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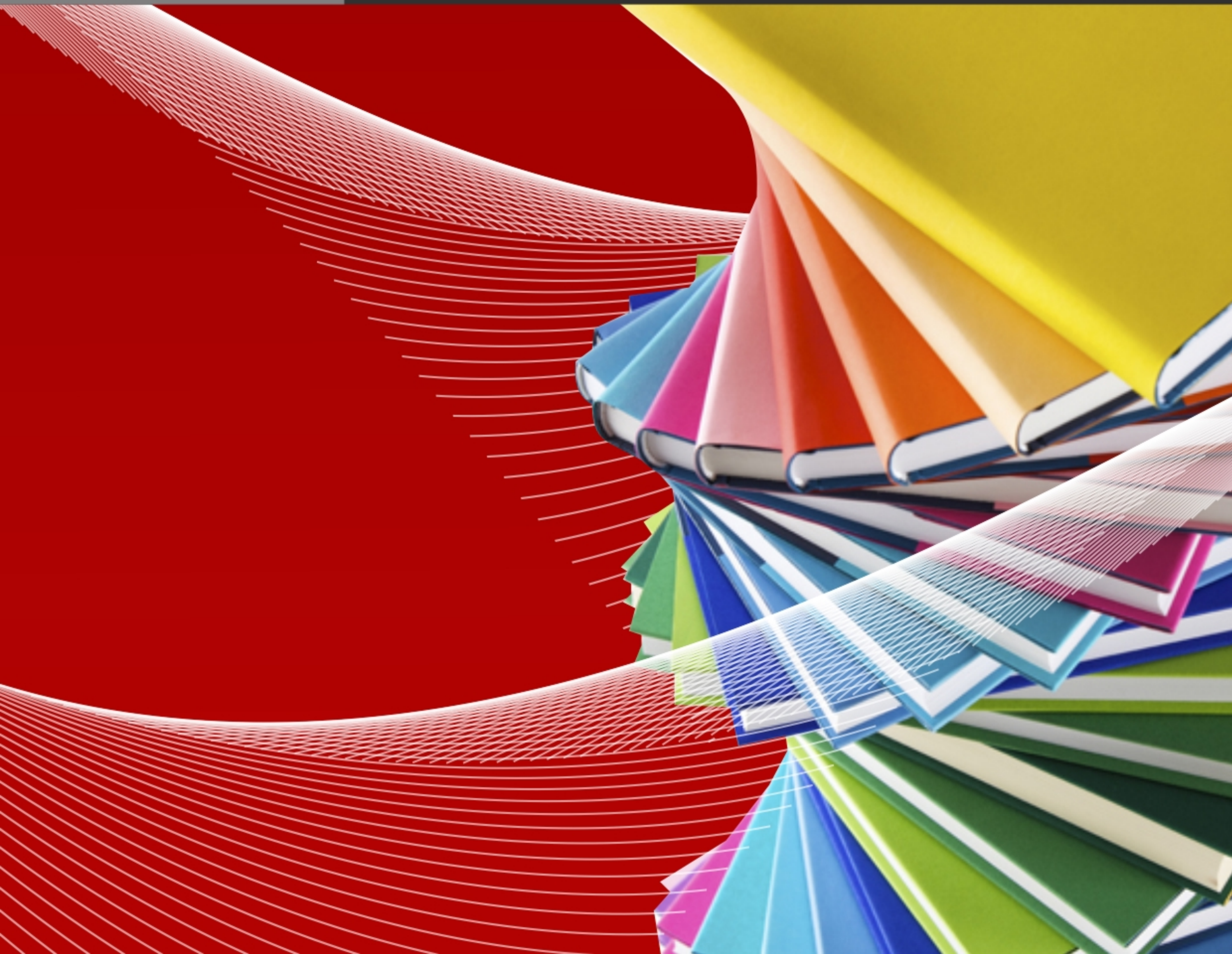

Platform of Wireless Sensor Network

by

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ABSTRACT

In the past years, the Wireless Sensor Networks (WSNs) were widely studied and apply in different areas, also different implements were developed for various applications. In addition, along the research and applications of the so call “Big Data”, WSNs are considered as one of the most effective means for data collections. In this project, various wireless technologies, e.g. WiFi, Bluetooth and ZigBee were preliminary studied. A prototype Wireless Sensor Network is designed and built based on the open standard ZigBee technology, open source hardware platform Arduino and free cloud platform Xively for WSNs data storage.

To demonstrate the operation of the proposed WSN, the proposed sensor nodes are designed to support various analog sensors, i.e. temperature, steam and ultrasonic sensors for distance measurement. The sensor nodes form a WSNs using the XBee technology which complies the ZigBee standard. Moreover, to achieve the high network deployment flexibility, network coordinator of the proposed WSN equips a 3G mobile communication capability for mobile Internet access. Therefore sensor data can be consolidated and uploaded to the cloud platform for WSNs data storage anywhere, anytime with the mobile network coverage.

Numbers of prototype sensor nodes are built and evaluated. The sensors report measured qualities with acceptable tolerance. e.g. ultra-sonic sensor reports < 0.52% average error for the distance test within 0.20 m to 4.00 m. All prototype sensor nodes in this project are power up by a single standard 3.70V batter and least for operation of ~300 days. The collected data are collected through the cloud based WSNs platform. A mobile GUI is designed and developed on open Android platform, which allows remote access and visualize the WSN data with certain analysis capabilities.

Finally, except the collect sensor data, the remote sensor nodes can report the power status of the battery so as to ease the maintenance and operations of the proposed WSNs smoothly. The proposed WSN provides a basic platform of the ZigBee WSN and demonstrate its high flexibility by integrating various open technologies, ZigBee, Arduino, Android and Cloud WSN data storage.

CHAPTER 1
INTRODUCTION

1.1 SENSOR NETWORK

Sensor network is widely used in many aspects such as environmental monitoring, heath monitoring, industrial process monitoring and so on. It is a combination of particular transducers that required monitoring, collecting or recording the information of different locations. It commonly monitored parameters as temperature, pressure, humidity, etc. In fact, a sensor network is consists of diverse detection stations, so called sensor nodes. As a sensor node, it should be a functional part of whole sensor network. Each sensor node must be small, portable, lightweight, so it can easy to install and simply to cooperate with others. There is an example is showing Wireless Sensor Network as Figure 1.1 [1.1].

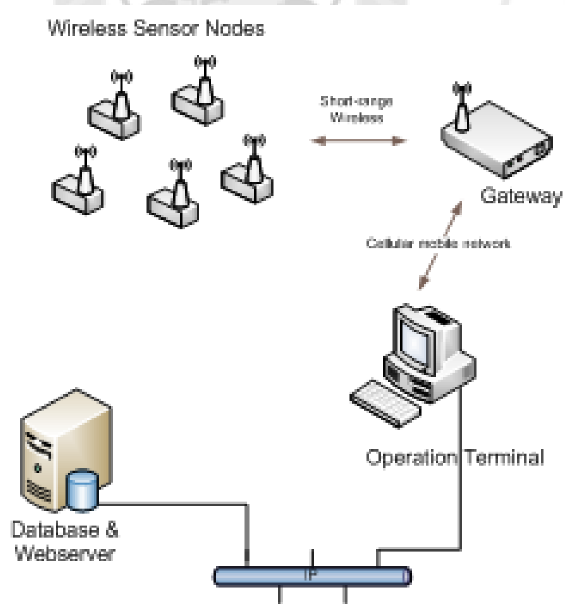

Figure 1.1 A Wireless Sensor network

1.2 WIRED SENSOR NETWORK AND WIRELESS SENSOR NETWORK

Commonly, a sensor network can be divided to two groups, one is wire senor network another is wireless sensor network, but these two kinds of network is mainly depend on the transceiver they used. If the transceiver is used hard-wired connection to the computing system, it is wire sensor network. If transceiver is used wireless connection, it should be wireless sensor network. As the different connection used in sensor network, it would have different performance of system. As the difference of two kinds of networks, the following part will indicate the benefits and disadvantage of wired network and wireless network.

1.2.1 WIRED SENSOR NETWORKS

For a wired network, it contains several advantages compare to a wireless network. The following example will show you why the enterprise will definitely use wired connection, many companies has including wired and wireless connection but the main operation of these companies are usually using wired connection, wireless connection is an optional choice of them because it often for visitors or senior management. It is because the wired connection is not only easy to control and more security, reliability and faster speed but also the cost effective is a main reason to concern using wired connection. The business can full control of the whole network (such as who is online, what is access) since physical connection is necessary to access the network of enterprise. This advantage of wired connection is obviously better than unauthorized visitors online on your network. As the wired connection using in enterprise, it will usually has a faster speed than a wireless network. It will connect the network and exchange data directly since it would connect the network using wire without any obstacles [1.2].

1.2.2 WIRELESS SENSOR NETWORKS (WSN)

While the popular of wireless networks, it should contain their own advantage which wired ones cannot provide. Wireless networks is good for a management view and it also provides low cost for network since it is costly and difficult to maintain for all wires connect around a building. For example, the extension of network on an enterprise example mentioned before, it is need physical connection to all new workers at their desk. If you using wireless connection for a network, the extensions are very easy since it is only need some setup of their device and it do not need any install with wire connection. Furthermore, the wireless connection is flexible than wire connection. If you are worker who work in a company, wireless connection is convenient you to bring your own devices to the office. For many workers bringing their devices to office, they can easy to connect to the network of enterprise with wireless network. As that kind of convenience, workers can use their devices to the work such as sharing ideas in meeting or discussion during office. It is more tide than wire network since it would not use any cables for connection [1.2].

Table 1.2 The comparison of wired network and wireless network

<table>
<tr><th>Wired Network</th><th colspan="2">Wireless Network</th></tr>
<tr><td>Easy to control</td><td colspan="2">Easy to maintain</td></tr>
<tr><td>More security</td><td colspan="2">Low cost for maintain</td></tr>
<tr><td>Reliability in connection</td><td colspan="2">Avoid the broken in wired connection</td></tr>
<tr><td>Faster speed</td><td rowspan="2">Flexible</td><td>Freedom of move</td></tr>
<tr><td>Cost effective</td><td>Easy for sharing</td></tr>
</table>

However, the risks of security of wireless networks can be reduced by development of encryption and some kinds of wireless security options. In addition, the cost of a wired system is mainly depended these factors, the level of difficulty to route or to connect the wires, the requirement of shielding, wire support and also the distance.

1.3 APPLICATIONS OF WIRELESS SENSOR NETWORKS

Wireless sensor networks were kinds of sensor network which mainly for detecting different measurable environment or physical value. The application of wireless sensor networks is wide, for example, the communication signal monitoring, industrial power control and home intelligence. A wireless sensor network was focus on the network rather than a node, since wireless sensor network is expected to capture amount of data. If there missing a sensor node of the network, the extensive of the network may also compensate the loss sensor node by that amount of data and historical data.

1.4 TECHNOLOGIES FOR WIRELESS SENSOR NETWORK

A wireless sensor network can be built in different ways of communication standard such as WiFi, Bluetooth, ZigBee and so on. For using a WiFi to build a network, the size of network is limited expect adding many routers for routing and forwarding, but it will increase the power consumption of the network. Bluetooth is simple to build the point to point wireless sensor network rather than a tree or mesh network (which will introduce in following chapter), but the power saving of the network is an advantage of this kinds of wireless sensor network. Therefore, XBees are developed base on the covering of wireless sensor network and the power saving of the network for low power and low complexity.

1.5 TYPES OF SENSOR

To be a wireless sensor network, a sensor is important for determine what kinds of data demanded to acquire. Sensor is widely used in many aspects and applications such as the temperature sensor can maintain the room temperature using air conditioner, gas sensor with spray used to protect or avoid the loss in fire. In thousands of different type of sensors, it can be classify to two main types, that is, analog and digital sensors.

1.5.1 ANALOG SENSORS

Analog sensors measure the physical phenomena and produce a series of analog voltage values usually, but it is not useful indeed. As the data is not readable, it often needs to be digitized by ADC at first. Then, the digital signals can be processed by Central Processing Unit (CPU) and Digital Signal Processing (DSP) chips. As CPU receiving a series of data from analog sensors, the data should be converting in meaningful value that is readable by human. For example, the reading of temperature analog sensors is several volts, CPU should make a decision of that voltage and calculate it in order to match the actual temperature in the real situation. The range of matching between analog value of sensors and meaningful numbers are not fixed since it depends on the real situation in different environment or condition. As the output voltage is usually contain a DC offset by a time varying signal, filters and amplifiers are developed to match the sensor output to the range of ADC as previous mentioned [1.5].

1.5.2 DIGITAL SENSORS

Digital sensors actually including all of voltage processing hardware mentioned in analog sensors since it will provide a digital interface cleanly. Because the sensors are powerful to deal with the linearization and compensation internally, they can output an appropriate scale of digital reading [1.5]. But the digital sensors usually more complex and consume more power than analog sensors.

Table 1.1 Some kinds of sensor with capabilities and power consumption

Discrete Sample Voltage				
Sensor Type	Current (mA)	Time (ms)	Requirement (V)	Manufacturer
Photo	1.9	0.33	2.7 – 5.5	Taos
Temperature	1	400	2.5 – 5.5	Dallas Semiconductor
Humidity	0.55	300	2.4 – 5.5	Sensirion
Pressure	1	35	2.2 – 3.6	Intersema
Magnetic field	4	0.03	Any	Honeywell
Acceleration	2	10	2.5 – 3.3	Analog Devices
Acoustic	0.5	1	2 – 10	Panasonic
Smoke	0.005	-	6 – 12	Motorola
Passive IR(motion)	0	1	Any	Melixis
Photosynthetic light	0	1	Any	Li-Cor
Soil moisture	2	10	2 – 5	Ech2o

For a commercial microcontroller, it usually can interact with multiple sensors whether in analog or digital. Table 1.1 [1.5] shows you common sensors with their capabilities and power consumption, so you can use microcontroller to interact with several kinds of sensor to construct a small network.

1.6 SENSOR NODE

Nowadays, a sensor will not only standalone and cooperate with a controller or a computing system, it will usually connect with several different type of sensors at a node and then cooperate with controller or a computing system, that is, sensor node. Sensor node is representing a node that contain several sensors which is able to gather the informations, process the information and communicate with other sensor nodes or computing system in a sensor network. Basically, a sensor node is usually consists of processer, transceiver, memory, power supply and one or more than one sensors [1.6]. A processer is usually a microcontroller which is a small computer for a single integrated circuit, it usually consists of a processor core, memory, and input/output which is programmable. A transceiver is a combination of transmitter and receiver that can receive and transmit signal for communication, it is mainly for transmits data to computing system and receives order or commands from terminal. Memory is the procedure of information which stored, retrieved and encoded. Power supply is often electric utility or a battery used to supply the electricity of each sensor. There is an example is showing Wired Sensor Network as Figure 1.2 [1.1].

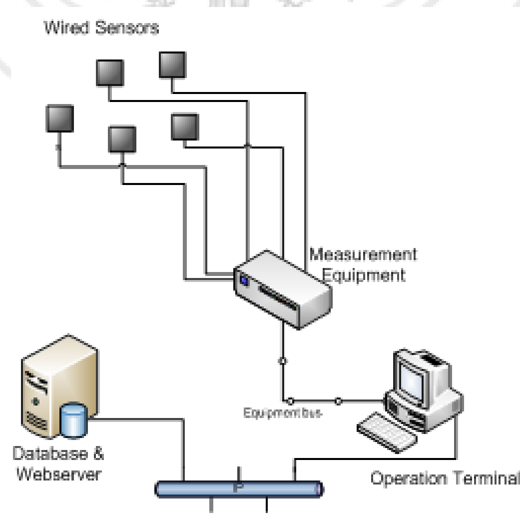

Figure 1.2 A Wired Sensor Network

1.7 MOTIVATION FOR BUILDING A WSN PLATFORM

Wireless networks are good for a management view and it also provides low cost for network since it is costly and difficult to maintain for all wires connect around a building [1.5]. WSN monitoring was not fulfilling the requirement of development. For some kinds of WSN, the management or control abilities were required. For example, the Fire exist in the department, the WSN can control the sprinklers to watering the fire or integrate with some kinds of control circuit to turn the fire extinguisher on. It would be reduced the life and economic loss when the instant reaction of WSN was performed. Actually, the lasting of the devices will be extended since the reuse abilities of the WSN. As the monitoring of WSN is increased, the demand of WSN control is also raising. Most of monitoring system is needed for instant reactions or instant control, it is reasonable to control the monitoring system to different setting, even to order a command or trigger by sensors for controlling. Building a WSN platform can allow the monitoring WSN implement the additional controlling and it is able to compatible or integrate different sensors for vary applications.

1.8 OBJECTIVE AND ORGANIZATION

1.8.1 OBJECTIVE

The objective of this work is mainly to building WSN platform for measuring the environment parameter such as temperature, luminosity, humidity, raining decision, water logging level, etc. For the project contributions, an example is delivered with some of environmental sensors to show the powerful, flexible of wireless sensor networks. As a trend of technology, the WSNs could also gather a lot of information for technical researches. Since the function of WSN can also provide an instant response and simple voltage signal with control component, the remote control action can be implemented. It would not only can provide a prevent disaster or economic loss by provided suitable protection facilities, but also can monitoring the quality of air, strength of wind by combined with different sensors or machine. Although WSN is powerful, the complexity of WSNs is complicated and not user friendly, this cause the application and development of WSN was limited. Actually, a wireless sensor network can simply build using XBee and integrate with microcontroller, remote control interface, cloud, etc. Such as electrical devices or development tool would advance the development of WSN and apply for society life. For the WSN built on this project, the water logging at Macau would also apply. Using WSN to notice the logging, reduce the loss, prevent the injury and indicate the series of logging at Macau.

1.8.2 REPORT ORGANIZATION

In this chapter, a brief introduction is given for the basic concepts of sensors and wireless sensor networks. As the organization of this report, there are six additional chapters. In Chapter 2, the detail of wireless sensor network will be discuss including an overview of history, structure of wireless sensor network, type of wireless sensor network and it's applications. Then, the details of XBee and ZigBee will be provided in Chapter 3 such as concept of XBee and ZigBee, topology they used, etc. After, in Chapter 4, the architecture of network will be introduced, more detail explanation of configuration, operating principle will be provided. Furthermore, the structure of sensor nodes and the sensors will be described in Chapter 5. Finally, the structure of complete wireless sensor network is included in Chapter 6. As a result, conclusions and further works will be produced in Chapter 7.

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CHAPTER 2

WIRELESS SENSOR NETWORKS (WSNS)

2.1 BACKGROUND OF WIRELESS SENSOR NETWORKS (WSNS)

For understanding thorough about WSNs todays, it is better to have a briefly knowledge about their history. Similar as many advanced technologies, WSNs is original appear in heavy industrial and military applications, but not apply in the consumer WSN application or light industrial that are common used today. The first wireless networks which can consider as a true or complete WSN compare to a recent WSN is the Sound Surveillance System (SOSUS) as Figure 2.1 [2.1], it was used to detect and trace Soviet submarines developed by Military of United States in the 1950s. It used submerged acoustic sensors (hydrophones) which are distributed in the Pacific oceans and Atlantic to function as a WSN. This technology is still using to service for monitoring volcanic activity and undersea wildlife today, but that is more peaceful as before military applications.

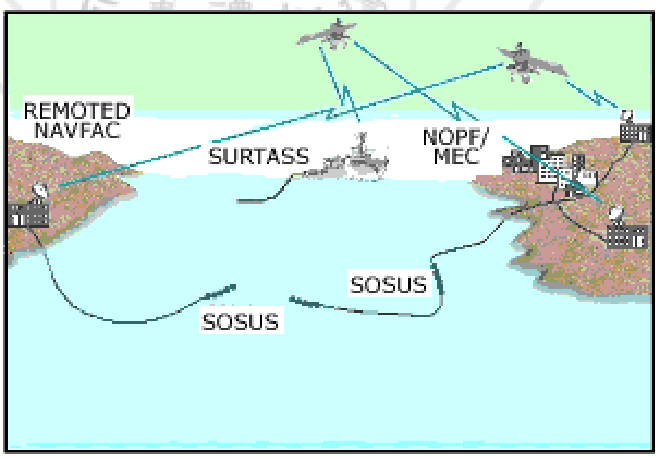

Figure 2.1 A Sound Surveillance System

In 1978, the Defense Advances Research Projects Agency (DARPA) held the Distributed Sensor Nets Workshop (DAR 1978), and concentrated on the research challenges of sensor network such as distributed algorithms, signal processing techniques and networking technologies. In the early 1980s, DARPA also studied the Distributed Sensor Networks (DSN) program, and then it was followed by the program of Sensor Information Technology (SensIT). Afterward, the University of California cooperated with the Rockwell Science Center at Los Angeles suggest the Wireless Integrated Network Sensors (WINS) concept. In the WINS project, one outcome was the Low Power Wireless Integrated Micro-sensor (LWIM), which introduced about 1996. That smart sensing system was combined by a CMOS chip, interface circuits, integrating multiple sensors, digital signal processing circuits, microcontroller and wireless radio on a single chip [2.3].

