer and Mesh (coming soon)
Number of Channels (software selectable)	16 Direct Sequence Channels	13 Direct Sequence Channels
Filtration Options	PAN ID, Channel and Source/Destination Addresses	PAN ID, Channel and Source/Destination Addresses
Agency Approvals		
FCC Part 15.247	OUR-XBEE	pending
Industry Canada (IC)	pending	pending
Europe	pending	pending

1.3. Mechanical Drawings

Figure 1-01. Mechanical drawings of the XBee/XBee-PRO OEM RF Modules (antenna options not shown)
XBee and XBee-PRO RF Modules are pin-for-pin compatible.



All data sheet downloading available:

www.libelium.com/.../3/31/**Data-sheet**-max-stream.**pdf**

H. Appendix H

3-Terminal 1 A Positive Voltage Regulator Datasheet

FAIRCHILD SEMICONDUCTOR®

August 2013

LM78XX / LM78XXA
3-Terminal 1 A Positive Voltage Regulator

Features

- Output Current up to 1 A
- Output Voltages: 5, 6, 8, 9, 10, 12, 15, 18, 24 V
- Thermal Overload Protection
- Short-Circuit Protection
- Output Transistor Safe Operating Area Protection

Description

The LM78XX series of three-terminal positive regulators is available in the TO-220 package and with several fixed output voltages, making them useful in a wide range of applications. Each type employs internal current limiting, thermal shut-down, and safe operating area protection. If adequate heat sinking is provided, they can deliver over 1 A output current. Although designed primarily as fixed-voltage regulators, these devices can be used with external components for adjustable voltages and currents.

Ordering Information(1)

Product Number	Output Voltage Tolerance	Package	Operating Temperature	Packing Method
LM7805CT				
LM7806CT				
LM7808CT				
LM7809CT				
LM7810CT	±4%		-40°C to +125°C	
LM7812CT				
LM7815CT		TO-220 (Single Gauge)		
LM7818CT				Rail
LM7824CT				
LM7805ACT				
LM7809ACT				
LM7810ACT	±2%		0°C to +125°C	
LM7812ACT				
LM7815ACT				

Note:
1. Above output voltage tolerance is available at 25°C.

All data sheet downloading available:

www.datasheetcatalog.com/datasheets_pdf/L/M/7/8/LM7805.shtml

I. Appendix I

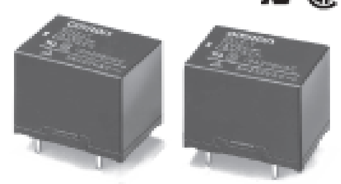
Cubic, Single-pole 10A Power Relay Datasheet

G5LE

PCB Power Relay

Cubic, Single-pole 10A Power Relay

- Ideal for a wide variety of applications such as home appliances, OA equipments, vending machines, etc.
- Ambient Operating Temperature 85°C
- UL class-B coil insulation for standard model.
- UL, CSA, EN standards approved and conforms to Electrical Appliance and Material Safety Law (300 V max.).



RoHS Compliant

■Model Number Legend

G5LE-□□□

1 2 3

1. Number of Poles
   1: 1-pole
2. Contact Form
   None: SPDT (1c)
   A: SPST-NO (1a)
3. Enclosure rating
   None: Flux protection
   4: Fully sealed

■Application Examples

- Home appliances
- OA equipments
- Vending machines

■Ordering Information

Terminal Shape	Classification	Contact form	Flux protection: Model	Flux protection: Rated coil voltage	Fully sealed: Model	Fully sealed: Rated coil voltage	Minimum packing unit
PCB terminals	Standard	SPDT (1c)	G5LE-1	5 VDC	G5LE-14	5 VDC	100 pcs/tray
				12 VDC		12 VDC	
				24 VDC		24 VDC	
		SPST-NO (1a)	G5LE-1A	5 VDC	G5LE-1A4	5 VDC	
				12 VDC		12 VDC	
				24 VDC		24 VDC	

Note. When ordering, add the rated coil voltage to the model number.
Example: G5LE-1 5 VDC
Rated coil voltage

■Ratings

●Coil

Rated voltage	Rated current (mA)	Coil resistance (Ω)	Must operate voltage (V)	Must release voltage (V)	Max. voltage (V)	Power consumption (mW)
			% of rated voltage			
5 VDC	79.4	63	75% max.	10% min.	170% at 23°C	Approx. 400
12 VDC	33.3	360				
24 VDC	16.7	1,440				

Note 1. The rated current and coil resistance are measured at a coil temperature of 23°C with a tolerance of ±10%.
2. The operating characteristics are measured at a coil temperature of 23°C.
3. The "Max. voltage" is the maximum voltage that can be applied to the relay coil.

