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- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks

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Registration	November 5, 2010
Camera ready	November 5, 2010

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- Complex Systems

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The Design of a Wireless Monitoring System for Unattended Environmental Applications

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Abstract: This paper presents the design, implementation and testing of a dual channels wireless sensing system that can be used for unattended environmental applications. The main tasks of this work are to measure temperature and pressure data of waste water line, the data is then stored and transmitted remotely. Two months of historical data is required. The transmitter is expected to have calibration facility using a suitable buttons and a graphical user interface. A suitable enclosure is required that protects the electronic equipment from the entire extremes of weather conditions and mechanical damage. The power consumption of the system is not expected to consume more than 0.5 A/hr over a six month period in order to suit the load ratings of both the battery and the solar cell.

Keywords: Wireless sensing, Unattended environment, Temperature and pressure measurement.

1. Introduction

Due to an increase in requirements for data collection in industrial sites to conform with resource management acts, there has been a rise in the need to have a wireless monitoring systems located remotely or in harsh conditions. The solution lies in the concept of a wireless transmitter. The proposed transmitter in this paper is characterized by low power consumption circuitry based on smart embedded systems technology. The unit is powered from a 12 Volt sealed lead acid battery constantly charged by a 4 W solar panel. The battery voltage is continuously measured to facilitate appropriate charge control.

The data from the two analogue signals is received in pure analogue form, the Atmel microcontroller then converts it to digital format. Using a C language based AVR studio development environment, the data is scaled and then sent to a SD card which further transfers the data to a GSM modem for transmission. The GSM modem is connected to the printed circuit board using a serial connection. The time stamped data is then sent to a modem and the Windows hyperlink terminal program is used to store the data and then further transfers it to a text file for printing. Fig. 1 below shows the overview of the entire system. Table 1 provides a summary of the tasks and constraints which the system is subject to.

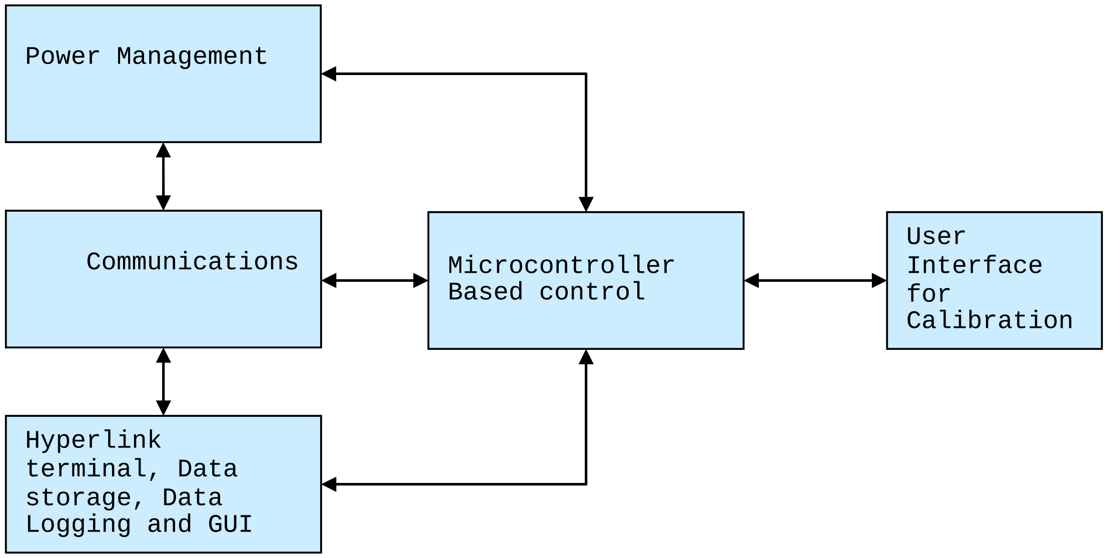

Fig. 1. Overview of the proposed system.

Table 1. Overall System Tasks and Constraints.