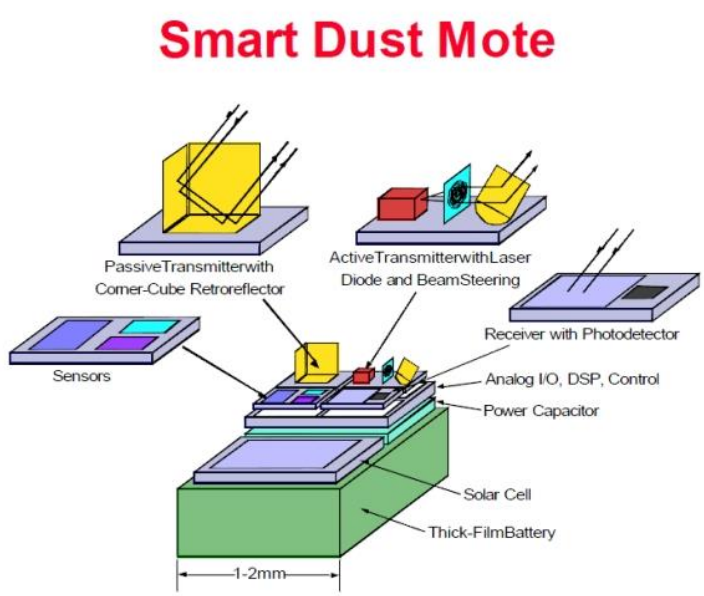

Figure 2.2 A Smart Dust Mote

At the University of California at Berkeley, the Smart Dust project was proposed to focus on the especially small sensor nodes design, so called motes. The objective of this project was to show that a complete sensor system is possible to integrate with tiny devices, such as a dust particle or sands dimension as Figure 1.2 [2.2]. There were two projects were focusing on low power consumption, one is the PicoRadio project, another is The MIT μAMPS (micro-Adaptive Multi-domain Power-aware Sensors) project. The previous one was study by the Berkeley Wireless Research Center (BWRC), which focused the power sensor devices development, thus, the power consumption is small enough that can support only by vibrational or solar energy. Another one is mainly focused on the software and hardware components in a sensor node, for example, the ability of microcontrollers work in dynamic voltage scaling, the restructure data processing algorithms techniques in order to reduce the required power at the software level [2.3].

At last, governments and universities were stared to using WSNs in other area application, such as forest fire detection, air quality monitoring, weather stations, natural disaster prevention and structural monitoring. Then, some engineering students were tried their best to combine the technology development and industry, for example, Bell Labs and IBM are began to introduced the WSNs applications of heavy industry such as waste water treatment, power distribution and specialize factory automation. Actually, there are more applications because the demand of WSNs is more strong than before, such limited applications is not enough today, the applications in the military, technology, science and heavy industry are too expensive, bulky and special network protocols. As the cost efficiency, supporting, power consumption and extension, the development of WSNs is stagnated and it prevented the widely used of WSNs deployment to a broader range application.

2.2 TOPOLOGY OF WSNS

As the WSNs are widely used modern, there are several topologies of WSNs are provided. In fact, there are many sensors applications are need to reduce the complexity, cost and power consumption. The follow section will give a brief concept about different topologies, and the four basic types of WSNs are introduced in following.

2.2.1 PEER TO PEER

Peer to Peer networks is also called Point to Point networks, it requires each node directly communicate to other nodes without any routing in the network. Each device which is already peering can be function as a client or a server corresponding to other nodes. Figure 2.3 [2.4] is showing you an example of Peer to Peer network [2.4]. It is obviously to obtain that each of node is directly to connect other nodes.

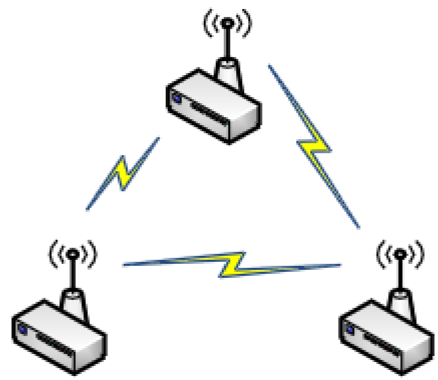

Figure 2.3 Peer to Peer networks

2.2.2 STAR

Star networks are connected to the centralized node such that all nodes cannot directly communicate to each other, but centralized node can. Each node should communicate to others through centralized node, that is, a responsibility of centralize node is routing. Therefore, all other nodes should be a client rather than a server, and the central node is representing a server. A star network example is shown as figure 2.4 [2.4]. It is no any direct path between all client nodes.

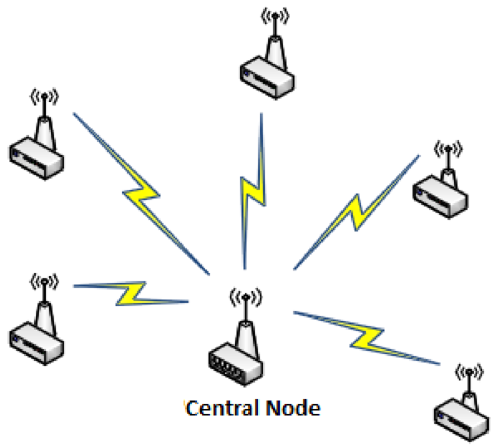

Figure 2.4 Star network

2.2.3 TREE

Tree networks introduce a new node called root, which is corresponding to the central node of star network, but not all nodes are necessary connect to the root directly, it can produce more than one central node to route the data. Which means it can have many levels on the tree, but it should contain three levels at least, because it will become star or peer to peer networks if there are only two levels. Figure 2.5 [2.4] is showing you an example of tree network, level one is root node, level two are central nodes, level three are normal nodes [2.4].

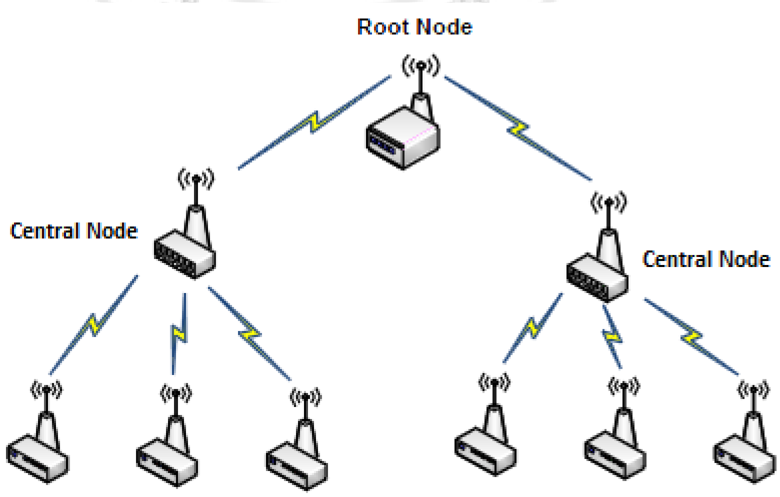

Figure 2.5 Tree networks

2.2.4 MESH

Mesh network is a network that similar to peer to peer network, but the additional function of this network is included, which is the routing functions of some node. This means there is some special node can route your data in order to reach your destination, but not directly transmit point to point. Therefore, it provides an option for communication and the communication will continue even one connection is interrupted. Then, this function is called self-healing, because the network can automatic recover by itself. Figure 2.6 [2.4] is showing you an example of mesh network.

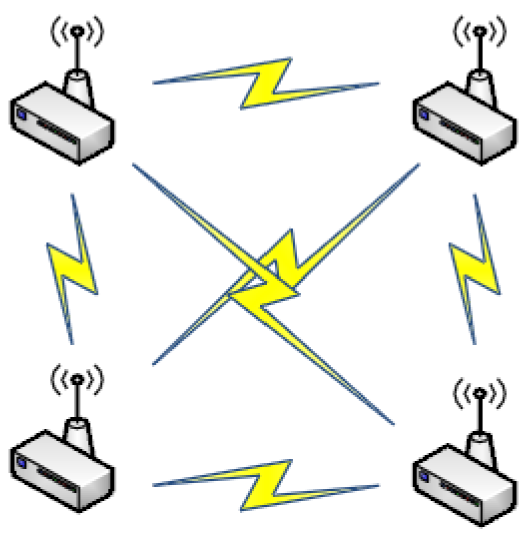

Figure 2.6 Mesh networks

As the conclusion of these four kinds of networks, the sensor nodes transmission ranges should be large enough that all nodes can be connected to centralize node for star network. And also as peer to peer network, all sensors node are required to have a large transmission range. Therefore, the power consumption is high according to the large transmission range. A Tree network is then provided a minimize power consumption since it is not required all sensor nodes connect directly to each other, but it can use other nodes to route their data to destinations. The drawback of tree network is not reliable since it cannot burden any broken or damaged of some important nodes such as root or central nodes. However, a mesh network is provided for prevent the damage exist in the networks and give another path to destination. As reliable network provide, the cost of mesh networks will increase, but also the complexity and power consumption will also increase.

2.3 ENABLED TECHNOLOGIES OF WIRELESS SENSOR NETWORK

2.3.1 WIFI

WiFi refer to Wireless Fidelity, which is a group of WiFi Alliance that compatibility with certified products use the 802.11 wireless local area network (WLAN) standard. This standard is published by Institute of Electrical and Electronic Engineers (IEEE). WiFi allows local area network (LANs) to connect the sever without wires, it increases the extension, flexible of LANs. It is a large improvement of traditional wired networks whatever in maintain or expansion. A common wireless router is using 802.11b or 802.11g with a high speed extension in the 2.4GHz band, and the range of WiFi technique is about 50 to 100 meters. For this communication standard, it usually needs an access point to centralize data and transmit to destinations. This access point is energy cost by the spending times of standby and routing. However, the bandwidth of 802.11 families is quite large, it about 11,000 Kb/s, it is good for huge data transmission. Obviously, it is not suitable to building WSNs for only 32 network sizes, but with quite high data rate and energy cost. Therefore, the applications of WiFi are focusing on Web, email, video and so on rather than monitoring [2.7].

2.3.2 BLUETOOTH

Bluetooth is a standard which focusing on cable replacement, it is design for a short range communication network. As the range of Bluetooth is short, the power consumption is low also, but the range of Bluetooth network is depended on the transceiver using in a Bluetooth device. Bluetooth is used frequency hopping spread spectrum technology that divided the data to different frequencies and transmit it in order to provide a good medium during transmission. This technology is also using 2.4GHz operating frequency, and it can only build a small network called Piconets, which is tolerance a maximum number of networks for 8 devices. There were several types of Bluetooth were developed, each of them contains there characteristic such as 2.0+EDR to increase the speed around 2 to 3 Mbps, 2.1+EDR to increase the security of transmission. Nowadays, 4.0+HS even provide more power saving than before [2.8]. As the development, Bluetooth is also advanced a new topology called Scatternet topology, which is connecting multi Piconets together and it may consider as an advance of Piconets. Therefore, Bluetooth is also a choice for WSNs.

2.3.3 ZIGBEE

WSNs are required a low power, low cost, less complexity and low data rate network communication. ZigBee is studied this aspect of network communication before IEEE 802.15.4 developed. A Personal Area Network (PAN) is defined by IEEE802.15, which is used to communication between the personal devices based on Bluetooth. To reach a low cost energy of WSNs, ZigBee provide a sleep mode for power saving when there is not activities exists. However, ZigBee is provided a lot of networking topology such as Ad-hoc, Peer to Peer, mesh or star, it is flexible to utilize in many applications. As this communication network is provided a low cost, power and reliability, it is benefit used in control or monitoring applications. Different to other type of WSNs, the network size of ZigBee can enhance to 65,536, it is also suitable to build for a widely wireless sensor network. In Chapter 3, the detail of ZigBee will be described. Table 2.1 will conclude the difference among, ZigBee, WiFi, Bluetooth [2.3].

Table 2.1 The comparison of different types of WSNs [2.7]

	ZigBee	Wi-Fi	Bluetooth
Range	10-100 meters	50-100 meters	10 – 100 meters
Standard	802.15.4	802.11a,b,g	802.15.1
System resources	50 to60Kbyes	>1 Mbytes	>250Kbytes
Network size	65,536	32	7
Bandwidth	20 to 250	11,000	720
Networking Topology	Ad-hoc, peer to peer, star, or mesh	Point to hub	Ad-hoc, very small networks
Operating Frequency	868 MHz (Europe) 900-928 MHz (NA), 2.4 GHz (worldwide)	2.4 and 5 GHz	2.4 GHz
Complexity (Device and application impact)	Low	High	High
Power Consumption (Battery option and life)	Very low (low power is a design goal)	High	Medium
Security	128 AES plus application layer security		64 and 128 bit encryption
Typical Applications	Industrial control and monitoring, sensor networks, building automation, home control	Wireless LAN connectivity, broadband Internet access	Wireless connectivity between devices such as phones, PDA, laptops, headsets

2.4 APPLICATION S OF WSNS

WSNs are commonly used today, it can sense a lot of physical parameters such as light, humility, air quality, water quality and so on. As the original used of WSNs is military, it is developed in wider than before such as environment monitoring, military application, Industrial power control, security and surveillance and home intelligence. In following, the applications of WSNs will be introduced.

2.4.1 MILITARY APPLICATION

WSNs can be used in military applications, such as battlefield monitoring, object protection, intelligent guiding, remote sensing, etc. In military, the current situation of battlefield is determined the victory of battlefield since you can track the action of enemy, the amount of enemy, even trap of battle. In additional, the sensor can also use to protect sensitive object, such as gas, oil, fire and so on. It is increase the safety of military and improved the opportunity of success [2.5]. For protection of enemies aircraft, anti-aircraft guns with aircraft detection sensor is shown as Figure 2.7 [2.9].

Figure 2.7 Anti-aircraft guns with sensor

2.4.2 ENVIRONMENTAL MONITORING

In environment, sensors are used to monitoring habitat. As ecology is need monitoring animals or plants at wild habitats, the sensors are benefit to monitoring rather than human monitoring. However, air or water quality control and monitoring is also improved by adding sensors to the system. For protection of disasters, such as forest fires and floods, sensors can also be a role to detect the disasters and report to government [2.5]. Moreover, environmental monitoring is benefit to plant or biological as shown in Figure 2.8 [2.10].

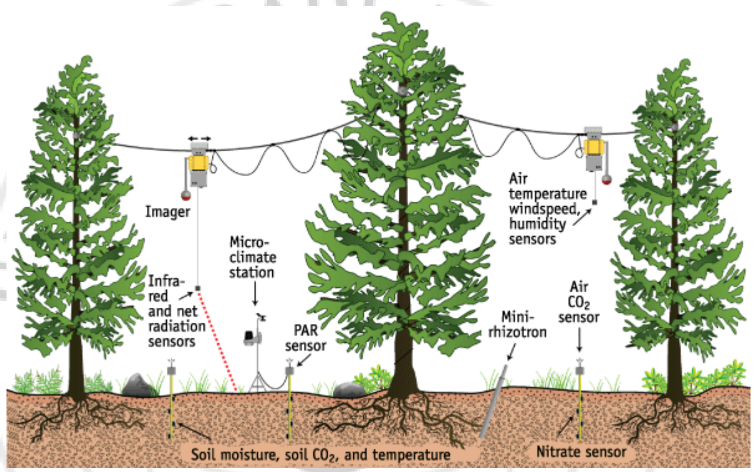

Figure 2.8 Environment Sensor network

2.4.3 HEALTH CARE APPLICATIONS

WSNs can also be monitoring health of patient such as blood pressure, behavior of patient. It can remind whether doctors or patient to make an attention about the situation of body. It will reduce the endanger situation of patient and provide an emergency assistance to patient[2.5]. Figure 2.9 [2.11] is shown an example of health care application using monitoring sensor.

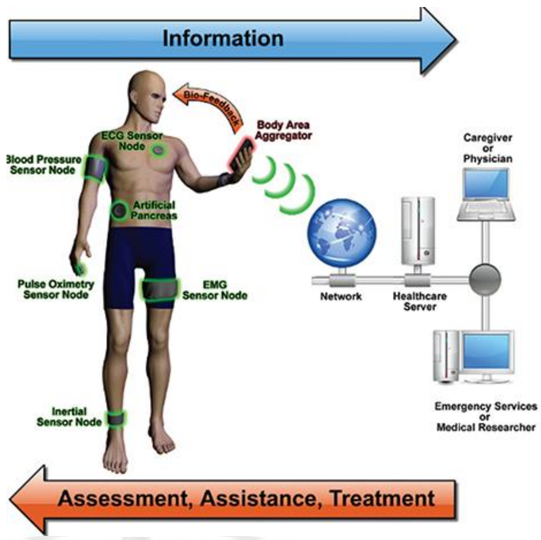

Figure 2.9 A Health care WSN

2.4.4 INDUSTRIAL PROCESS CONTROL

For the process of industrial, it is critical to monitor such as chemical plants, oil refiners. As the production and quality of product is needed to commit, the wireless sensors is suitable to install in a factory. As the protection of leakage oil or chemical, WSNs can also provide a detect function and control the emergency system[2.5]. In the industrial, the delivering process is a heavy section, that is, the industrial process control is utilized to make sure the quality of industry as the example shown in Figure 2.10 [2.12].

Figure 2.10 Industrial process control

2.4.5 HOME INTELLIGENCE

WSNs are convenience for daily life, because it can construct the home intelligence, such as the control of room temperature, the lighting system, the water automatic door, remote metering, etc. The utility meters can be remotely read in your home, for example, gas, water, or electricity in order to send it back to terminal [2.5]. An example of application is shown on Figure 2.11 [2.13].

Figure 2.11 Home intelligence of temperature

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Chapter 3

Digi XBee® Wireless RF Modules

As the concept of WSNs is introduced in previous chapters, XBees will be provided in order to match the requirement WSNs such as low cost, less power consumption. In general, XBee is a brand that including varies of communication standards such as ZigBee, WiFi, 802.15.4, etc. In this project, XBee is a core of WSN because it plays a role of transceiver in a sensor node. The detail of XBee will be provided in the following sections [3.1].

3.1 TYPES OF XBEE RADIO

As there are varies of XBee products delivered, there are also a lot of XBee radio provided such as XBee Series 1 hardware, XBee Series 2 hardware. In general, Serial 1 is based on point to point communications, which is designed for cable replacements and simple communication networks. Serial 2 is allowed several meshes networking, which is used to widely sensor networks. And the comparison of Series 1 and Series 2 are shown in Table 3.1 [3.2-3].

No matter in the range or power of Series 2 [3.4], it is better than Series 1. It is mentioned before that a WSN should including wide range and low energy cost, but it is not the most concern is these two types of hardware. In Table 3.1, Series 2 not only contains self-healing, interoperable mesh routing and ad hoc network creation, but also exists varies networking topologies. It is more reliable than Series 1, and suitable to build a larger WSN.

Table 3.1 Series 1 versus Series 2 for regular XBees

	Series 1 of XBee	Series 2 of XBee
Indoor/ outdoor range	30 m	40 m
Expectation range	100 m	120 m
Transmit/Receive current	45/50mA	40/40mA
Power off current	10 uA	1 uA
Firmware	802.15.4 (point-to-point)	ZB (ZigBee mesh)
Digital input/output pins	8(plus 1 input-only)	11
No. of pins of analog input	7	4
No. of pins of Analog (PWM) output	2	0
Low power, cost bandwidth. Simply to address, small standardized, popular	Yes	Yes
Creation self-healing networks of ad hoc network, interoperable mesh routing,	No	Yes
star, Point to point topologies	Yes	Yes
cluster tree, Mesh topologies	No	Yes
Single firmware for all modes	Yes	No
Requires coordinator node	No	Yes
Point to point configuration	Simple	More involved
Standards based networking	Yes	Yes
Standards based applications	No	Yes
Underlying chipset	Freescale	Ember
available firmware	DigiMesh (proprietary), 802.15.4 (IEEE standard)	ZB (ZigBee2007), ZNet 2.5 (out-of-date)
Up to date and actively supported	Yes	Yes

3.2 BASIC CONCEPT OF XBEE AND ZIGBEE

While the hardware is chosen to build a WSN, the reason should be known for understanding the low power transmission. Basically, there are two main reasons for choosing XBee. One is the transmission power is reduced by distance, that is, Inverse Square Law. This theory is easy to understand through Figure 3.1 [3.1], it is obviously to obtain the transmission power is inversely proportional to the distance r. Therefore, the intensity is reduced by square of distance. ZigBee mesh networks is depended on this law to design, in order to transmit data in a short distance in each time and routing the data to destination. This technique is to maintain the power loss in minimum and maximize the utilization of WSNs. Another reason is the sleep mode in XBee, there are several different sleep modes in XBee. First kind of sleep mode is called pin wake mode, this mode enable an external device to control XBee sleep or wake up by controlling a pin to high or low. Another sleep mode is used to a cyclic wake or sleep for certain period, it is called cyclic sleep mode, and it can used to long time monitoring for slow changing physical parameters.