●Contacts

Item / Load	Resistive load	Inductive load ($\cos\phi$ = 0.4)
Contact type	Single	
Contact material	Ag-alloy (Cd free)	
Rated load	10 A at 120 VAC; 8 A at 30 VDC	5 A at 120 VAC; 4 A at 30 VDC
Rated carry current	10 A	
Max. switching voltage	250 VAC, 125 VDC (30 VDC when UL/CSA standard is applied)	
Max. switching current	10 A	5 A

■Characteristics

Contact resistance *1		100 mΩ max.
Operate time		10 ms max.
Release time		5 ms max.
Insulation resistance *2		100 MΩ min.
Dielectric strength	Between coil and contacts	2,000 VAC, 50/60 Hz for 1 min
	Between contacts of the same polarity	750 VAC, 50/60 Hz for 1 min
Impulse withstand voltage	Between coil and contacts	4,500 V (1.2×50 μs)
Vibration resistance	Destruction	10 to 55 to 10 Hz, 0.75 mm single amplitude (1.5 mm double amplitude)
	Malfunction	10 to 55 to 10 Hz, 0.75 mm single amplitude (1.5 mm double amplitude)
Shock resistance	Destruction	1,000 m/s²
	Malfunction	100 m/s²
Durability	Mechanical	10,000,000 operations min. (at 18,000 operations/hr)
	Electrical	100,000 operations min. (at 1,800 operations/hr)
Failure rate (P level) (reference value) *3		100 mA at 5 VDC
Ambient operating temperature		-25°C to 85°C (with no icing or condensation)
Ambient operating humidity		35% to 85%
Weight		Approx. 12 g

Note. The data given above are initial values.
*1. Measurement conditions: 5 VDC, 1 A, voltage drop method.
*2. Measurement conditions: The insulation resistance was measured with a 500 VDC megohmmeter at the same locations as the dielectric strength was measured.
*3. This value was measured at a switching frequency of 120 operations/min.

G5LE

All data sheet downloading available:

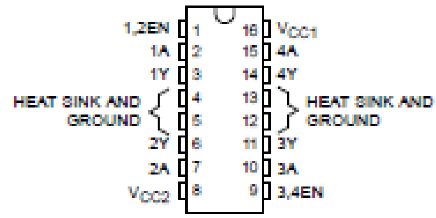
www.omron.com/ecb/products/pdf/en-g5le.pdf

Appendix J

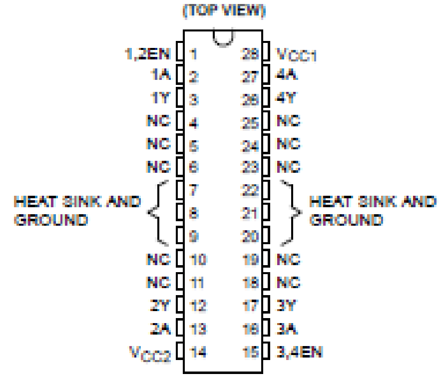
L293, L293D Quadruple Half-H Drivers Datasheet

- **Featuring Unitrode L293 and L293D Products Now From Texas Instruments**
- **Wide Supply-Voltage Range: 4.5 V to 36 V**
- **Separate Input-Logic Supply**
- **Internal ESD Protection**
- **Thermal Shutdown**
- **High-Noise-Immunity Inputs**
- **Functional Replacements for SGS L293 and SGS L293D**
- **Output Current 1 A Per Channel (600 mA for L293D)**
- **Peak Output Current 2 A Per Channel (1.2 A for L293D)**
- **Output Clamp Diodes for Inductive Transient Suppression (L293D)**