Tasks	Constraints
Measure temperature	
Measure pressure	
Store 2 months historical data	Accurate data
Provide calibration facility for sensors	User friendly data acquisition
Robust enclosure	Low cost
Circuit not to draw more than 500ma continuously for an hour	6 months continuous operation without battery checks

A lot of works have been carried out previously by various individuals or organizations with a noble idea of transmitting real-time data from sensors by wireless transmission. One of these works [1] is a case study of a product called the LP 300, manufactured by a company called T-BOX. The LP300 is a wireless, low power controller design used in remote non-attended monitoring and control applications. It combines monitoring, data logging, controlling, alarming, SMS, Email and FTP Internet functions into a portable and robust IP66 enclosure. LP-300 Remote Terminal Unit (RTU) can be used as a standalone station or as an integral part of a complete short and long range wireless control network. The LP300 consumes low power, manipulates wireless technology and is capable of high-speed data transmission. The transmitter has radio and GSM data transmission plus superb immunity to interference. In addition to its standard monitoring and control functions, the LP-300 can be connected to a wide range of sensors such as tank level, soil moisture, soil temperature, pollution, water flow, water pressure, water and sewage, weather station, frost and many other environmental related sensors. The controls circuitry consists a low- power 16 Bit CPU capable of executing 7.4 MIPS. It has an embedded Real Time clock, a battery backed 256 K Flash memory and a 128 K static memory. The communications are provided through three built-in communications ports COM1: RS232 dedicated for programming and diagnostics. COM2 is mainly for Radio modem board and COM3is for GSM or Radio modem board Protocol: MODBUS RTU (or other protocols). The radio Frequencies covered are: multi channel 922 MHz or 2.4 GHz, license free RF rate: 9600 baud. Pre-selected Radio Transmitter power: 130 mW (922 MHz), 50 mW (2.4 GHz) Radio Receiver sensitivity: -110 db (922 MHz), -107 db (2.4 GHz) and an option of an external antenna. The inputs and output options consist of 8 self powered 20 Volt Max digital outputs, 8 digital inputs at 30 Volts maximum and four 10 Bit analogue inputs. The power requirements are 12 VDC from a 1.3 A/hr-to-7.0 A/hr battery. The total power consumption is 3 mW minimum if CPU is in sleep mode. The transmitter has a programmable battery charger for optimum conservation and also has a built-in temperature regulated charging [1].

Looking at other wireless systems, [2] designed a wireless probe system (WPS) to monitor moisture content of wood during the drying process in real-time. The WPSs installed at various locations of the world had self-powered radio transmitter to send data to a receiver at a central station using unlicensed ISM bands of 900 MHz in North America or 433 MHz in Europe. The experiment proved that the WPS greatly improved the accuracy and efficiency of the drying processes and reduced the cost of the data acquisition system.

Agricultural facilities, such as greenhouses and animal-feeding facilities, including HVAC, lighting control, energy management, access control, structural monitoring and fire/security have been using the WPS technology. Standards for wired HVAC control systems have been established for a long time. Standards for wireless-based systems are currently under development [3]. While [4] presented the design of a remote health-monitoring system for cattle that incorporated various sensors, including a GPS unit, a pulse oximeter, a core body temperature sensor, an electronic belt, a respiration transducer and an ambient temperature transducer. The system communicated wirelessly with a base station via Bluetooth telemetry. In [5] a study has been reported on a “smart”, comprehensive animal management system. Each animal is fed with a wireless sensor and a mote, which can provide accurate measurements of the location and health-related information of the animal wirelessly. Haapala [6] tested the performance of electronic identification tags and various readers on cattle under extremely cold temperature in Finland. Brown-Brandl et al. in [7] tested a short-range telemetry system for measuring core body temperature in poultry, beef and dairy cattle. Temperature transmitters were implanted into the body of animals. A CorTempTM miniaturized ambulatory logger received the temperature data wirelessly. Test results showed good accuracy, resolution, and response time for temperature measurement. Kononoff et al. [8] used a wireless automatic system to record the chewing and ruminating behaviours to study the dietary factors affecting normal rumen function of dairy cows. Butler et al. [9] developed a “moving virtual fence” algorithm for herding cows. Each animal in the herd is given a smart collar consisting of a GPS, a PDA, a radio unit (WLAN) and a sound amplifier. The animal’s location was determined using the GPS and was verified through a measurement of proximity of the cow relative to the fence boundary. When approaching the perimeter, the animal was presented with a sound stimulus, which drove the animal away from the fence.