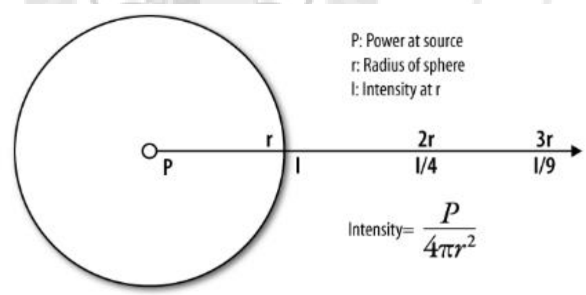

Figure 3.1 Inverse square Law

3.2.1 INPUT/OUTPUT

As mentioned previously, XBee can consider as a transceiver of WSNs. In general, XBee provided multiple pins for connection of different sensors. Figure 3.2 [3.2] is showing the physical pins for an XBee, there are totally 20 pins of an XBee. Each of them have their own function, the function of each pin is shown as Table 3.2 [3.2]. For example, there are several pins can used to connect analog sensors, and also digital sensor. If there is physical parameters need to sense in analog sensors such as temperature, the digital pins can also use to indicate the situation of process by control LED such as flashing LED when temperature higher than 25˚C or turn off the LED representing temperature lower than 10˚C. In additional, XBee I/O has their voltage limitation [3.4], that is, the analog input range is only available between 0 to 1.2 Volts (refer to Appendix A.1 for more information).

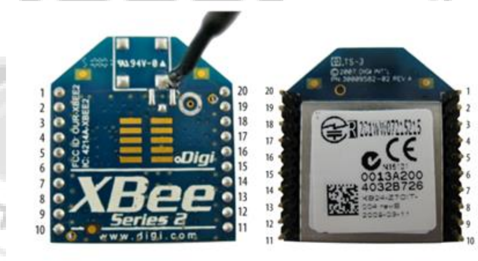

Figure 3.2 The view of XBee

Table 3.2 Explanation of each XBee pin

Pin #	Name(s)	Description
1	VCC	3.3V
2	DOUT	Data Out (TX)
3	DIN	Data In (RX)
4	DIO 12	Digital I/O 12
5	RESET	Module reset (asserted low by bringing pin to ground)
6	PWM0/RSSI/DIO 10	Pulse-width modulation analog output 0, Received Signal Strength Indicator, Digital I/O 10
7	DIO 11	Digirtal I/O 11
8	Reserved	Do not connect
9	DTR/SLEEP_RQ/DIO8	Data Terminal Ready (hardware handshaking signal), Pin Sleep Control (asserted low), Digital I/O 8
10	GND	Ground
11	DIO4	Digital I/O 4
12	CTS/ DIO7	Clear to Send (hardware handshaking), Digital I/O 7
13	ON/SLEEP	Sleep indicator (off when module is sleeping)
14	VREF	Not used in Series 2
15	ASS0C/ DIO5	Association indicator: blinks if module is associated with a network, steady if not; Digital I/O 5
16	RTS/DIO6	Request to Send (hardware handshaking), Digital I/O 6
17	AD3/DIO3	Analog Input 3, Digital I/O 3
18	AD2/DIO2	Analog Input 2, Digital I/O 2
19	AD1/DIO1	Analog Input 1, Digital I/O 1
20	AD0/DIO0/COMMIS	Analog Input 0, Digital I/O 0, Commissioning Button

3.2.2 NETWORK TOPOLOGY

Section 2.2 mentioned about the topology of WSNs, it is common for every WSN including XBee. For ZigBee networks, it defines three roles to construct the WSNs, that is, coordinator, router and end device.

COORDINATOR(C)

A coordinator is function as centralize node, which for collecting data and send it out. It is responsible for managing network, forming network, handing out addresses [3.2]. In a ZigBee network, there is only one coordinator existed. It always used to manage a network by a series of command or control a sensor node through a microcontroller.

ROUTER(R)

Router is responsible for routing data mainly, it cannot form the network, but it can join the existing network, receive data, send information, and also routing the data [3.2]. Routing is a communication method if there is need a node for transfer messages to destination such as the far away path between two nodes. In a large WSN, routers usually act as a joint of network, but it also performs as a sensor node to monitoring the parameters. It is not any requirement of number of routers.

END DEVICE(E)

End device is usually performed as a sensor node, it do not have any function of routing. Typically, an end device should follow by a router or coordinator which can help them to storage their data when they asleep or routing their data to destination. It is not possible to connect two end devices together.

A ZigBee network is built with three roles are mentioned previous, it is almost including all WSNs topology mentioned in section 2.2. There is an example of different network topology for ZigBee networks as shown in Figure 3.3 [3.2].

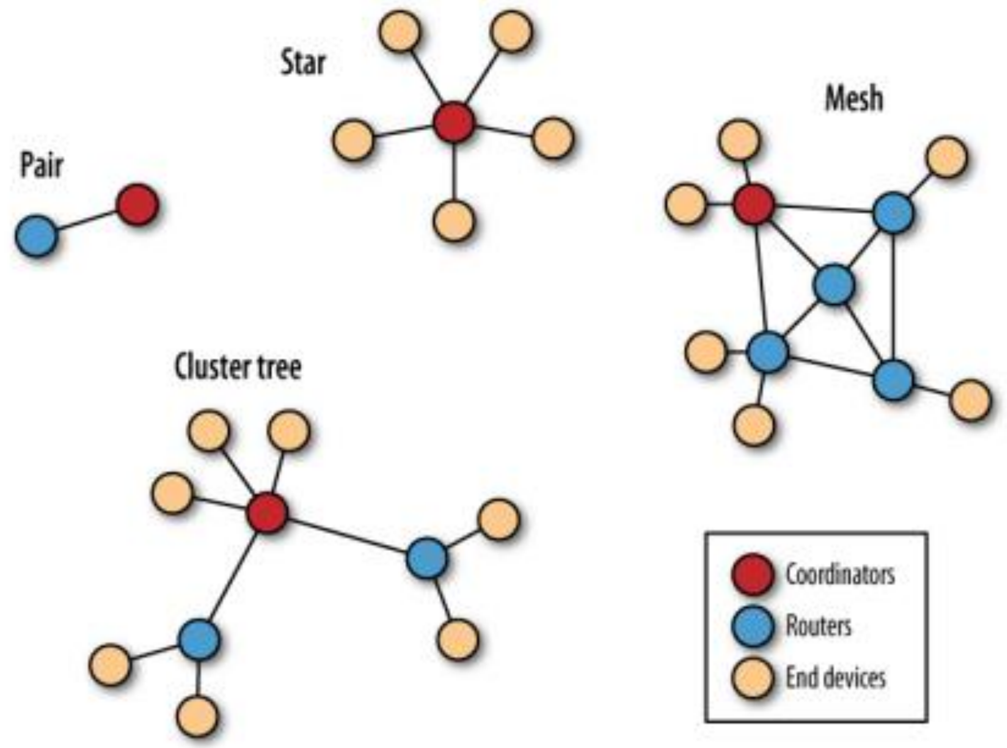

Figure 3.3 The topology of ZigBee network

3.3 ZIGBEE NETWORK

In a ZigBee network, there is need a method to connect them together, that is, Personal Area Network (PAN) address. This PAN address is similar to authenticate identification of network, it is not allowed if a ZigBee network contains more than one PAN address. It is better to have an example for demonstration. Figure 3.4 is an example for ZigBee networks.

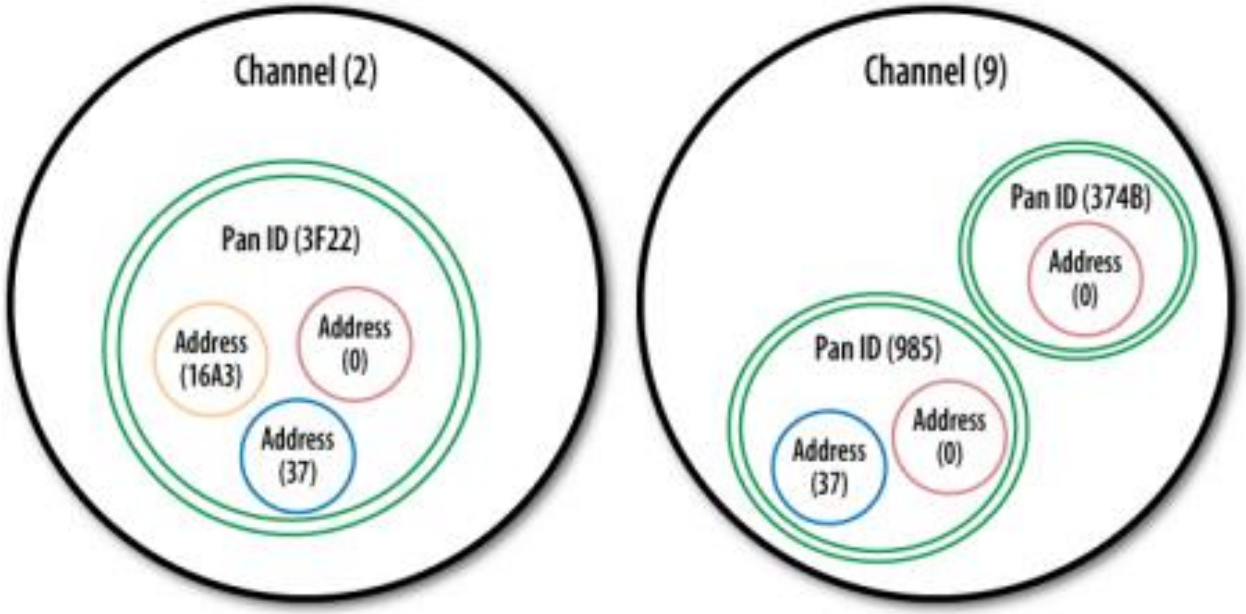

Figure 3.4 ZigBee networks

In Figure 3.4 [3.1], there is a coordinator, router and end device to construct the network using the same PAN ID 3F22, and each of device have their own address called network address or 16 bit address. It is unique for a network such as Internet Protocol (IP) address using in TCP/IP, it will not have any same IP addresses in a network. In additional, there is a channel in this figure, different channels are regarding as different frequencies using. However, Channels can also use to separate different networks as Figure 3.4 shown, but it is often used different PAN ID to separate different network. Therefore, the same PAN ID should be set in order to construct the network and allow others to join the networks.

3.4 AT AND API MODE

Two modes are defined in a ZigBee network in order to communicate with ZigBee, that is, AT mode and API mode. Commonly, AT mode is for human directly interact with XBee, API mode is mainly for computer work efficiently.

3.4.1 AT MODE

AT is stands for Attention, it is a standard command to get an attention to your devices. AT mode can configured XBee directly through AT commands. It is also divided to two modes, one is transparent mode, and another is command mode [3.2][3.6].

- Transparent mode is a default mode for XBee communications, it will pass data when it received. This is a common mode when an XBee is working, it will transmit the data to destination radio without any additional action.

- Command mode is typically for configure an XBee, it is necessary to enter this mode in order to check the state of XBee, configure it, etc. In this mode, XBee will not pass through data to destination radio, it will receive all your command and react with it.

The following is showing an example of configure XBee [3.1]

+++	**// Enter to command mode**
OK	// An XBee response
ATID *3012*	**// Personal area network ID**
OK	
ATDH *0013A200*	**// Destination address**
OK	
ATDL *730E3F46*	**// Destination address**
OK	
ATID	**// Check the current setting of XBee**
3012	
ATDH	
13A200	
ATDL	
730E3F46	
ATWR	
OK	

For more information about AT command, you can refer to Appendix A.2

3.4.2 API MODE

API is stand for application programming interface, which is a standard for interaction of different software program. It will improve the efficiency of XBee and provide an interface for programing communication. Table 3.2 [3.1] is showing a simple structure of API mode. Refer to Appendix A.3 and A.4 for more about API mode.

Table 3.2 basic structure of API frame

Start delimiter	Length	Frame data	Checksum
Byte 1	Byte 2, Byte 3	Byte 4 to Byte n	Byte n+1
0x7E	MSB, LSB	API-specific structure	Single byte

3.5 SUMMARY

ZigBee standard is benefit to WSNs since it is low power consumption, low cost and easy to connect to sensors with its own pins. There are several networking topology for XBee network, it is built by setting their PAN ID. As there are two modes can configure XBees through programing or directly configure, it is useful for using a programming device to control it or direct drive by series port such as computers.

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CHAPTER 4
WSN DESIGN

For the complete WSN, the function should not be unitary for sampling data and display it. Just imagine the digital age for now, the instantaneous data were not adequate, there should storage amount of data for other application such as to predict the coming day temperature using historical temperature, to analysis the tendency of rain. For storing data, the more data storing would perform the more useful applications. That is, a large amount of storing size was recommended. Furthermore, the more convenient way to access the data would contribute the more useful of the WSN. Hence, the simple and flexible to access data was supposed to. As a result, the cloud store sever is demanded for WSN and a component for access internet or cloud is necessary.

4.1 WSN ARCHITECTURE

By combining the components the component mentioned, the construction of entire WSN could be imagined as it shown as Figure 4.1. The whole network was able to collect the physical or environmental data from particular location, calculate the data by Arduino, upload the data to the cloud and finally utilize the remote user interface to request the data, analysis them and control the WSN. For the component built in Figure 4.1, the detail of each component would be provided.

4.1.1 THE STRUCTURE OF COORDINATOR

Since XBees cannot process data itself, there is missing a role to deal with data, present, manage data and control the network. That is, an Arduino is utilized for a microcontroller in order to covert the data to actual value. Therefore, the coordinator side of XBee will contain additional component call Arduino. This microcontroller contains a processor, memory, and also programmable input/output, it can regard as a small computer, which is suitable to controlled devices, such as order a command to XBee when apply different configurations, calculated and process the data values to actual parameters.

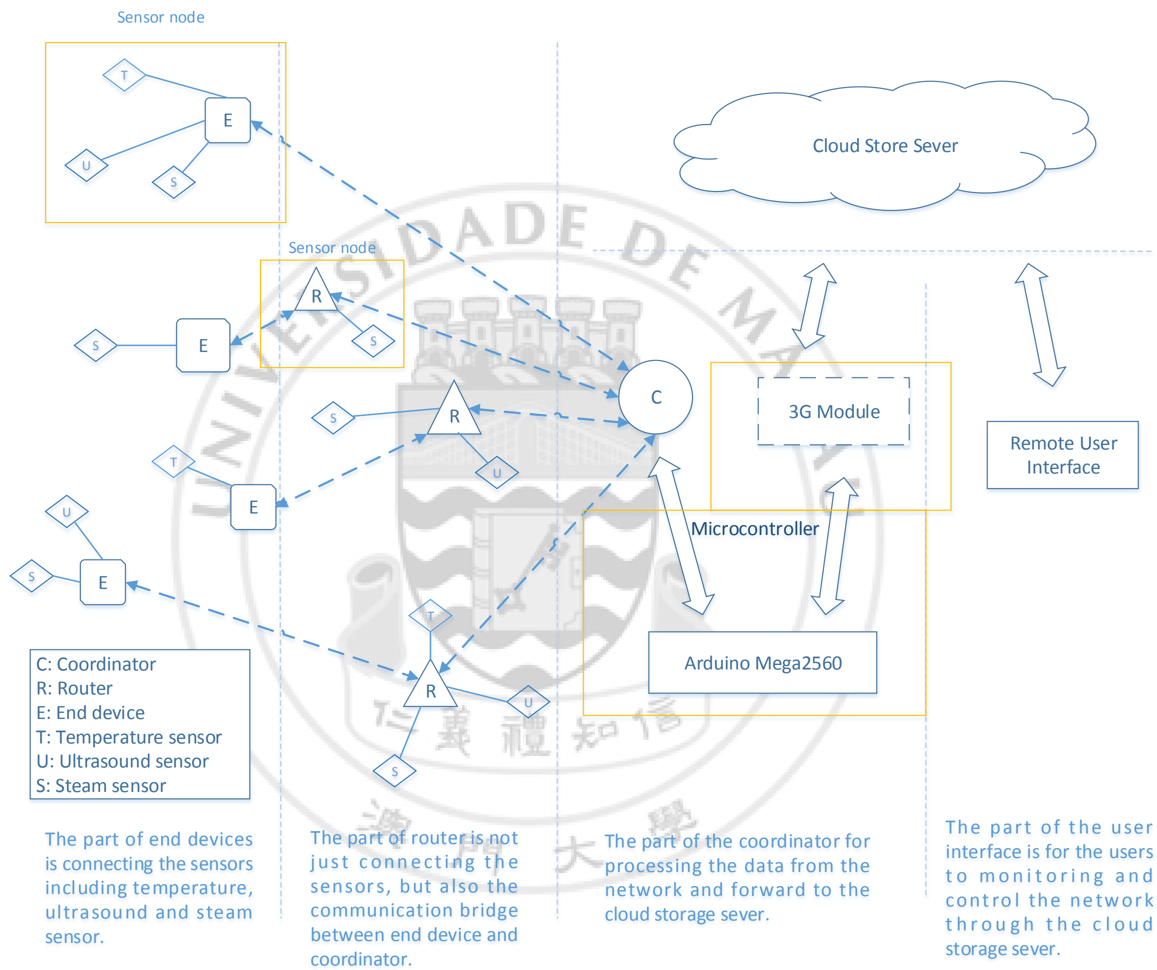

Figure 4.1 The block diagram of complete WSN

4.1.2 ARDUINO

Arduino actually is an open source microcontroller, which design was focused on the flexibility of electronics prototyping platform. As the main design purpose, the Arduino would be compatible to many additional components, for example, take a photo with a photoduiono shield, control a 3D printer, making a call even access internet with a 3G shield. That is why Arduino is appropriated to this project, it not just controls the XBees, but also can access to the internet using a 3G shield.

4.1.3 3G MODULE

In fact, the 3G shield, so called SIM5218A module is used for access internet, making call and so on, it just similar to the mobile phone without the display. So that, a 3G card was desired and some kind of configurations were required equally to the mobile, but the method for setting the 3G shield was different as mobile since it used AT command and directly configured by Arduino through the serial port of them.

4.1.4 CLOUD SEVER OF WSN DATA

Cloud Store Sever was based on the computing of internet, it was able to share the message, data or information. As a supporting of Arduino, the powerful of cloud computing was useful to back up the data, process data and presenting data. For the development of cloud computing, the storing data not only remain in the Arduino, but equally display in other devices such as PC, apple devices or android devices.

4.1.5 REMOTE USER INTERFACE

Andriod was selected the remote user interface and present the user flexible and friendly sense, which could present the data by request the data from cloud and control the WSN through the transmitting command from android to cloud and cloud to Arduino. For requesting data from cloud it can also capture the data for required time period, store this kind of data and illustrate the data in different form.

4.2 THE OPERATING PRINCIPLE OF PROPOSED WSN

As the network component was decided, the operating process can also define. Figure 4.1 was shown the flowchart for theoretical operating procedure of WSN.

The theoretical operating principle of the WSN can be start from sensor:

1. The sensors are convert physical parameter to voltage value and provide to XBees.

2. XBees were receiving the voltage values, convert to analog parameters and transmitted to their parents.

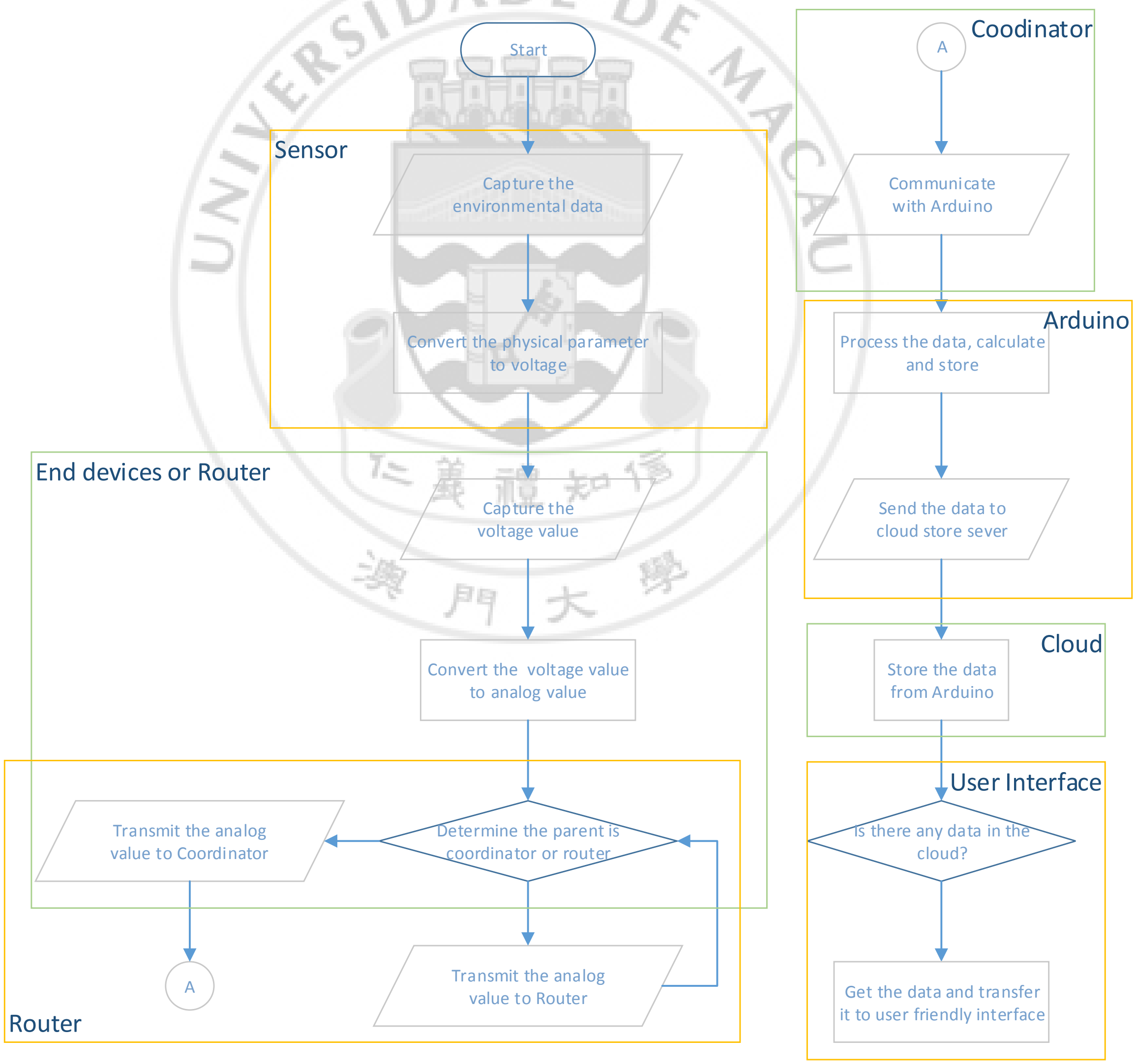

Figure 4.1 the operating process of WSN

3. If the parent of that XBee is not a coordinator, it would forward the message to coordinator.

4. If it is a coordinator, it will communicate with Arduino for storing data within certain amount and upload that amount of information to cloud store sever.