N, NE PACKAGE
(TOP VIEW)



DWP PACKAGE
(TOP VIEW)



description

The L293 and L293D are quadruple high-current half-H drivers. The L293 is designed to provide bidirectional drive currents of up to 1 A at voltages from 4.5 V to 36 V. The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V. Both devices are designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

All inputs are TTL compatible. Each output is a complete totem-pole drive circuit, with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs, with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled and their outputs are active and in phase with their inputs. When the enable input is low, those drivers are disabled and their outputs are off and in the high-impedance state. With the proper data inputs, each pair of drivers forms a full-H (or bridge) reversible drive suitable for solenoid or motor applications.

On the L293, external high-speed output clamp diodes should be used for inductive transient suppression.

A V_{CC1} terminal, separate from V_{CC2}, is provided for the logic inputs to minimize device power dissipation.

The L293and L293D are characterized for operation from 0°C to 70°C.

recommended operating conditions

			MIN	MAX	UNIT
	Supply voltage	V_{CC1}	4.5	7	V
		V_{CC2}	V_{CC1}	36	V
V_{IH}	High-level input voltage	$V_{CC1} \le 7$ V	2.3	V_{CC1}	V
		$V_{CC1} \ge 7$ V	2.3	7	V
V_{IL}	Low-level output voltage		−0.3†	1.5	V
T_A	Operating free-air temperature		0	70	°C

† The algebraic convention, in which the least positive (most negative) designated minimum, is used in this data sheet for logic voltage levels.

electrical characteristics, V_{CC1} = 5 V, V_{CC2} = 24 V, T_A = 25°C

PARAMETER			TEST CONDITIONS		MIN	TYP	MAX	UNIT
V_{OH}	High-level output voltage		L293: $I_{OH} = -1$ A L293D: $I_{OH} = -0.6$ A		$V_{CC2}-1.8$	$V_{CC2}-1.4$		V
V_{OL}	Low-level output voltage		L293: $I_{OL} = 1$ A L293D: $I_{OL} = 0.6$ A			1.2	1.8	V
V_{OKH}	High-level output clamp voltage		L293D: $I_{OK} = -0.6$ A			$V_{CC2} + 1.3$		V
V_{OKL}	Low-level output clamp voltage		L293D: $I_{OK} = 0.6$ A			1.3		V
I_{IH}	High-level input current	A	$V_I = 7$ V			0.2	100	µA
		EN				0.2	10	
I_{IL}	Low-level input current	A	$V_I = 0$			−3	−10	µA
		EN				−2	−100	
I_{CC1}	Logic supply current		$I_O = 0$	All outputs at high level		13	22	mA
				All outputs at low level		35	60	
				All outputs at high impedance		8	24	
I_{CC2}	Output supply current		$I_O = 0$	All outputs at high level		14	24	mA
				All outputs at low level		2	6	
				All outputs at high impedance		2	4	

switching characteristics, V_{CC1} = 5 V, V_{CC2} = 24 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	L293NE, L293DNE			UNIT
			MIN	TYP	MAX	
t_{PLH}	Propagation delay time, low-to-high-level output from A input	C_L = 30 pF, See Figure 1		800		ns
t_{PHL}	Propagation delay time, high-to-low-level output from A input			400		ns
t_{TLH}	Transition time, low-to-high-level output			300		ns
t_{THL}	Transition time, high-to-low-level output			300		ns

switching characteristics, V_{CC1} = 5 V, V_{CC2} = 24 V, T_A = 25°C

PARAMETER		TEST CONDITIONS	L293DWP, L293N L293DDWP, L293DN			UNIT
			MIN	TYP	MAX	
t_{PLH}	Propagation delay time, low-to-high-level output from A input	C_L = 30 pF, See Figure 1		750		ns
t_{PHL}	Propagation delay time, high-to-low-level output from A input			200		ns
t_{TLH}	Transition time, low-to-high-level output			100		ns
t_{THL}	Transition time, high-to-low-level output			350		ns

All data sheet downloading available:

http://users.ece.utexas.edu/~valvano/Datasheets/L293d.pdf