5. Cloud store sever would manage a large amount of data, store, process or present that kinds of data for further used

6. Remote user interface was permitted to acquire the data storing in the cloud and capture the certain period data as the user demanded.

7. Remote user interface could sort out the data using the friendly, designed interface and collect the commands imported by user to upload back to the cloud store sever.

8. The cloud store sever stored the data from the remote user interface.

9. Arduino checked the command from cloud store sever through the 3G module and control or manage the network through these command.

As XBees are not only transmitting data to coordinator, it can also receive data transmitted by coordinator. If coordinator transmits the AT command to particular nodes, the command may control that node for demanding, even for checking the state of the network by the response of that AT command. The control method is related to the microcontroller and the API frame of data, referring Appendix A.3 for more information of AT command control can help for building kinds of API frame similar to Appendix A.3, and replace AT command as required can check and control different configuration of XBees. In the network, the voltage level of each node is important information, it should be check for a certain period when the system operation. Therefore, this command request is needed. The construction of WSN, performance evaluation of components and configurations of network will be the main issue of this report.

4.3 NETWORK STRUCTURE

As the XBee provided network topologies, the cluster tree were selected to be the network structure of this project since the coordinator may connect to end devices directly by the dimension limit of this network, and also the routers may use to receive the far away end devices data and re-transmitting to coordinator, which may help the extension of the network. By the way, the number of children (end device) for each parents (coordinator or router) were limited, it was acceptable with the number of WSN which shown as Figure 4.2.

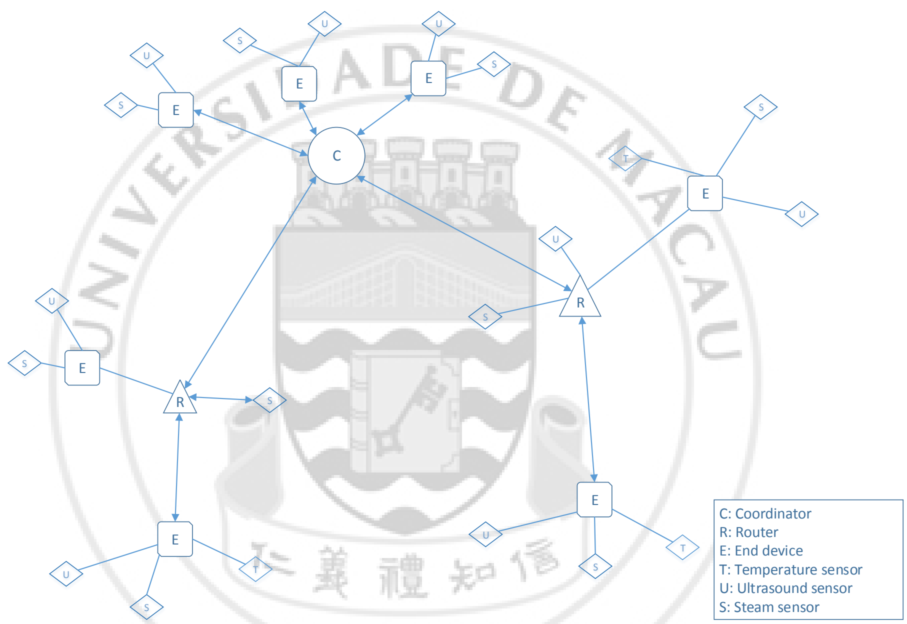

Figure 4.2 The simple WSN connection of devices

4.3.1 CONNECTION OF XBEE NETWORK

By the self-connection function of XBee, the network was built directly. In most of WSN, the network pairing is the trouble and time consuming process, but XBee will auto search whatever the channel of network for the configured PAN ID and attempt to participate the network built by the coordinator. The priority of self-connection was depended on the smallest distance between the network and the devices which attempt to join the network. It means that, the network was built when all the devices power on and with identical PAN ID. Moreover, this self-connection function of XBee also cause the self-healing of XBee network, the children may auto connect to other parents when their parents (precisely network) were loss.

4.3.2 COORDINATOR

As the project designed, the coordinator was required to communicate to other members or sensor nodes. Therefore, the coordinator can control others configuration through a microcontroller. It was needed if the environment around the sensor nodes was changing or the data change rapidly. Normally, the coordinator was responsibility of building network and gather data since it was a bridge of between the network and the microcontroller for gather data and process by microcontroller.

4.3.3 ROUTER

Router is mainly focus on routing data for extension of ZigBee network if the essential distance was too far away. Unfortunately, this property of router was not utilized in the project obviously since the dimension of this project was coverable for the XBee transmission distance. For the data sampling of router, the ultrasound, temperature and steam sensors were chosen to be the sensors (it will be explained in detail for later chapter), which not only performed and demonstrated the WSN platform, but also gather the information of environment and monitoring the parameter of object.

4.3.4 END DEVICE

As the sensors used in router, the end device was also connecting to those sensors. Just similar to the router, after the end devices were collected the temperature and the distance information, the end devices will return the data to coordinator (through the router) and leave the data for processing. Since end devices does not perform any extra function, the power consumption of end devices were the least.

4.4 CONFIGURATIONS OF XBEE

For the configurations of XBee, X-CTU is software which utilize the AT command to setup the setting of XBee through the serial port between XBee and computer. As shown in Figure 4.3, the interface of X-CTU was provided. Most of AT commands using for the XBee would be provide in this software, even for monitoring the serial port, changing the communication baud rate or remote configuration in API mode.

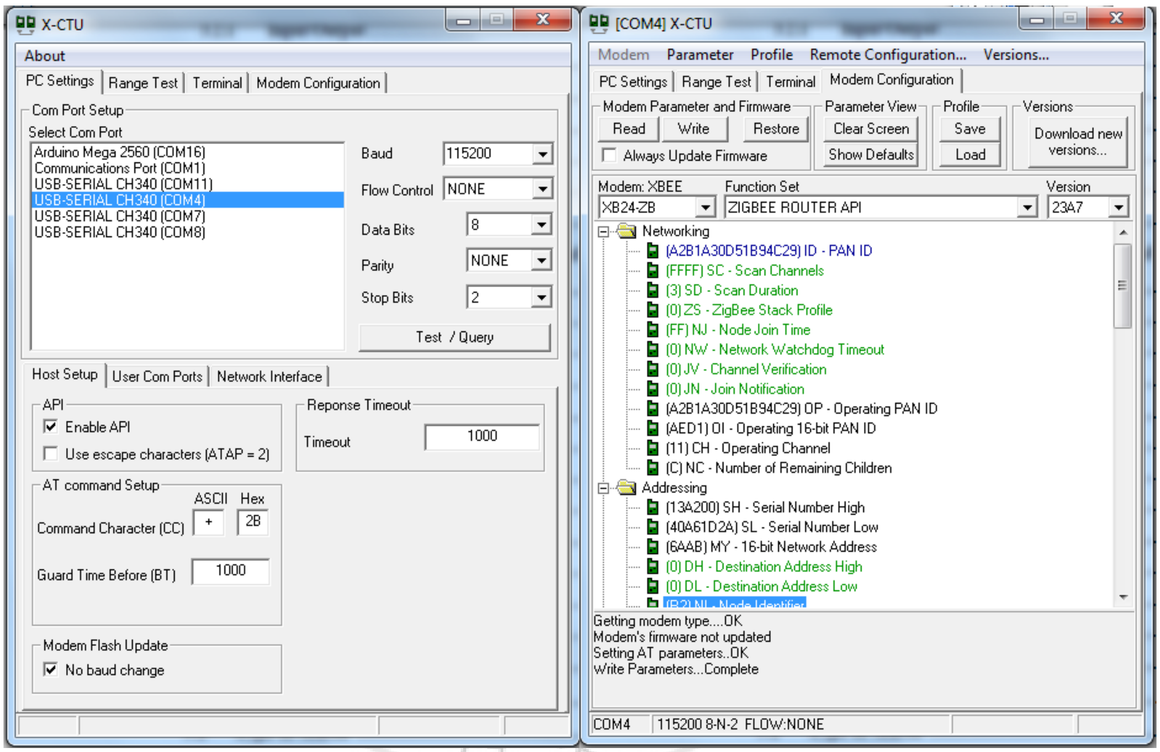

Figure 4.3 The configurations software of XBee

4.3.1 PAN ID (ATID)

Although the parameters of XBees were numerous, the key parameters and the basic configuration for building WSN were just several. As mentioned, the PAN ID is necessary configure to the identical as the coordinator since all nodes including routers and end devices were required to connect to the coordinator for communication, data transfer or building powerful WSN. PAN ID is required in the particular range typically, but the updated firmware XBee can even form more networks by the range of XBee was enhance from 0-0xFFFF to 0-0xFFFFFFFFFFFFFFFF. However, it was not necessary to configure specific PAN ID, it can be a random number within the range. Remind that, all ID of the network members must be the same, the form using in PAN ID is hexadecimal notation and the configuration of PAN ID is shown in Table 4.1.

4.3.2 SAMPLE RATE (ATIR)

As a WSN, the sample rate was the core of the network since it will affect the reporting rate of the network and it also directly affects the performance of the network. Using different sample rate may cause different transmission problem, for example, the data re-transmission, data loss, buffer overflow and so on. Therefore, the suitable sample rate must be designed by several experimental tests or accuracy calculations. To configure the XBee sample rate, it was using hexadecimal notation also and the range of sample rate is 0x32-0xFFFF for millisecond. The ATIR setting is also shown in Table 4.1.

4.3.3 SLEEPING

Building WSN is also meaning that the power supply of sensor nodes cannot supplied by the regular wired power source, it should be support by battery, new energy power such as solar cell, wind power, etc. For extending the life cycle of sensor node, several ways were able to use as suggestion. First, reducing the power consumption on each node, which was used to this project and it is an efficiently method. Second, enlarge the battery capacities, it is not recommended since the battery size, weight were also influence the performance of sensor node. To reduce the power consumption of sensor node, sleeping of XBee is needed to saving power since sleep state almost stop all activities on XBee similar to turn off the XBee. Limited the data of transmission and receiving is also a method to decrease the power consumption of XBee.

SLEEP MODE (ATSM)

By the sleep mode of XBee, several sleep modes were provided and the mode 5, which is cyclic sleep with pin wake, was used in this project. By the sleep mode of XBee, it may jump to sleep depend on different setting, and how long the XBee awake. Typically, the sleep schedule is fixed, it will not suddenly change if there is not any AT commands to changing the configuration of XBee [4.1]. However, pin wake is XBee allow to wake up by external trigger to ground. In addition, the sleep mode will also influence the sample rate of network and the command applies if XBee is during sleep. Therefore, XBee will only start to do any data samplings or command applying when it awake.

CYCLIC SLEEP PERIOD (ATSP) AND TIME BEFORE SLEEP (ATST)

By the quarter second resolution, XBees were limited from 0x20-0xAF0 (×10ms), but it can also extend by the number of sleep periods to multiple the sleep period. The maximum sleep period is almost 3 weeks before wake up. Although the sleep period can reduce the power consumption, the time before sleep or wake up time should be well control in order to maximize the life cycle of sensor node. It is because the XBee will consume a few tens of milliamps when it wake up, but only a few ten of microamps when it sleeping. However, a long awake time can prevent the data loss by re-transmission. That is, ST is also the main parameter for sleeping and the number of sleep period and time before sleep is shown on Table 4.1.

Table 4.1 Key parameter for the WSN

AT Command	Parameter (hexadecimal)
ATID	1111
ATIR	1B58
ATSM	5
ATSN	180
ATSP	3E8
ATST	2710

4.3.2 RANGE TEST

As the connectivity of XBee network, the range of different power level is necessary to verify in order to have good understanding for build a WSN. For checking the range of XBee on each power level, two XBees were utilizing for AT mode and transmitting the same data to each other and make an evaluation of the received data. Note that, the XBee may use in outdoor situation, the experimental test for power level was also test on outdoor, for estimate the free space environment, the test was trial in Taipa Macau East Asian Games Dome at night for preventing noise environment in day time.

The configurations of Range test is shown as Figure 4.4. For testing the power range of XBee, a network would also require, that is, the PAN ID of two XBee should be configured. Remind that, the number of PAN ID is not necessary to be 121 as the configuration of Figure 4.3, but remain the identical number. For the configuration of power level, it could be found in RF interfacing and the power level 0 to 4 are represent the lowest to highest power of XBee. Figure 4.4 is shown range test result and the data of range test is shown in Table 4.2.

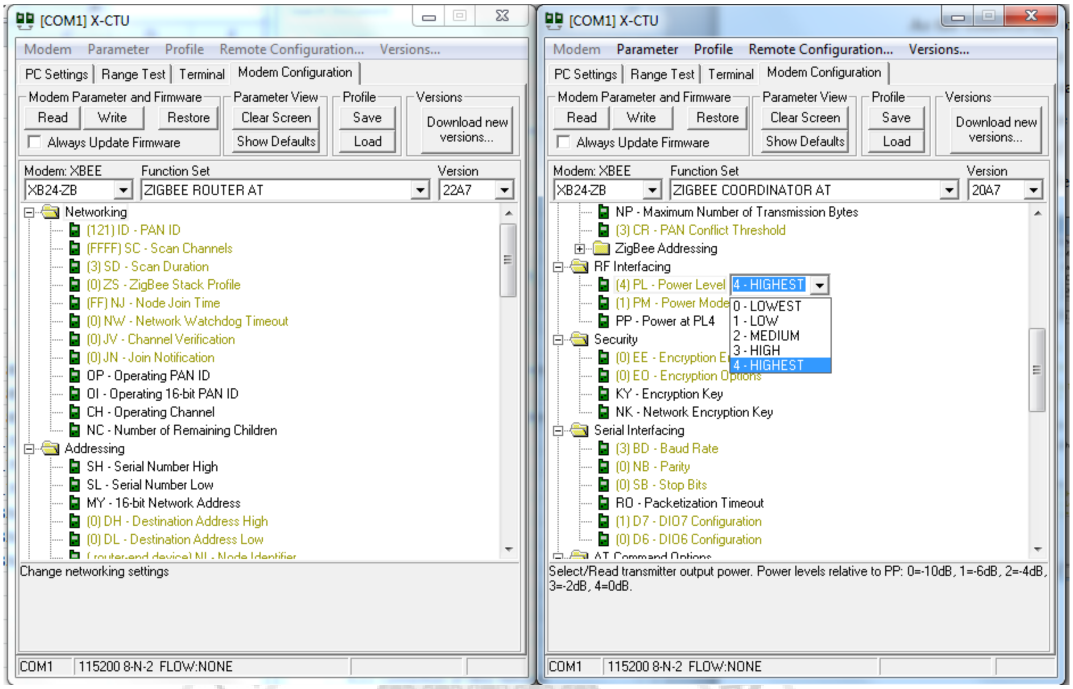

Figure 4.3 The configuration of XBee

Table 4.2 The average of correct data received of XBees on each power level

Distance(m)	Power level(0-4)	Data received
85	0	99.9%
	2	99.7%
	4	100%
170	0	99.8%
	2	100%
	4	99.9%
350	0	0%
	2	38.8%
	4	97.5%

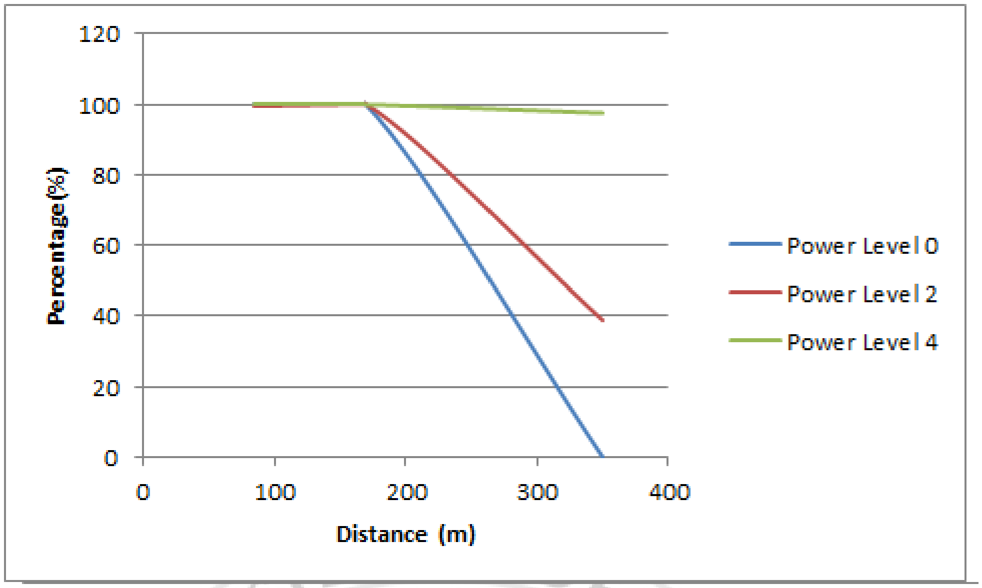

Figure 4.4 The configuration of XBee

Figure 4.2 shown the data received of XBees is 0% for power level 0 when the distances between two XBees are 350m, around 40% at power level 2 and above 90% for power level 4. The outdoor transmission range of XBee was above 170m for both power level 0 and 2, even 350m transmission range can be form for power level 4. Table 4.2 is shown for more precise percentage data.

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CHAPTER 5
STRUCTURE OF SENSOR NODES

In this chapter, the structure of sensor nodes would be discussed in detail, and some of sensors even contain with the experimental test for verify the physical dimension and readable parameters. The temperature sensor was utilized for measuring the real temperature of environment, which not only suitable for monitoring a large sever system room, but also the assist to measure the environment temperature. The ultrasound sensor for estimate the distance between object and the sensor. The steam sensor for sensing the steam or water.

5.1 TYPE OF SENSOR

5.1.1 TEMPERATURE

Temperature sensors were the common and basic sensor that could deal with. Since the wide utilization and the application, temperature sensor was selected to become one type of sensor for the WSN to monitoring the environment temperature. In addition, the real-time temperature parameters were necessary for correcting the other data accuracy such as (temperature variant) sound speed can modify by the real time temperature and correct the distance error caused by temperature.

5.1.2 ULTRASOUND

Ultrasound sensor was used to estimate the distance from the sensor to the target. In the project, the ultrasound sensors were applied to measure water level since the water logging problems at Macau was extremely serious. These ultrasound sensors were to help the citizens to understand the particular situation through the value detected by ultrasound sensors and calculation of Arduino. For widely applying the WSN, most of regions of Macau may cover for sense the water level or the growth rate of water.

5.1.3 STEAM SENSOR

Steam sensors were focus on detection of raining, it may trigger the XBee using pin wake and sending the sampling data to coordinator, which indicate the raining situation of that steam sensor region. At that time, the coordinator would notice that the region of that steam sensor may require sample rate changing, that is, what previous mention the trigger and sudden change. Through the Steam Sensor, the warning or remind message was built to such kind of mechanism could be compensated the cycle sleep mode [5.2].

5.2 SENSOR PERFORMANCE EVALUATION

5.2.1 TEMPERATURE SENSOR

The temperature sensors used on this project were MCP9700 and TMP36 since both of them was easily implement and compatibility with XBee. As the scale factor of both temperature sensor is 10mV/˚C and the sensing range of those sensors were -40˚C to 125˚C refer to Appendix B.1 [5.3] and B.2 [5.4]. That is, according to this information, the readable temperature can be calculated by coordinator through the equation Eq. (1) and Eq. (2):

$$\text{voltage} = \text{analogValue} / 1023.00 \times 1.23 \qquad \text{Eq. (1)}$$

$$\text{temperature} = (\text{voltage} - 0.55) / 0.01; \qquad \text{Eq. (2)}$$

Eq. (1) was converting the analog value received by XBee to actual voltage since XBee would convert the voltage within 0-1.23V to the range of 0 to 1023. Eq. (2) converting the voltage to actual temperature and initializes the temperature start from 0˚C.

5.2.2 ULTRASOUND

CALCULATION

As mentioned in previous, ultrasound sensors most likely to be the main sensors of the sensor node since this WSN were focus on the water level and the grown rate of water level. LV-MaxSonar-EZ0 MB1000 and XL-MaxSonar-WR MB7060 were selected to be a rangefinder which was made use of the reference (or ground) level of the ultrasound sensor detect minus the real-time distance to estimate the water level even could predict the grown rate of the water level by using the historical data. The equation of water level is shown as Eq. (3):

$$waterLevel = actualLevel - referenceLevel \qquad \text{Eq. (3)}$$

Since the value gather from XBee was always an analog value, the Eq. (1) again used to convert the analog value to voltage. Then, apply the datasheet information of MB1000 and WR7060 as shown on Appendix B.3 [5.5] and B.4 [5.6], 6.4mV/in or (2.538 mV/cm) and 3.2mV/cm to transform the voltage to actual distance. Using the scaling factor of both sensors as Eq. (4):

$$distance = voltage / scalingFactor + initialDistance \qquad \text{Eq. (4)}$$

Since the ultrasound sensor existed a range limitation (20cm to 645cm for MB1000 and 20cm to 765cm for WR7060), the initial distance should be considered to match to 20cm to compensate the difference.

DATA CORRETION

As the critical sensors of the network, the accuracy of data had to verify. That is, the simple WSN with ultrasound sensor was built as an experimental test for proved the data accuracy. For this experiment, two XBees and one Arduino were used, and one of XBee was configured as coordinator for receiving data from another XBee (router or end device). Another XBee was utilized for collected and transmitted the data sensed by the ultrasound sensor. Make used of the process ability of Arduino, the simple WSN was done. Figure 5.1 was schematic diagram.

Figure 5.1 The experiment Schematic diagram

A+X: Arduino and XBee, X+U: XBee +ultrasound.

Table 5.1 The data of experimental test for MB1000

Actual distance(cm)	Calculated Distance(cm)	Percentage Error (%)
20	20.62	**-3.11**
30	28.19	6.02
40	35.77	**10.58**
50	45.71	8.58
60	56.12	6.46
70	66.06	5.62
80	76.48	4.40
90	86.42	3.98
100	96.83	3.17
110	109.61	0.35
120	120.03	-0.02
130	129.97	0.02
140	139.91	0.07
150	150.32	-0.22
160	163.10	-1.94
170	172.57	-1.51
180	180.14	-0.08
190	190.56	-0.29
200	200.50	-0.25
210	210.91	-0.43
220	220.85	-0.39
230	231.27	-0.55
240	241.21	-0.50
250	253.99	-1.60
260	261.56	-0.60
270	271.03	-0.38
280	281.44	-0.52
290	291.39	-0.48
300	304.17	-1.39
310	314.58	-1.48
320	322.15	-0.67
330	331.62	-0.49
340	339.19	0.24
350	349.61	0.11
360	359.55	0.13
370	370.91	-0.25
380	380.85	-0.22
390	390.32	-0.08

Table 5.1 is shown the calculated distances and actual distance for comparing and observed the error percentage of MB1000 ultrasound sensor. Obviously, the maximum of distance error calculated by the equations was between -3.11% and 10.58%. To obtain the error and the performance of MB1000 is better to have a diagram to display as shown in Figure 5.2. Obtain the error percentage, the error is decided when the distance past 50cm. It may explain the acoustic phase effects cause in near field, the cancellation exists within 20 to 50cm by the waveform returned. After 50cm measurement, the cancellation of acoustic phase effects may decreased, thus, the result of measurement distance error percentage was reduced.

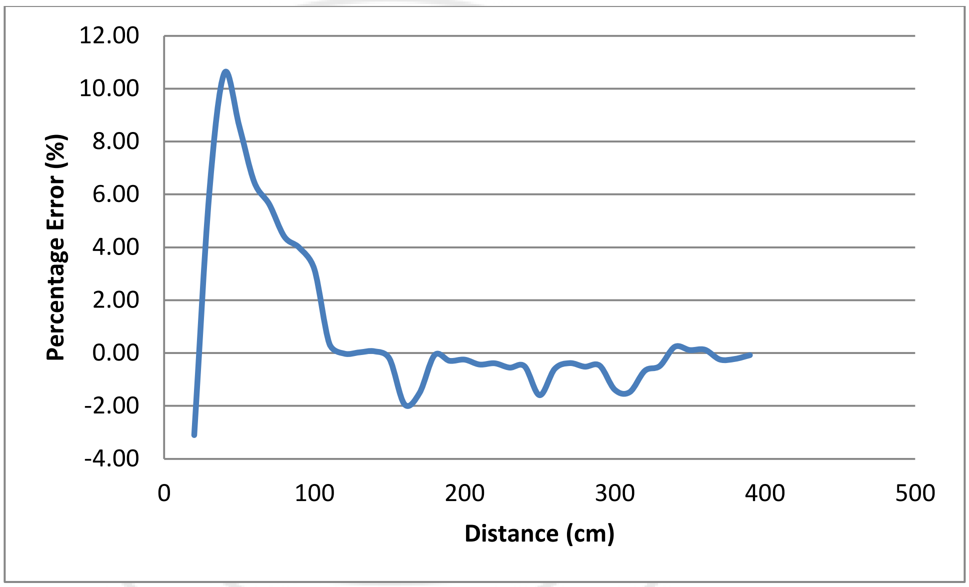


Figure 5.2 Percentage errors vs. the measurement distance of MB1000

As MB1000 experiment, Table 5.2 is shown the distance which estimated by WR7060 and actual distance for comparing and verification of the data. Evidently, the error of distance which calculated by the equations was larger as -1.65 % and -2.21 %, which is limited within ±2.3 % and the influence of acoustic phase effects was less than MB1000. The selection of ultrasound sensor had to accuracy, WR7060 would be the suitable choice for detection by the performance of two different ultrasound sensors.

Table 5.2 The data of experimental test for WR7060

Actual distance(cm)	Calculated Distance(cm)	Percentage Error (%)
50	50.06	-0.12
60	59.45	0.91
70	68.85	**1.65**
80	79.74	0.32
90	90.26	-0.29
100	101.16	-1.16
110	112.43	**-2.21**
120	121.45	-1.21
130	131.59	-1.23
140	140.99	-0.70
150	150.38	-0.25
160	160.52	-0.33
170	169.92	0.05
180	180.06	-0.03
190	190.21	-0.11
200	200.35	-0.18
210	210.50	-0.24
220	220.64	-0.29
230	231.91	-0.83
240	240.93	-0.39
250	251.08	-0.43
260	260.47	-0.18
270	271.74	-0.64
280	281.13	-0.41
290	291.28	-0.44
300	301.05	-0.35
310	310.82	-0.26
320	320.96	-0.30
330	331.48	-0.45
340	341.25	-0.37
350	351.40	-0.40
360	361.92	-0.53
370	370.56	-0.15
380	381.83	-0.48
390	391.22	-0.31
400	401.37	-0.34

For the evaluation and the Performance of data, the diagram of actual distance and calculated distance are shown in Figure 5.3. The vary data of ultrasound limited in only 2%, even 1% for more farer distance.

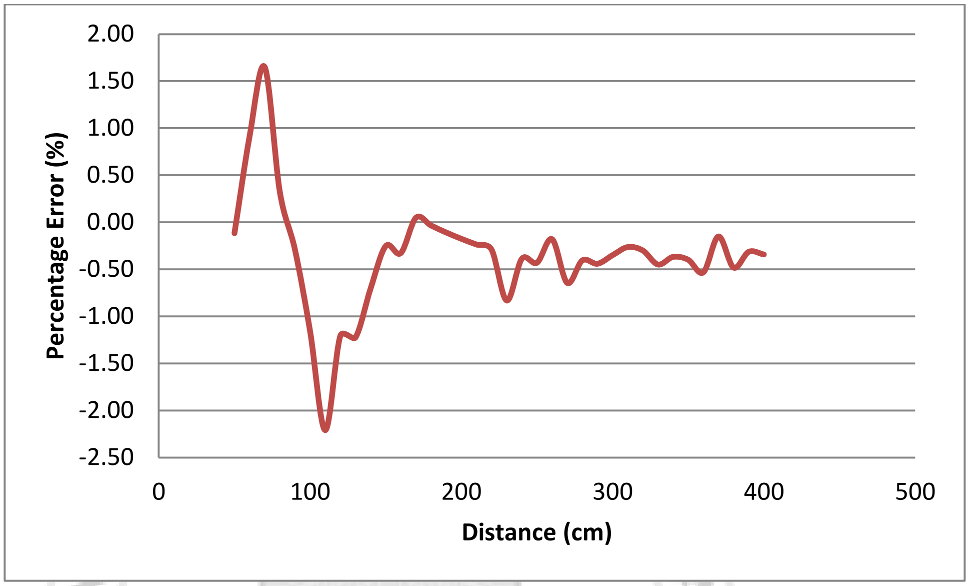


Figure 5.3 Percentage errors vs. the measurement distance of WR7060

5.3 SENSOR NODE STRUCTURE

Combine all sensors and XBee together, the sensor node would be delivered. Actually, the sensor node was not only including the sensors mentioned above such as temperature, ultrasound and steam sensor, but also the regulator, capacitors, battery, LEDs, ON/OFF power button should also built in the sensor node. Note that, the LEDs were utilized to indicate the power is supplying by the battery or not, the XBee is now sleeping or awake, and the measuring data was transmitted or not. Of course the ON/OFF power button is used to disconnect the power source from XBee. All components are summarize in

Table 5.3 The component list for a sensor node

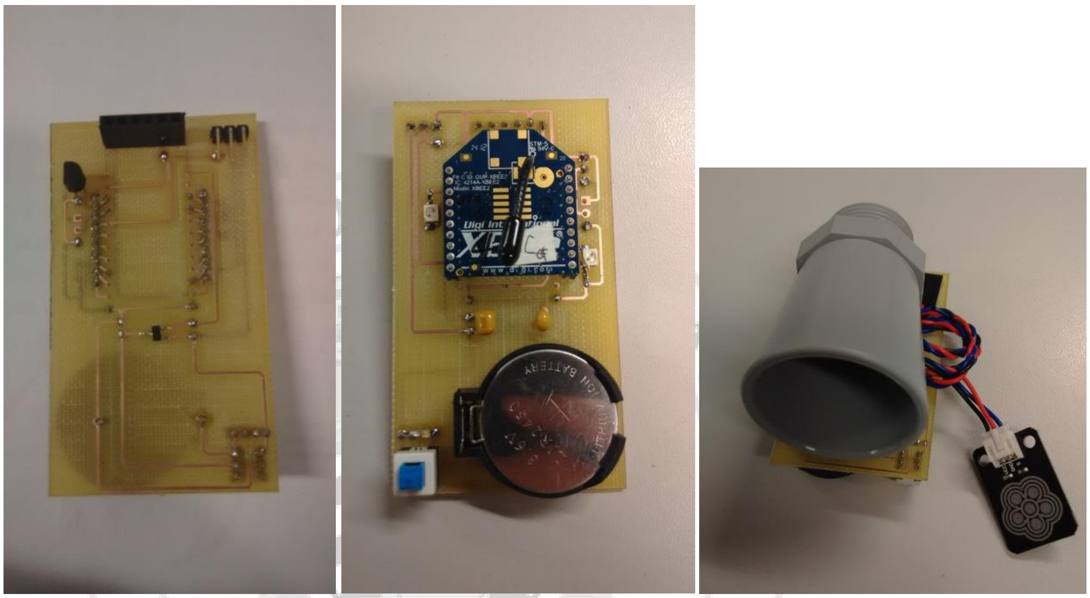
Sensor node component		
1	Communication component	XBee
2	Sensors	Temperature
		Ultrasound
		Steam
4	Power component	Regulator
		Battery
5	Additional component	LED
		ON/OFF button
		capacitors

As the XBee power supply is demand for 2.1V to 3.6V, a stable power source was desired for settling the XBee, but the battery of LiR2450 might not identical for different industries product (refer to Appendix B.4), and the voltage level of the battery would drop when the sensor node operating. As a result, a regulator was required to stabilize the voltage level which supply by the battery, the regulator MCP33 was selected to be a regulator since the maximum output current of the regulator is 160mA (refer to Appendix A.8) [5.7] and the output voltage is 3.3V, which as much as the sensor node consumption as Table 5.4 shown.

Table 5.4 The power consumption of sensor node

Type	XBee	Temperature	Ultrasound	Steam Sensor
Voltage (V)	2.1-3.6	2.3/2.7-5.5	2.5/3-5.5	3.3 or 5
Current (mA)	40	0.05/0.012	2/50	<0.001(measure)

Consequently, the limitation of the regulator not only required 1μF capacitors on both size, but also demand the range of voltage supply from 3.4V to 4.8V. Fortunately, the battery LiR2450 was compatible with that regulator and the size of the battery was also suitable to the sensor node requirement so that the sensor node could remain small. For the hardware of the sensor node is shown as Figure 5.4.



(a) (b) (c)

Figure 5.4 The sensor node structure (a) the bottom side (b) the front side (c) the sensor node with sensors

5.4 SUMMARY

For different sensors used in the WSN, the application of WSN would totally difference. The chapter introduced several sensors in order to present the usage of WSN in Macau. As the sensor accuracy was the main part of WSN, to verify the accuracy of the sensor was necessary part for evaluation the data worth. Using linear regression method could reduce the error existed during measuring or data capturing and improved the result of the sensor performance. Moreover, the design of sensor node not only need to considered sensors, but also the power supply, regulator and indicator.

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CHAPTER 6
CONCLUSION AND PROSPECTIVE

6.1 CONCLUSION

The WSN platform was available measuring temperature, water logging and also determine that location is raining or not. As the “Big Data” for the research and applications, WSNs are the data capturing system which utilized effectively. By the enabled technologies used in WSN such as Blue tooth, ZigBee and WiFi, the suitable solution of WSN was selected, make use of different sensor and utilize the sensors to WSN should go through a lot of performance evaluations such as ultrasound sensor should verify the data accuracy. These kinds of experiments were required for performing the real data received and matching it to the actual distance. Without the experiment, the analog value return to the coordinator is meaningless, so whatever hardware devices were provide, the performance of that devices should be tested.

The demonstration of WSN operation wasplatform shows that the functions of WSN may different by integrate with different sensor, controller or additional component such as the user friendly interface (e.g. Android Tablet, mobile devices). Remote user interface can allow user capture the updated network information through the cloud service provided the storing sever to save data and Arduino cooperate with 3G module to provide the internet access function. Both applications were compatible with WSN and cause the variation of applications. WSN is widely utilized in many applications and it could be more users friendly and flexible for the development and application.

The qualities of sensors were proved by the measuring within acceptable tolerance. e.g. average error of ultra-sonic sensor is less than 0.35% for the distance experiment between 0.2 m to 4.0 m. Moreover, all prototype sensor nodes in this project are power up by a single standard 3.7V battery and last for operation of

~300 days approximated. It reduced replacement of sensor node battery since sensor node would also place in hard and tough environment. The cloud based WSNs platform is storing the collected data. An open Android platform is a mobile GUI for development, which enhance the analysis capabilities by allows remote access and visualizes the WSN.

For the network built by the XBees would perform a region of location monitoring and even an alarm for notification. If there exist a WSN in Macau, citizen may not need to waiting for the message from government, it may directly sent to the user for any emergency information or indicate any alarms for that location through WSN access to the cloud service. Water logging was the urgency problem existed at Macau, the complete WSN could be able to deliver a method to reduce the loss and dangerous of citizen, even to protest the logging by measuring the water logging level using ultrasound sensor with Arduino calculations. In addition, the WSN can also provide the environmental parameters for more location typically such as the temperature sensor for detecting the degree of temperature and the steam sensor to determine raining is begin. For provide more easy understanding data for user, the WSN would not just using in the industry.

6.2 FUTURE WORKS

For more users friendly and simpler to design of WSN, the development of WSN would be quickly and the application of WSN would also extend. By using the more powerful microcontroller such as Raspberry Pi, it can perform more function than Arduino, for example to install an OS to Raspberry Pi device, it can also function as powerful as computer. For the operation of WSNs with computer, the functionalities may also increase, for example, the clothes would be shift under the roof when the weather is not good or start to rain, the drains and rainfall can predict the loading lasting limit and the suitable time for dredge the water. The detection of environment temperature may also assist the selection of dressing. For the larger cover of WSN, the development of WSN would also benefit for the requests. Matching the different or additional sensor or controller, WSN can even to monitoring the house physical parameter such as the lighting in the house, the door in open or close, can also comfortable. As the safety awareness decrease and the employee increase for a family, an empty house may raise during the working hours. Burglary may also increase by the crime increase, the WSN can also be an alarm and an engine to turn on the electricity in the house for scaring the burglar and notice the police. Using cloud also remotely control the home facility as an intelligent home system.

APPENDIX

A.1 Analog input of XBee

The limitation of XBee analog input is about 0 to 1.2 Volts, if a sensor is not work in this range, a voltage divider is considered to be a technique for transfer the analog sensor to suitable value. The formula (1) is to illustrate the voltage divider where V_{out} is the value which is transferred to suitable range, V_{in} is an analog sensor output voltage. Figure A.1 is shown a voltage divider circuit.

$$V_{out} = \frac{R_2}{R_1+R_2} \times V_{in} \qquad (1)$$

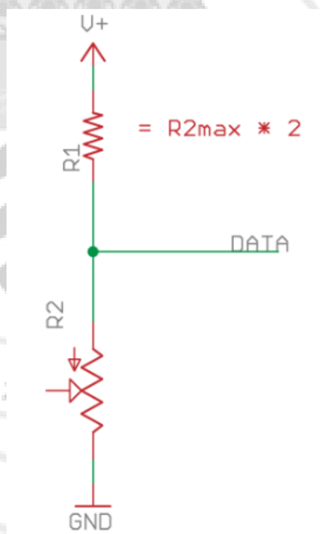


Figure A.1 voltage divider circuit

A.2 AT Command

The following part is about the common AT command which frequently used in simply WSN. +++ is a necessary command enter to command mode, AT is a command to make sure whether the XBee is available or not. ATSM, ATSP, ATSN, ATST are sleep mode command that control the XBee sleep in different cyclic.

Table A.1 The summary of common AT command

AT command	Used for
+++	Enter to command mode
AT	To know that whether XBee is active or not
ATID	To assign/check the current PAN ID
ATSH/ ATSL	To check the serial number of XBee
ATDH/ ATDL	To assign / check the destination address
ATCN	Go back to transparent mode (XBee will automatic go back to transparent mode if there is not any command for 10 second)
ATWR	To save the current configuration to XBee
ATMY	To check the current network address
ATSM	Cyclic sleep
ATSP	Sleep time
ATSN	Numbver of sleep cycles
ATST	Time awake

Table A.2 The basic AT command of I/O

AT command		Used for
ATD0 to ATD7 (pin 0 to 7) ATP0 to ATP2 (pin 10 to12)	0	Disable the I/O pin
	1	Built in function
	2	Analog input, limit to pins D0 to D3
	3	Digital input
	4	Digital output, low (0 Volts)
	5	Digital output, high (3.3 Volts)
ATIR		Sample rate (millisecond, in HEX)

A.3 API Frame

This part is to show you some basic API frame which is common used in XBee. Table A.3 is shown an API frame example of XBee, which can implement AT command through API mode, that is, to control an XBee.

Table A.3 API format for AT command control XBee

Byte	Example	Description
0	0x7E	Start byte – indicate beginning of data frame
1	0x00	Length – the length of data
2	0x10	
3	0x17	Frame type – 0x17 is AT command request
4	0x52	Frame ID – Command sequence number
5	0x00	64 bits Destination Address, also call serial number of each XBee
6	0x13	
7	0xA2	
8	0x00	
9	0x40	
10	0x77	
11	0x9C	
12	0x49	
13	0xFF	Destination Network address 0xFFFE is broadcast
14	0xFE	
15	0x02	Remote command options (0x02 is to apply change)
16	0x44	AT command Name (two ASCII characters) 0x44 is D, 0x02 is 2, that means ATD2.
17	0x02	
18	0x04	Command Parameter (queries if not present)
19	0xF5	Checksum

Table A.4 is an example showing the API frame of sampling data, which help the programmer to distinguish the data and address mainly.

Table A.4 API format for sampling I/O data

Byte	Example	Description
0	0x7E	Start byte – indicate beginning of data frame
1	0x00	Length – the length of data
2	0x14	
3	0x92	Frame type – 0x92 is a data sample
4	0x00	64 bits Source Address, also call serial number of each XBee
5	0x13	
6	0xA2	
7	0x00	
8	0x40	
9	0x77	
10	0x9C	
11	0x49	
12	0x36	Source Network address
13	0x6A	
14	0x01	Receive Opts. 01 is Packet Acknowledged. 02 is Broadcast packet
15	0x01	Number of sample set
16	0x00	Digital Channel Mask – indicate which pins are set to DIO refer to Table A.4
17	0x20	
18	0x01	Analog Channel Mask – indicate which pins are set to ADC refer to Table A.5
19	0x00	Digital Sample Data (if any)
20	0x14	
21	0x04	Analog Sample data (if any)
22	0x25	
23	0xF5	Checksum (0xFF minus by the sum from byte3 to here)

Table A.4 Digital Channel Mask

First Byte							
N/A	N/A	N/A	D12	D11	D10	N/A	N/A
Second Byte							
D7	D6	D5	D4	D3	D2	D1	D0

For example, a set of digital channel mask is 0x00 0x13, which is equal to 0000 0000 0000 1101and that is mean pins D3, D2 and D0 are set.

Table A.5 Analog Channel Mask

Byte							
N/A	N/A	N/A	N/A	A3	A2	A1	A0

B.1 Temperature sensor datasheet of TMP36

ANALOG DEVICES

Low Voltage Temperature Sensors

Data Sheet

TMP35/TMP36/TMP37

FEATURES

- Low voltage operation (2.7 V to 5.5 V)
- Calibrated directly in °C
- 10 mV/°C scale factor (20 mV/°C on TMP37)
- ±2°C accuracy over temperature (typ)
- ±0.5°C linearity (typ)
- Stable with large capacitive loads
- Specified −40°C to +125°C, operation to +150°C
- Less than 50 µA quiescent current
- Shutdown current 0.5 µA max
- Low self-heating
- Qualified for automotive applications

APPLICATIONS

- Environmental control systems
- Thermal protection
- Industrial process control
- Fire alarms
- Power system monitors
- CPU thermal management

GENERAL DESCRIPTION

The TMP35/TMP36/TMP37 are low voltage, precision centigrade temperature sensors. They provide a voltage output that is linearly proportional to the Celsius (centigrade) temperature. The TMP35/TMP36/TMP37 do not require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range.

The low output impedance of the TMP35/TMP36/TMP37 and its linear output and precise calibration simplify interfacing to temperature control circuitry and ADCs. All three devices are intended for single-supply operation from 2.7 V to 5.5 V maximum. The supply current runs well below 50 µA, providing very low self-heating—less than 0.1°C in still air. In addition, a shutdown function is provided to cut the supply current to less than 0.5 µA.

The TMP35 is functionally compatible with the LM35/LM45 and provides a 250 mV output at 25°C. The TMP35 reads temperatures from 10°C to 125°C. The TMP36 is specified from −40°C to +125°C, provides a 750 mV output at 25°C, and operates to 125°C from a single 2.7 V supply. The TMP36 is functionally compatible with the LM50. Both the TMP35 and TMP36 have an output scale factor of 10 mV/°C.

FUNCTIONAL BLOCK DIAGRAM

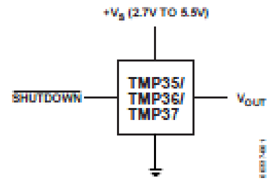


Figure 1.

PIN CONFIGURATIONS

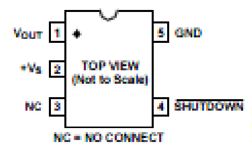


Figure 2. RJ-5 (SOT-23)

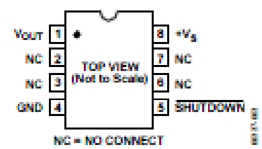


Figure 3. R-8 (SOIC_N)

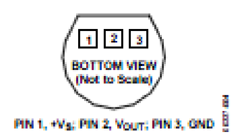


Figure 4. T-3 (TO-92)

The TMP37 is intended for applications over the range of 5°C to 100°C and provides an output scale factor of 20 mV/°C. The TMP37 provides a 500 mV output at 25°C. Operation extends to 150°C with reduced accuracy for all devices when operating from a 5 V supply.

The TMP35/TMP36/TMP37 are available in low cost 3-lead TO-92, 8-lead SOIC_N, and 5-lead SOT-23 surface-mount packages.

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700

SPECIFICATIONS

V_S = 2.7 V to 5.5 V, −40°C ≤ T_A ≤ +125°C, unless otherwise noted.

Table 1.

Parameter[1]	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
ACCURACY						
TMP35/TMP36/TMP37 (F Grade)		T_A = 25°C		±1	±2	°C
TMP35/TMP36/TMP37 (G Grade)		T_A = 25°C		±1	±3	°C
TMP35/TMP36/TMP37 (F Grade)		Over rated temperature		±2	±3	°C
TMP35/TMP36/TMP37 (G Grade)		Over rated temperature		±2	±4	°C
Scale Factor, TMP35		10°C ≤ T_A ≤ 125°C		10		mV/°C
Scale Factor, TMP36		−40°C ≤ T_A ≤ +125°C		10		mV/°C
Scale Factor, TMP37		5°C ≤ T_A ≤ 85°C		20		mV/°C
		5°C ≤ T_A ≤ 100°C		20		mV/°C
		3.0 V ≤ V_S ≤ 5.5 V				
Load Regulation		0 µA ≤ I_L ≤ 50 µA				
		−40°C ≤ T_A ≤ +105°C		6	20	m°C/µA
		−105°C ≤ T_A ≤ +125°C		25	60	m°C/µA
Power Supply Rejection Ratio	PSRR	T_A = 25°C		30	100	m°C/V
		3.0 V ≤ V_S ≤ 5.5 V		50		m°C/V
Linearity				0.5		°C
Long-Term Stability		T_A = 150°C for 1000 hours		0.4		°C
SHUTDOWN						
Logic High Input Voltage	V_{IH}	V_S = 2.7 V	1.8			V
Logic Low Input Voltage	V_{IL}	V_S = 5.5 V			400	mV
OUTPUT						
TMP35 Output Voltage		T_A = 25°C		250		mV
TMP36 Output Voltage		T_A = 25°C		750		mV
TMP37 Output Voltage		T_A = 25°C		500		mV
Output Voltage Range			100		2000	mV
Output Load Current	I_L		0		50	µA
Short-Circuit Current	I_{SC}	Note 2			250	µA
Capacitive Load Driving	C_L	No oscillations[2]	1000	10000		pF
Device Turn-On Time		Output within ±1°C, 100 kΩ‖100 pF load[2]		0.5	1	ms
POWER SUPPLY						
Supply Range	V_S		2.7		5.5	V
Supply Current	I_{SY} (ON)	Unloaded			50	µA
Supply Current (Shutdown)	I_{SY} (OFF)	Unloaded		0.01	0.5	µA

[1] Does not consider errors caused by self-heating.
[2] Guaranteed but not tested.

B.2 Temperature Sensor of MCP9700

MCP9700/9700A
MCP9701/9701A

Low-Power Linear Active Thermistor™ ICs

Features

- Tiny Analog Temperature Sensor
- Available Packages: SC-70-5, SOT-23-5, TO-92-3
- Wide Temperature Measurement Range:
  - -40°C to +125°C
- Accuracy:
  - ±2°C (max.), 0°C to +70°C (**MCP9700A/9701A**)
  - ±4°C (max.), 0°C to +70°C (**MCP9700/9701**)
- Optimized for Analog-to-Digital Converters (ADCs):
  - 10.0 mV/°C (typical) **MCP9700/9700A**
  - 19.5 mV/°C (typical) **MCP9701/9701A**
- Wide Operating Voltage Range:
  - V_{DD} = 2.3V to 5.5V **MCP9700/9700A**
  - V_{DD} = 3.1V to 5.5V **MCP9701/9701A**
- Low Operating Current: 6 µA (typical)
- Optimized to Drive Large Capacitive Loads

Typical Applications

- Hard Disk Drives and Other PC Peripherals
- Entertainment Systems
- Home Appliance
- Office Equipment
- Battery Packs and Portable Equipment
- General Purpose Temperature Monitoring

Description

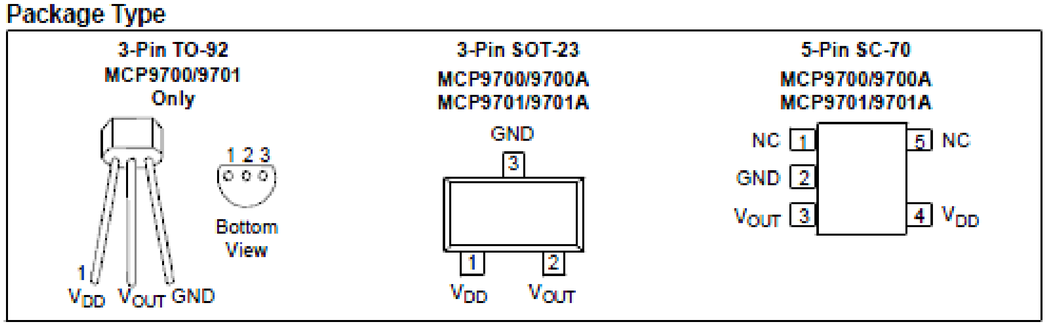
The MCP9700/9700A and MCP9701/9701A family of Linear Active Thermistor™ Intergrated Circuit (IC) is an analog temperature sensor that converts temperature to analog voltage. It's a low-cost, low-power sensor with an accuracy of ±2°C from 0°C to +70°C (MCP9700A/9701A) ±4°C from 0°C to +70°C (MCP9700/9701) while consuming 6 µA (typical) of operating current.

Unlike resistive sensors (such as thermistors), the Linear Active Thermistor IC does not require an additional signal-conditioning circuit. Therefore, the biasing circuit development overhead for thermistor solutions can be avoided by implementing this low-cost device. The voltage output pin (V_{OUT}) can be directly connected to the ADC input of a microcontroller. The MCP9700/9700A and MCP9701/9701A temperature coefficients are scaled to provide a 1°C/bit resolution for an 8-bit ADC with a reference voltage of 2.5V and 5V, respectively.

The MCP9700/9700A and MCP9701/9701A provide a low-cost solution for applications that require measurement of a relative change of temperature. When measuring relative change in temperature from +25°C, an accuracy of ±1°C (typical) can be realized from 0°C to +70°C. This accuracy can also be achieved by applying system calibration at +25°C.

In addition, this family is immune to the effects of parasitic capacitance and can drive large capacitive loads. This provides Printed Circuit Board (PCB) layout design flexibility by enabling the device to be remotely located from the microcontroller. Adding some capacitance at the output also helps the output transient response by reducing overshoots or undershoots. However, capacitive load is not required for sensor output stability.

Package Type



1.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings †

V_{DD}:.. 6.0V

Storage temperature: .... -65°C to +150°C

Ambient Temp. with Power Applied:.. -40°C to +125°C

Junction Temperature (T_J):................................. 150°C

ESD Protection On All Pins (HBM:MM):.... (4 kV:200V)

Latch-Up Current at Each Pin: .... ±200 mA

†Notice: Stresses above those listed under "Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at those or any other conditions above those indicated in the operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

DC ELECTRICAL CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated:
MCP9700/9700A: V_{DD} = 2.3V to 5.5V, GND = Ground, T_A = -40°C to +125°C and No load.
MCP9701/9701A: V_{DD} = 3.1V to 5.5V, GND = Ground, T_A = -10°C to +125°C and No load.

Parameter	Sym	Min	Typ	Max	Unit	Conditions
Power Supply						
Operating Voltage Range	V_{DD} V_{DD}	2.3 3.1	— —	5.5 5.5	V V	**MCP9700/9700A** **MCP9701/9701A**
Operating Current	I_{DD}	—	6	12	µA	
Power Supply Rejection	$\Delta°C/\Delta V_{DD}$	—	0.1	—	°C/V	
Sensor Accuracy (Notes 1, 2)						
T_A = +25°C	T_{ACY}	—	±1	—	°C	
T_A = 0°C to +70°C	T_{ACY}	-2.0	±1	+2.0	°C	**MCP9700A/9701A**
T_A = -40°C to +125°C	T_{ACY}	-2.0	±1	+4.0	°C	**MCP9700A**
T_A = -10°C to +125°C	T_{ACY}	-2.0	±1	+4.0	°C	**MCP9701A**
T_A = 0°C to +70°C	T_{ACY}	-4.0	±2	+4.0	°C	**MCP9700/9701**
T_A = -40°C to +125°C	T_{ACY}	-4.0	±2	+6.0	°C	**MCP9700**
T_A = -10°C to +125°C	T_{ACY}	-4.0	±2	+6.0	°C	**MCP9701**
Sensor Output						
Output Voltage, T_A = 0°C	$V_{0°C}$	—	500	—	mV	**MCP9700/9700A**
Output Voltage, T_A = 0°C	$V_{0°C}$	—	400	—	mV	**MCP9701/9701A**
Temperature Coefficient	T_C	—	10.0	—	mV/°C	**MCP9700/9700A**
	T_C	—	19.5	—	mV/°C	**MCP9701/9701A**
Output Non-linearity	V_{ONL}	—	±0.5	—	°C	T_A = 0°C to +70°C **(Note 2)**
Output Current	I_{OUT}	—	—	100	µA	
Output Impedance	Z_{OUT}	—	20	—	Ω	I_{OUT} = 100 µA, f = 500 Hz
Output Load Regulation	$\Delta V_{OUT}/\Delta I_{OUT}$	—	1	—	Ω	T_A = 0°C to +70°C, I_{OUT} = 100 µA

Note 1: The MCP9700/9700A family accuracy is tested with V_{DD} = 3.3V, while the MCP9701/9701A accuracy is tested with V_{DD} = 5.0V.

2: The MCP9700/9700A and MCP9701/9701A family is characterized using the first-order or linear equation, as shown in Equation 4-2.

3: The MCP9700/9700A and MCP9701/9701A family is characterized and production tested with a capacitive load of 1000 pF.

4: SC-70-5 package thermal response with 1x1 inch, dual-sided copper clad, TO-92-3 package thermal response without PCB (leaded).

DC ELECTRICAL CHARACTERISTICS (CONTINUED)

Electrical Specifications: Unless otherwise indicated:
MCP9700/9700A: V_{DD} = 2.3V to 5.5V, GND = Ground, T_A = -40°C to +125°C and No load.
MCP9701/9701A: V_{DD} = 3.1V to 5.5V, GND = Ground, T_A = -10°C to +125°C and No load.

Parameter	Sym	Min	Typ	Max	Unit	Conditions
Turn-on Time	t_{ON}	—	800	—	µs	
Typical Load Capacitance (**Note 3**)	C_{LOAD}	—	—	1000	pF	
SC-70 Thermal Response to 63%	t_{RES}	—	1.3	—	s	30°C (Air) to +125°C (Fluid Bath) (**Note 4**)
TO-92 Thermal Response to 63%	t_{RES}	—	1.65	—	s	

Note 1: The MCP9700/9700A family accuracy is tested with V_{DD} = 3.3V, while the MCP9701/9701A accuracy is tested with V_{DD} = 5.0V.

2: The MCP9700/9700A and MCP9701/9701A family is characterized using the first-order or linear equation, as shown in Equation 4-2.

3: The MCP9700/9700A and MCP9701/9701A family is characterized and production tested with a capacitive load of 1000 pF.

4: SC-70-5 package thermal response with 1x1 inch, dual-sided copper clad, TO-92-3 package thermal response without PCB (leaded).

TEMPERATURE CHARACTERISTICS

Electrical Specifications: Unless otherwise indicated:
MCP9700/9700A: V_{DD} = 2.3V to 5.5V, GND = Ground, T_A = -40°C to +125°C and No load.
MCP9701/9701A: V_{DD} = 3.1V to 5.5V, GND = Ground, T_A = -10°C to +125°C and No load.

Parameters	Sym	Min	Typ	Max	Units	Conditions
Temperature Ranges						
Specified Temperature Range	T_A	-40	—	+125	°C	**MCP9700/9700A** (**Note**)
	T_A	-10	—	+125	°C	**MCP9701/9701A** (**Note**)
Operating Temperature Range	T_A	-40	—	+125	°C	
Storage Temperature Range	T_A	-65	—	+150	°C	
Thermal Package Resistances						
Thermal Resistance, 5LD SC-70	θ_{JA}	—	331	—	°C/W	
Thermal Resistance, 3LD SOT-23	θ_{JA}	—	336	—	°C/W	
Thermal Resistance, 3LD TO-92	θ_{JA}	—	131.9	—	°C/W	

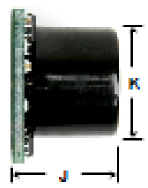
Note: Operation in this range must not cause T_J to exceed Maximum Junction Temperature (+150°C).

B.3 Ultrasound sensor datasheet of MB1000

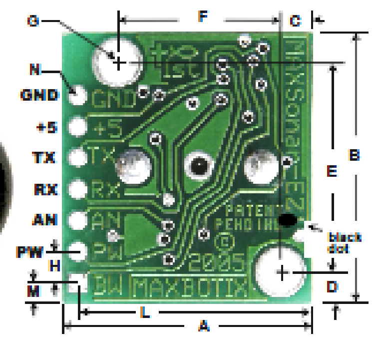
MB1000

LV-MaxSonar®-EZ0™ High Performance Sonar Range Finder

With 2.5V - 5.5V power the LV-MaxSonar®-EZ0™ provides very short to long-range detection and ranging, in an incredibly small package. The LV-MaxSonar®-EZ0™ detects objects from 0-inches to 254-inches (6.45-meters) and provides sonar range information from 6-inches out to 254-inches with 1-inch resolution. Objects from 0-inches to 6-inches typically range as 6-inches. The interface output formats included are pulse width output, analog voltage output, and serial digital output.



approximately actual size



A	0.785"	19.9 mm
B	0.870"	22.1 mm
C	0.100"	2.54 mm
D	0.100"	2.54 mm
E	0.670"	17.0 mm
F	0.510"	12.6 mm
G	0.124" dia.	3.1 mm dia.

H	0.100"	2.54 mm
J	0.610"	15.5 mm
K	0.645"	16.4 mm
L	0.735"	18.7 mm
M	0.065"	1.7 mm
N	0.038" dia.	1.0 mm dia.
weight, 4.3 grams		

values are nominal

Features

- Continuously variable gain for beam control and side lobe suppression
- Object detection includes zero range objects
- 2.5V to 5.5V supply with 2mA typical current draw
- Readings can occur up to every 50mS, (20-Hz rate)
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- All interfaces are active simultaneously
- Serial, 0 to Vcc, 9600Baud, 81N
- Analog, (Vcc/512) / inch
- Pulse width, (147uS/inch)
- Learns ringdown pattern when commanded to start ranging
- Designed for protected indoor environments
- Sensor operates at 42KHz
- High output square wave sensor drive (double Vcc)

Benefits

- Very low cost sonar ranger
- Reliable and stable range data
- Sensor dead zone virtually gone
- Lowest power ranger
- Quality beam characteristics
- Mounting holes provided on the circuit board
- Very low power ranger, excellent for multiple sensor or battery based systems
- Can be triggered externally or internally
- Sensor reports the range reading directly, frees up user processor
- Fast measurement cycle
- User can choose any of the three sensor outputs

Beam Characteristics

The LV-MaxSonar®-EZ0™ has the most sensitivity of the LV-MaxSonar®-EZ™ product line, yielding a controlled wide beam with high sensitivity. Sample results for measured beam patterns are shown below on a 12-inch grid. The detection pattern is shown for;

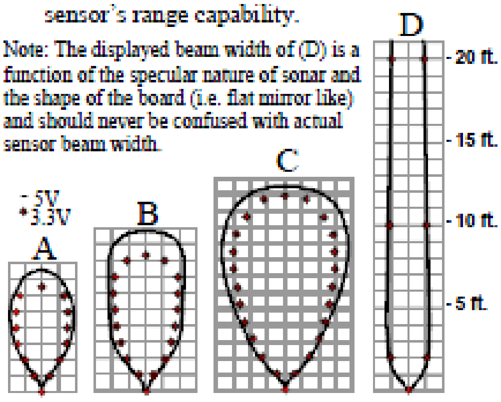
(A) 0.25-inch diameter dowel, note the narrow beam for close small objects,

(B) 1-inch diameter dowel, note the long narrow detection pattern,

(C) 3.25-inch diameter rod, note the long controlled detection pattern,

(D) 11-inch wide board moved left to right with the board parallel to the front sensor face and the sensor stationary. This shows the sensor's range capability.

Note: The displayed beam width of (D) is a function of the specular nature of sonar and the shape of the board (i.e. flat mirror like) and should never be confused with actual sensor beam width.



beam characteristics are approximate

LV-MaxSonar®-EZ0™ Pin Out

GND – Return for the DC power supply. GND (& Vcc) must be ripple and noise free for best operation.

+5V –Vcc – Operates on 2.5V - 5.5V. Recommended current capability of 3mA for 5V, and 2mA for 3V.

TX – When the *BW is open or held low, the TX output delivers asynchronous serial with an RS232 format, except voltages are 0-Vcc. The output is an ASCII capital "R", followed by three ASCII character digits representing the range in inches up to a maximum of 255, followed by a carriage return (ASCII 13). The baud rate is 9600, 8 bits, no parity, with one stop bit. Although the voltage of 0-Vcc is outside the RS232 standard, most RS232 devices have sufficient margin to read 0-Vcc serial data. If standard voltage level RS232 is desired, invert, and connect an RS232 converter such as a MAX232. When BW pin is held high the TX output sends a single pulse, suitable for low noise chaining. (no serial data).

RX – This pin is internally pulled high. The EZ0™ will continually measure range and output if RX data is left unconnected or held high. If held low, the EZ0™ will stop ranging. Bring high for 20uS or more to command a range reading.

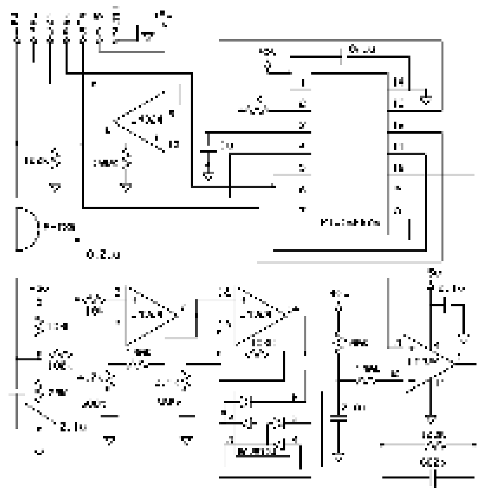
AN – Outputs analog voltage with a scaling factor of (Vcc/512) per inch. A supply of 5V yields ~9.8mV/in. and 3.3V yields ~6.4mV/in. The output is buffered and corresponds to the most recent range data.

PW – This pin outputs a pulse width representation of range. The distance can be calculated using the scale factor of 147uS per inch.

BW – *Leave open or hold low for serial output on the TX output. When BW pin is held high, the TX output sends a pulse (instead of serial data), suitable for low noise chaining.

LV-MaxSonar®-EZ0™ Circuit

The LV-MaxSonar®-EZ0™ sensor functions using active components consisting of an LM324, a diode array, a PIC16F676, together with a variety of passive components.



LV-MaxSonar®-EZ0™ Timing Description

250mS after power-up, the LV-MaxSonar®-EZ0™ is ready to accept the RX command. If the RX pin is left open or held high, the sensor will first run a calibration cycle (49mS), and then it will take a range reading (49mS). After the power up delay, the first reading will take an additional ~100mS. Subsequent readings will take 49mS. The LV-MaxSonar®-EZ0™ checks the RX pin at the end of every cycle. Range data can be acquired once every 49mS.

Each 49mS period starts by the RX being high or open, after which the LV-MaxSonar®-EZ0™ sends thirteen 42KHz waves, after which the pulse width pin (PW) is set high. When a target is detected the PW pin is pulled low. The PW pin is high for up to 37.5mS if no target is detected. The remainder of the 49mS time (less 4.7mS) is spent adjusting the analog voltage to the correct level. When a long distance is measured immediately after a short distance reading, the analog voltage may not reach the exact level within one read cycle. During the last 4.7mS, the serial data is sent. The LV-MaxSonar®-EZ0™ timing is factory calibrated to one percent at five volts, and in use is better than two percent. In addition, operation at 3.3V typically causes the objects range, to be reported, one to two percent further than actual.

LV-MaxSonar®-EZ0™ General Power-Up Instruction

Each time after the LV-MaxSonar®-EZ0™ is powered up, it will calibrate during its first read cycle. The sensor uses this stored information to range a close object. It is important that objects not be close to the sensor during this calibration cycle. The best sensitivity is obtained when it is clear for fourteen inches, but good results are common when clear for at least seven inches. If an object is too close during the calibration cycle, the sensor may then ignore objects at that distance.

The LV-MaxSonar®-EZ0™ does not use the calibration data to temperature compensate for range, but instead to compensate for the sensor ringdown pattern. If the temperature, humidity, or applied voltage changes during operation, the sensor may require recalibration to reacquire the ringdown pattern. Unless recalibrated, if the temperature increases, the sensor is more likely to have false close readings. If the temperature decreases, the sensor is more likely to have reduced up close sensitivity. To recalibrate the LV-MaxSonar®-EZ0™, cycle power, then command a read cycle.

B.4 Ultrasound sensor datasheet of WR7060

XL-MaxSonar®- WR/WRC™ Series

High Resolution, IP67 Weather Resistant, Ultra Sonic Range Finder

MB7052, MB7060, MB7062, MB7066, MB7067, MB7068,
MB7070, MB7072, MB7076, MB7077, MB7078, MB7092

The XL-MaxSonar-WR and XL-MaxSonar-WRC sensor series provide users with robust range information in air. These sensors also feature high-power acoustic output along with real-time auto calibration for changing conditions (supply voltage sag, acoustic noise, or electrical noise), operation with supply voltage from 3V to 5.5V, object detection from 0-cm to 765-cm (select models) or 1068-cm (select models), and sonar range information from 20-cm out to 765-cm (select models) or 1068-cm (select models) with 1-cm resolution. Objects from 0-cm to 20-cm range as 20-cm or closer. The sensor is housed in a robust PVC housing, designed to meet the IP67 water intrusion standard, and matches standard electrical/water ¾" PCV pipe fittings. The user interface formats included are pulse-width (select models), real-time analog-voltage envelope (select models), analog voltage output, and serial output.

Features

- Real-time auto calibration and noise rejection
- High acoustic power output
- Precise narrow beam
- Object detection includes zero range objects
- 3V to 5.5V supply with very low average current draw
- Free run operation can continually measure and output range information
- Triggered operation provides the range reading as desired
- All interfaces are active simultaneously
- RS232 Serial, 0 to Vcc, 9600 Baud, 81N
- Analog, (Vcc/1024) / cm for standard models
- Analog, (Vcc/1024) / 2cm for 10-meter models (MB7066, MB7076)
- Sensor operates at 42KHz

Benefits

- Acoustic and electrical noise resistance
- Reliable and stable range data
- Sensor dead zone virtually non-existent
- Robust, low cost IP67 standard sensor
- Narrow beam characteristics
- Very low power excellent for battery based systems
- Ranging can be triggered externally or internally
- Sensor reports the range reading directly, frees up user processor
- Easy hole mounting or mating with standard electrical fittings
- Filtering allows very reliable operation in most environments

Applications and Uses

- Tank level measurement
- Bin level measurement
- Proximity zone detection
- Environments with acoustic and electrical noise
- Distance measuring
- Long range object detection
- Industrial sensor
- -40°C to +65°C (limited operation to +85°C)

About Ultrasonic Sensors

Our ultrasonic sensors are desired for use in air, non-contact object detection and ranging sensors that detect objects within a defined area. These sensors are not affected by the color or other visual characteristics of the detected object. Ultrasonic sensors use high frequency sound to detect and localize objects in a variety of environments. Ultrasonic sensors measure the time of flight for sound that has been transmitted to and reflected back from nearby objects. Based upon the time of flight, the sensor then outputs a range reading.

XL-MaxSonar-WR/WRC Pin Out

Pin 1- Leave open (or high) for serial output on the Pin 5 output. When Pin 1 is held low the Pin 5 output sends a pulse (instead of serial data), suitable for low noise chaining.

Pin 2- This pin outputs a pulse-width representation of range. To calculate the distance, use a scale factor of 58uS per cm. (MB7052, MB7060, MB7062, MB7066, MB7067, MB7068)

This pin outputs the analog voltage envelope of the acoustic waveform. For the MB7070 series and MB7092 sensors, this is a real-time always-active output (MB7070, MB7072, MB7076, MB7077, MB7078, MB7092)

Pin 3- **AN**-This pin outputs analog voltage with a scaling factor of (Vcc/1024) per cm. A supply of 5V yields ~4.9mV/cm., and 3.3V yields ~3.2mV/cm. Hardware limits the maximum reported range on this output to ~700 cm at 5V and ~600 cm at 3.3V. The output is buffered and corresponds to the most recent range data.

For the 10-meter sensors (MB7066, MB7076) Pin 3 outputs an analog voltage with a scaling of (Vcc/1024) per 2cm. A supply of 5V yields ~4.9mV/2cm., and 3.3V yields ~3.2mV/2cm. This Analog Voltage output steps in 2cm increments.

Pin 4- **RX**- This pin is internally pulled high. If Pin-4 is left unconnected or held high, the sensor will continually measure the range. If Pin-4 is held low the sensor will stop ranging. Bring high 20uS or more to command a range reading.

Pin 5- **TX**- When Pin 1 is open or held high, the Pin 5 output delivers asynchronous serial data in an RS232 format, except the voltages are 0-Vcc. The output is an ASCII capital "R", followed by ASCII character digits representing the range in centimeters up to a maximum of 765 (select models) or 1068 (select models), followed by a carriage return (ASCII 13). The baud rate is 9600, 8 bits, no parity, with one stop bit. Although the voltages of 0V to Vcc are outside the RS232 standard, most RS232 devices have sufficient margin to read the 0V to Vcc serial data. If standard voltage level RS232 is desired, invert, and connect an RS232 converter such as a MAX232.When Pin 1 is held low, the Pin 5 output sends a single pulse, suitable for low noise chaining (no serial data).

V+ Operates on 3V - 5.5V. The average (and peak) current draw for 3.3V operation is 2.1mA (50mA peak) and 5V operation is 3.4mA (100mA peak) respectively. Peak current is used during sonar pulse transmit.

GND-Return for the DC power supply. GND (& V+) must be ripple and noise free for best operation.

Auto Calibration

Each time before the XL-MaxSonar-WR takes a range reading it auto calibrates. The sensor then uses this data to range objects. If the temperature, humidity, or applied voltage changes during sensor operation, the sensor will continue to function normally. (The sensors do not apply compensation for the speed of sound change verses temperature to any range readings.) If the application requires temperature compensation please look at the HRXL-MaxSonar-WR sensor line.

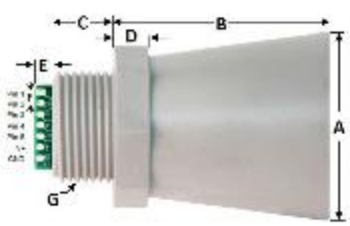
Supply Voltage Compensation

During power up, the XL-MaxSonar-WR sensor line will calibrate itself for the supply voltage. Additionally, the sensor will compensate if the supplied voltage gradually changes.

If the average voltage applied to the sensor changes faster than 0.5V per second, it is best to remove and reapply power to the sensor.

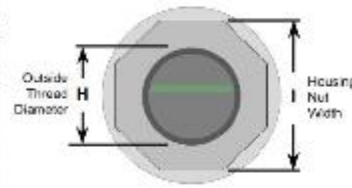
For best operation, the sensor requires noise free power. If the sensor is used with noise on the supplied power or ground, the accuracy of the readings may be affected. Typically, adding a 100uF capacitor at the sensor between the V+ and GND pins will correct most power related electrical noise issues.

XL-MaxSonar-WR Mechanical Dimensions

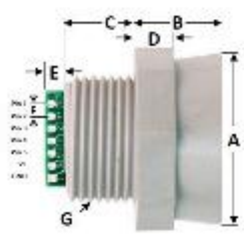


Values Are Nominal

A	1.72" dia	43.8 mm dia
B	2.00"	50.7 mm
C	0.58"	14.4 mm
D	0.31"	7.9 mm
E	0.23"	5.8 mm
F	0.1"	2.54 mm
G	3/4"-14 National Pipe Thread Straight	
H	1.032" dia	26.2 mm dia
I	1.37"	34.8 mm
	Weight	50 grams

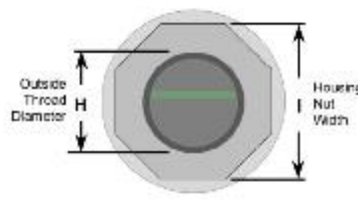


XL-MaxSonar-WRC Mechanical Dimensions



Values Are Nominal

A	34.7 mm dia.	1.37" dia.
B	17.9 mm	0.700"
C	14.4 mm	0.570"
D	7.9 mm	0.310"
E	5.8 mm	0.230"
F	2.54 mm	0.100"
G	3/4"-14 National Pipe Thread Straight	
H	26.2 mm dia.	1.032" dia.
I	34.8 mm	1.370"
	Weight	32 grams



Range "0" Location

The XL-MaxSonar-WR and XL-MaxSonar-WRC reports the range to distant targets starting from the front of the transducer as shown in the diagram below.

The range is measured from the front of the transducer.

Base Sensor (MB7060 and MB7070)

The MB7060 and MB7070 are the base models of the XL-MaxSonar-WR sensor line. These sensors are recommended for general purpose usage. All other sensors in this series are based off these sensor models. The additional features are mentioned in their respective sections below.

XL-MaxSonar-WR1 (MB7062 and MB7072)

The XL-MaxSonar-WR1 sensors feature a 3 reading stability filter that ranges to the first detectable target. This filter requires that 3 consecutive range readings are within 10cm of each other to be considered a valid range reading. If the range readings are outside 10cm, the sensor discards the range reading set and reports the last valid range reading. This sensor does not view maximum range as a valid range, and will not report 765 when no target is detected. If this sensor does not detect a target for 1 hour, the sensor will go into fail-safe and report 000.

XL-MaxSonar-WRL (MB7066 and MB7076)

The XL-MaxSonar-WRL will report a maximum distance of 10 meters for large targets.

XL-MaxSonar-WRM (MB7052 and MB7092)

The XL-MaxSonar-WRM sensors are equipped with filtering firmware that allows the sensor to ignore smaller targets and noise, and still report the target that gives the largest acoustic reflection. This sensor will also reject infrequent and random noise, even if the noise has a higher amplitude than the acoustic return from the target. If the largest target is removed from the field of view, the XL-MaxSonar-WRM will switch to the target that gives the next largest detectable return.

The XL-MaxSonar-WR sensors were designed for applications where users are concerned with ranging the distance to flat targets (such as water and fuel tanks). This filtering algorithm stands in contrast to the other XL-MaxSonar-WR sensors that are designed to report the distance to the first detectable target.

In general, the XL-MaxSonar-WR will select the largest target from its field of view and report its range. Even so, objects up close may provide significantly greater returns over distant objects. Users are encouraged to test the sensor in their application to verify usability.

When targets are of similar amplitude reflections, preference is gen to the closest target.

XL-MaxSonar-WRC (MB7067 and MB7077)

The XL-MaxSonar-WRC sensors are the compact version of the MB7060 and MB7070. These sensors have a maximum detection range of 645 cm, and will report 765 cm when there are not targets detectable. If size is a concern in your application, you may want to consider the MB72XX sensors at http://www.maxbotix.com/WRUC.

XL-MaxSonar-WRC1 (MB7068 and MB7078)

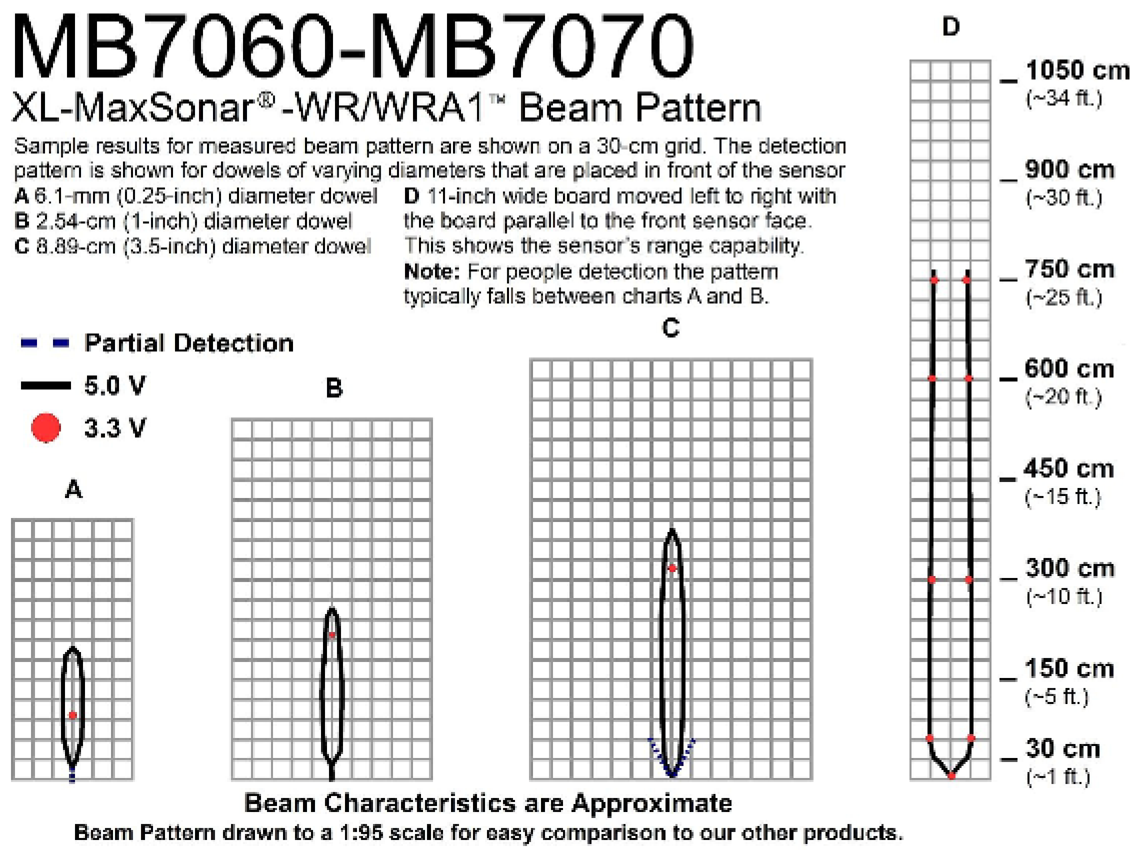
The XL-MaxSonar-WRC1 sensors are the compact version of the MB7062 and MB7072. These sensors have a maximum detection range of 645 cm. If size is a concern in your application, you may want to consider the MB72XX sensors at http://www.maxbotix.com/WRUC.

Sensor Minimum Distance - No Sensor Dead Zone

The XL-MaxSonar-WR sensors have a minimum reported distance of 20-cm (7.87 inches). However, the XL-MaxSonar-WR will range and report targets to the front sensor face. Large targets closer than 20-cm will typically range as 20-cm. For the XL-MaxSonar-WRC, objects between 3-cm and 20-cm will typically range as 20-cm.

MB7060-MB7070 XL-MaxSonar®-WR/WRA1™ Beam Pattern and Uses

The XL-MaxSonar-WR/WRA1 reports the range to the first detectable target. The MB7060 and MB7070 sensors are the most recommended XL-MaxSonar-WR sensor. This is a good starting place when unsure of which XL-MaxSonar-WR to use.



MB7060-MB7070 Features and Benefits

- Real-time calibration, and noise rejection for every ranging cycle
- Readings can occur up to every 100mS (10Hz)
- Analog voltage (Vcc/1024) / cm
- Precise narrow beam
- Continuously variable gain

MB7060-MB7070 Applications and Uses

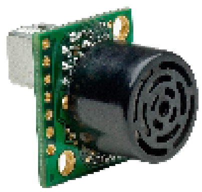
- Applications where a stability filter is not needed or desired
- Multi-Sensor Arrays
- Distance Measuring
- People Detection

Have the right MaxSonar for your application?
Check out our MaxSonar Product Lines

Indoor Use
(or protected environments)

1 mm Resolution
HRLV-MaxSonar-EZ

1 in Resolution
LV-MaxSonar-EZ
LV-ProxSonar-EZ



1 cm Resolution
XL-MaxSonar-EZ
XL-MaxSonar-AE
XL-MaxSonar-EZL
XL-MaxSonar-AEL
I2CXL-MaxSonar-EZ

1 mm Resolution
HRUSB-MaxSonar-EZ

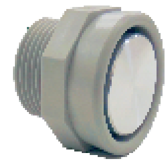
1in Resolution
USB-ProxSonar-EZ

Outdoor Use
(or rugged environments) IP67

1 mm Resolution
HRXL-MaxSonar-WR
HRXL-MaxSonar-WRS
HRXL-MaxSonar-WRT
HRXL-MaxSonar-WRM
HRXL-MaxSonar-WRMT
HRXL-MaxSonar-WRL
HRXL-MaxSonar-WRLT
HRXL-MaxSonar-WRLS
HRXL-MaxSonar-WRLST

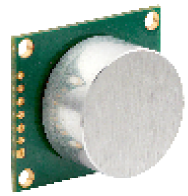
1 cm Resolution
XL-MaxSonar-WR
XL-MaxSonar-WRL
XL-MaxSonar-WRA
XL-MaxSonar-WRLA
I2CXL-MaxSonar-WR

F-Option Available for all WR models. For additional protection when necessary in hazardous



1 mm Resolution
HRXL-MaxSonar-WRC
HRXL-MaxSonar-WRCT

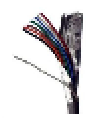
1 cm Resolution
XL-MaxSonar-WRC
XL-MaxSonar-WRCA
I2CXL-MaxSonar-WRC



1 cm Resolution
UCXL-MaxSonar-WR
UCXL-MaxSonar-WRC

Accessories-More information available online

MB7954 - Shielded Cable

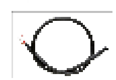


The MaxSonar Connection Wire is used to reduce interference caused by electrical noise on the lines. This cable is a great solution to use when running the sensors at a long distance or in an area with a lot of EMI and electrical noise.

MB7950 - XL-MaxSonar-WR Mounting Hardware

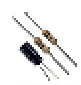
The MB7950 Mounting Hardware is selected for use with our outdoor ultrasonic sensors. The mounting hardware includes a steel lock nut and two O-ring (Buna-N and Neoprene) each optimal for different applications.

MB7955 / MB7956 / MB7957 / MB7958 / MB7972 - HR-MaxTemp



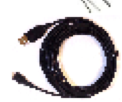
The HR-MaxTemp is an optional accessory for the HR-MaxSonar. The HR-MaxTemp connects to the HR-MaxSonar for automatic temperature compensation without self heating.

MB7961 - Power Supply Filter



The power supply filter is recommended for applications with unclean power or electrical noise.

MB7962 / MB7963 / MB7964 / MB7965 - Micro-B USB Connection Cable



The MB7962, MB7963, MB7964, and MB7965 Micro-B USB cables are USB2.0 compliant and backwards compatible with USB 1.0 standards. Varying lengths.

MB7973 CE Compliance Widget

The MB7973 adds protection for the CE requirement for Lightning/Surge IEC61000-4-5

B.4 Datasheet of Battery Lir2450

PowerStream

PowerStream Li-ion Button Cell Lir2450 Data Sheet

1. Preface

2. Description and Model

2.1 Description		Rechargeable Lithium-ion button battery
2.2 Model		LiR2450
3. Specification		
3.1 Capacity	Nominal	100mAh
	Typical	120mAh
3.2 Charging Voltage		4.20V
3.3 Nominal Voltage		3.7V at 0.2C mA
3.4 Standard Charging Method		Constant current:50mA Constant voltage 4.20V
3.5 Cut-off Discharge Voltage		3.00V
3.6 Max.Discharge Current		200mA
3.7 Max.Charge Current		100mA
3.8 Cycle Life		>500 cycles at 0.2C mA discharge
3.9 Ambient Temperature		
for Standard Charge		0 to 45 degrees C
for Discharge		-20 to + 60 degrees C
3.10 Storage		
for within the temperature		-20 ~ 60 C
for within the humidity		75%
3.11 Energy Density		
Wh/L		~200
Wh/Kg		~90
3.12 Weight of Bare Cell		~5.5g
3.13 Charge State Internal Impedance		<400mOhms

4.Appearance

Appearance shall be free from any remarkable scratch,flaws, rust, discoloration or electrolyte leakage(visible or by smell)

5.Standard Test condition

5.1 Environment Conditions

Unless otherwise specified,all test stated in this Product Specification are conducted within the temperature 15~25 C and the humidity 45~85%RH.

http://www.powerstream.com/licoin.htm

PowerStream Li-ion Button Cell Lir2450 Data Sheet

5.2 Test Equipment

(1) Impedance meter

The impedance meter with AC 1kHz should be used

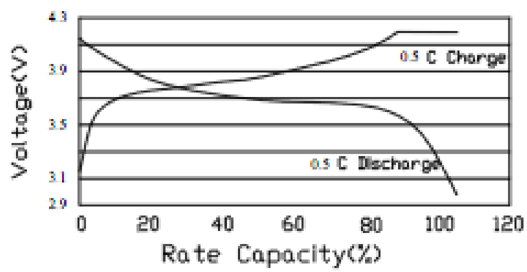
6.Test Procedure and Its Standard

Item	Measureing Procedure	Standard
6.1 Appearance	Visual	No Defect and Leak
6.2 Dimension	Caliper	As item 8
6.3 Weight	Scale	As item 3.12
6.4 Maximum Charge Current	CCCV(Constant Current Constant Voltage)	100mA
6.5 Full charge	CCCV	CC-0.2CmA CV- 4.2V total 8h
6.6 Open Circuit Voltage	Within 1hr after full charge,measure Open circuit voltage	>4.15V
6.7 Internal Impedance	Measure the battery with 1kHz AC	<400mOhms
6.8 Discharge Capacity	Within 1hr after full charge,discharge until final discharge,at 0.2C mA and measure the capacity	>100mAh
6.9 Maximum Discharge Current	Until final discharge voltage	200 mA
6.10 Charge/Discharge Cycle Life	Charge:CCCV,CC- 0.2CmA,CV- 4.2V total 8h Discharge:0.2CmA to 3.00V,This charge/discharge shall be repeated 500 times	Discharge capacity should be >70% of item 6.8
6.11 Leakage Proof	After full charging,the battery shall be stored at 40±2 degrees C, humidity 80.5 %for 21 days	No leakage should be observed by visual inspection
6.12 Temperature Characteristics	1)After full charge at 20±5C ,stand at -20±2C for 18h,then discharge at 0.2C mA and measure the capacity 2)After full charge at 20±5 C ,stand at 55±2C for 2hrs ,then discharge at 1C mA and measure the capacity	Discharge capacity should be>60% of item 6.8 and no abnormality on its appearance and stucture
6.13 Charge Retention	After full charging,stand at 20±5C for 28 days,measure the discharge capacity according to item 6.8	Discharge capacity should be>85% of item 6.8

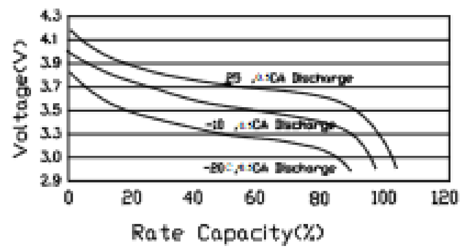
PowerStream

PowerStream Li-ion Button Cell Lir2450 Data Sheet

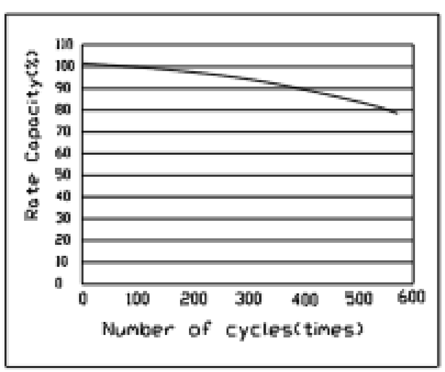
7.1 Charge/Discharge Characteristics
Charge:CC/CV 4.2V, 50mA(0.5C), total 5h
Discharge:50mA(0.5C) Cut-off at 3.00V
Temperature:25 C



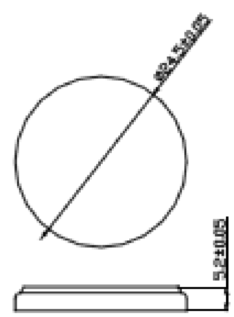
7.3 Temperature Characteristics
Charge: CC/CV 4.2V 0.5CA,total 5h
Discharge:0.5CA,Cut-off at 3.00V



7.2 Charge/Discharge Cycle Life
Charge:CC/CV 4.2V 0.2CA, total 8h
Discharge:0.2CA,Cut-off at 3.00V
Temperature:25 C



8. Dimension(Bare cell) mm



B.6 The regulator of MCP33

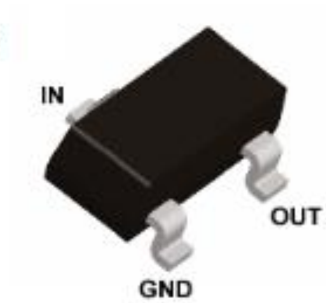
MCP33

≤1uA 超低功耗低压差稳压器

Microcontrol

O特性

- 最大输出电流 160mA (不超过封装最大可承受功率损耗)
- 输出电压级别: 3.0/3.3V
- 高准确度:输出电压 ±2%
- 极低静态功耗: ≤1.0uA@VOUT=3.3V
- 输入稳定性:典型值 0.2%/V
- 低压差需求: 0.4V/160mA (VOUT=3.3V)
- 小体积封装: SOT23 (150mW 损耗可承受)
- 工作温度范围: -30~+80℃



型号	封装	输出电压
MCP33	SOT-23	3.3V
MCP33-30	SOT-23	3.0V

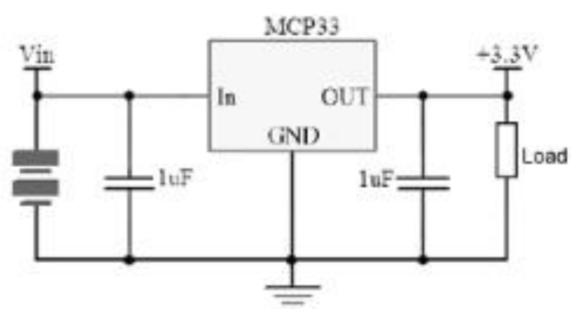
O功能描述

MCP33 是一个特定制、高性能的三端引脚稳压器。透过激光制程技术使得输出电压十分准确和高精度保证。应用了精良的 CMOS 工艺，将静态耗电量低至 1uA 或更低，达到了业界顶级水平。适合应用于电池供电的设备以及极低待机电量消耗的需求场合。

O应用

- 手持式电池供电设备、微能量供电装置。
- 低功耗无线采集器装置、物联网无线装置、气体及电力监控装置、水热气表。
- 手持式医疗仪器仪表、手持抄表装置。
- 特适用于 MSP430、STM8L、STM32L、EFM32 等低功耗单片机系统的电源应用。
- 应用领域：电力、地质、水利、海洋、气象、工控、农业、环境监测自动化等。

O典型应用电路



MCP33 应用电路非常简单易用。只需在输入和输出端并联一个 1uF 电容就可使用。由于采用 SOT-23 封装和使用外围元件少的特点，使得占用 PCB 面积和物理空间极小。这使用户可减少产品的生产成本。再加上极小静态电流性能和低价格的优势；是低功耗设计中的首选电源方案。

O真实最大范围

参数	符号	最大值	单位
输入电压	Vin	12	V
输出电流	Iout	500	mA
输出电压	Vout	Vss-0.3~Vin+0.3	V
连续总功耗	Pd	150	mW
工作环境温度	Topr	-30~+80	℃
贮藏温度	Tstg	-40~+125	℃
峰值回流焊温度		260	℃

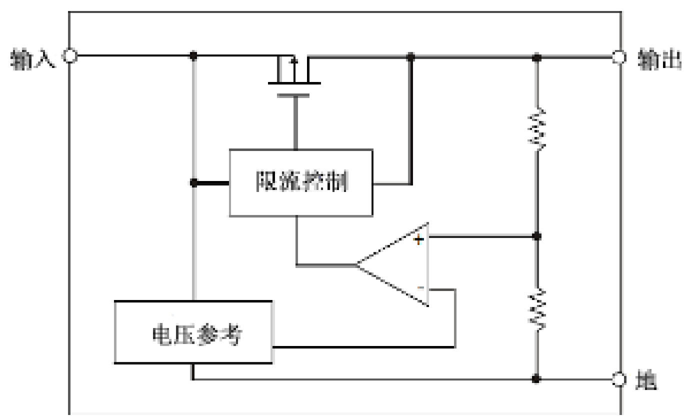
O电气特征(Ta=25℃, Vin-Vout+1V, 除非另有说明)

参数	符号	条件	最小	典型	最大	单位	电路
输出电压	Vout	Iout=40mA, Vin=Vout+1V	-2.0		+2.0	%	1
性线控制	$\frac{\Delta Vout}{\Delta Vin \cdot Vout}$	Iout=40mA, Vout+1V ≤Vin≤10.0V(注 1)		0.2	0.3	%/V	
负载控制	$\frac{\Delta Vout}{\Delta Iout \cdot Vout}$	Vin=Vout+1V, 1mA≤ Iout≤80mA(注 1)		0.02	0.03	%/mA	
供应电流	Iss	Vin=Vout+1V		1.0	2.9	uA	2
差压 Vout>2.5	Vd	Iout=160mA(注 2)		400	700	mV	1

注 1：负载和性线调整的测量是在固定结温下由低周期脉冲测试的。

注 2：低压差的测试是以输出电压下降到标称电压的 2%时测得。

O结构图



O典型工作特性

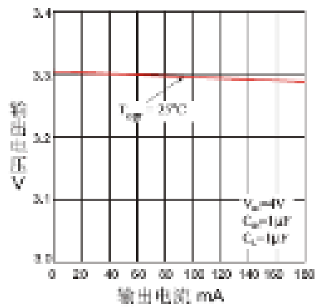


图1：输出电压对输出电流

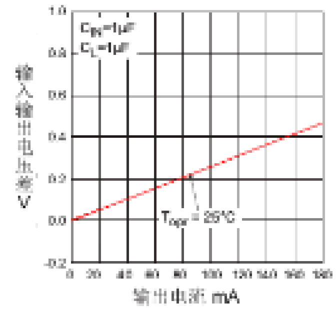


图2：输出输入电压差对输出电流

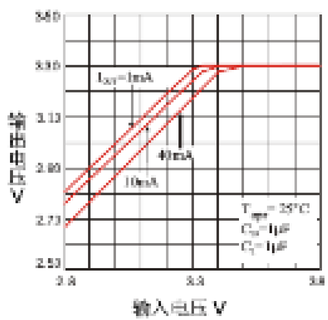


图3：输出电压对输入电压

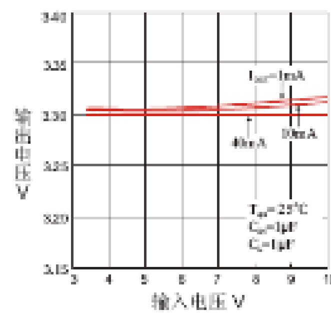


图4：输出电压对输入电压

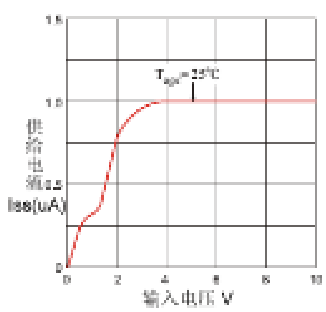


图5：供给电流对输入电压

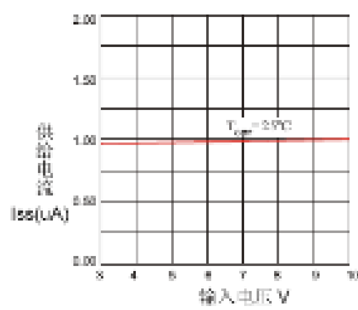


图6：供给电流对输入电压

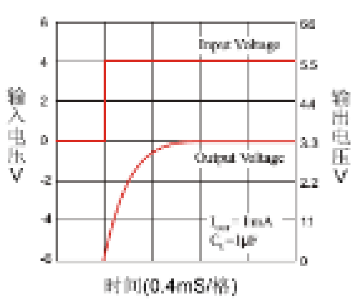


图7：输入瞬态响应

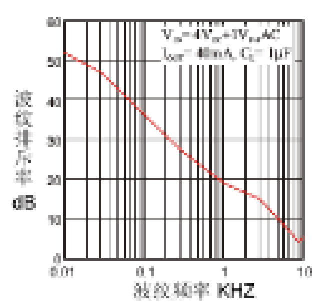
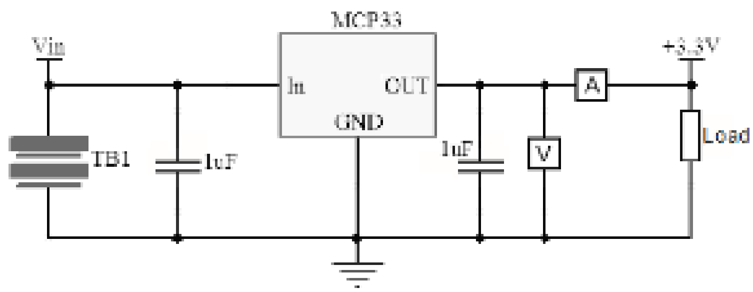
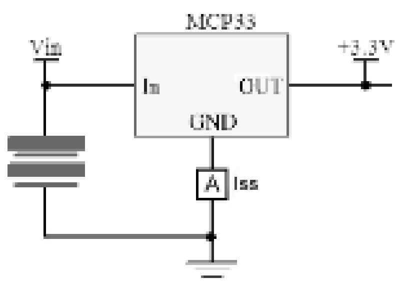


图8：波纹排斥率

○测试电路


MCP33
Vin
In
OUT
GND
+3.3V
A
Load
TB1
1uF
1uF
V

电路 1


MCP33
Vin
In
OUT
GND
+3.3V
A
Iss

电路 2

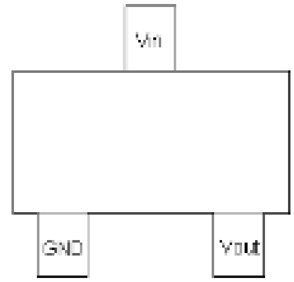
○ 应用测评参考

负载电流(mA) / 输入电压(V)	空载	5	10	15	17.2	20	30	40	60	100	160
2	2	1.98									
3	3	2.98									
3.27	3.27	3.25									
3.28	3.28	3.26									
3.29	3.28	3.27	3.26								
3.3	3.28	3.28	3.27				3.22				
3.31	3.28	3.28	3.28	3.27			3.23				
3.35	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.26			
3.4	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.2		
3.47	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.23	3.09
3.5	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.27	3.12
3.6	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.27	3.22
3.63	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.27	3.26
3.7	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.27	3.26
3.8	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.27	3.26
4	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27	3.27	3.26
5	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27	3.27		
6	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27			
7	3.28	3.28	3.28	3.28	3.28	3.28	3.27	3.27			
8	3.28	3.28	3.28	3.28	3.28	3.28	3.27				
9	3.28	3.28	3.28	3.28	3.28	3.28					
10	3.28	3.28	3.28	3.28	3.28	3.28					
11	3.28	3.28	3.28	3.28	3.28						
12	3.28	3.28	3.28	3.28	3.28						
最小压差	0V	0V	10mV	50mV	0.1V	0.1V	0.1V	0.1V	0.17V	0.2V	0.37V
最高可用电压	12	12	12	12	12	10.8	8.3	7	5.8	4.8	4.2

由上表可见，MCP33 最适合于单锂离子/锂聚合物可充电池的场合，此时压差最小，效率最高，可输出电流也最大。测试过程中 MCP33 在可用电压和负载时 Iq 可维持在~0.5uA。

○引脚定义

符号	功能描述
GND	接地端
Vin	电压输入端
Vout	电压输出端

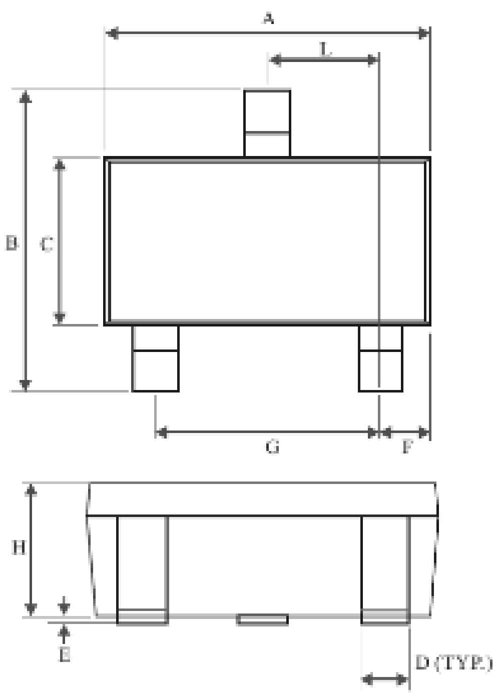


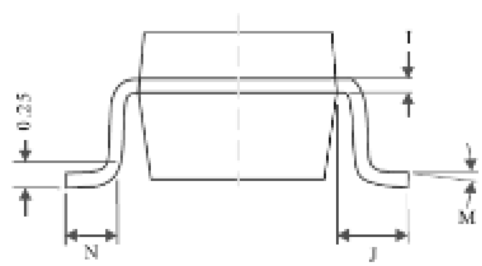
○产品包装

器件型号	封装	卷盘尺寸	带子宽度	数量	备注
MCP33/xx	SOT-23	直径 7 寸	8mm	3000	符合 RoHS 环保

产品中文全称:超低功耗低压差稳压器

○体积规格





符号	单位:mm	
	Min	Max
A	2.70	3.10
B	2.10	2.95
C	1.20	1.70
D	0.30	0.50
E	0	0.15
F	0.45	0.55
N	0.30	0.60
G	2.10 REF.	
H	0.70	1.30
I	0.10	0.20
J	0.54 REF.	
L	0.95 REF.	
M	0°	10°