Wireless sensor technology is still at its early development stage. Applications of wireless sensors in agriculture and food industry are still rare. Generally a data collection point receives and stores data from all wireless measurement sensors. Information is then sent to a secure web server. Data can also be stored directly on the gateway if an Internet connection is not available. A more extensive review on the application of wireless sensors in agriculture has been reported in [10].

Despite the fact that wireless sensor technology has great potential, many have not recognized the technology especially here in New Zealand. The development of this technology has been supported by enthusiastic industry alliances. Adoption of wireless sensor technology has not been as fast as one would imagine.

2. Background

2.1. Telemetry Systems Overview

Telemetry is a highly automated communications technique with the help of which measurements and data collection are done at remote locations and transmitted for monitoring. This technique commonly uses wireless transmission. The most important uses of telemetry include weather-data collection, monitoring power generation plants and keeping track of manned and unmanned space flights.

A telemetering system typically consists of a transducer as an input device, a transmission medium in the form of wired lines or radio waves, signal processing devices, and devices for recording or displaying data. The transducer converts a physical quantity such as temperature, pressure or vibration into a corresponding electrical signal, which is then transmitted over a distance for the purpose of measurement and recording.

The original systems of telemetry that were introduced in the beginning of the 20th Century used to be supervisory in nature, since they would be used to monitor the distribution of electric power. In the earliest system that was introduced in Chicago in 1912, a central monitoring center would use telephone lines to receive operational data from far away power plants. Other fields began to implement such systems, with improvements being made over the decades that followed.

The use of aerospace telemetry dates back to the 1930s, when balloon-borne equipment would be used to gather data about the prevailing atmospheric conditions. This form of telemetry was extended for use in observatory satellites in the 1950s. Satellites put to use the telemetry principle for several applications that include recording weather conditions, observing space phenomena and remote sensing. Such satellites have increased in their complexity since, and there are several hundred of them that orbit the Earth today.

Telemetry applications in the fields of scientific research are constantly being developed today. One such area is biomedicine, in which crucial data about the internal organs of a patient is transmitted by devices that are surgically implanted inside that body. Another exciting field is that of oceanography, which involves remotely gathering data related to aspects under the sea such as the chemical composition of undersea rocks or their seismic behavior.

Most activities related to healthy crops and good yields depend on timely availability of weather and soil data. Therefore, wireless weather stations play a major role in disease prevention and precision irrigation. These stations transmit major parameters needed for good decisions to a base station: air temperature and relative humidity, precipitation and leaf wetness for disease prediction models, solar radiation and wind speed to calculate evapotranspiration, and sometimes also soil moisture, crucial to understand the progress of water into soil and roots for irrigation decisions.

Because local micro-climates can vary significantly, such data needs to come from right within the crop. Monitoring stations usually transmit data back by terrestrial radio though occasionally satellite systems are used. Solar power is often employed to make the station independent from local infrastructure [11].

2.2. Power Management Overview

Data acquisition devises (DAQ) are designed to provide wireless connectivity for wide range of applications, some application require both wire both wireless data connection and wireless power connection. Power requirements vary from one application to another depending on the component selection and sizing. In most applications batteries are used as a backup power source, but when they are used as the main power, solar panels are used for charging.

The most important aspect to consider is how long the application must run on batteries. This consideration then determines the size and type of battery to use. The other factors to consider are capacity measured in (Ah), energy density measured in (wH/kg) and voltage level. A battery with a higher energy density such as the Li ion, will weigh less than a battery with a lower energy density such as the NiMH for the same capacity.

There various means of storing energy in a battery, the most popular technologies in use today are, alkaline, lithium and nickel metal hydride. Alkaline batteries are usually used for single use or disposable applications. These batteries are usually cheap and can have high energy densities. The downside of these batteries is that they produce very low voltages in the ranges of 1.2 to 1.5 Volts. Nickel metal hydride batteries are the most commonly used rechargeable batteries. These batteries are known to maintain a constant voltage over time and are cheap.

The disadvantage of this chemistry is that they have a short shelf life and a self discharge rate of 1 to 2 percent per day when stored in room temperature.

Lithium ion battery technology is the other available option, these batteries have a low self discharge rate of approximately 5 percent per month, they have a high energy density, and they are lighter in weight as compared to NiMH batteries of similar capacity. Lithium ion batteries produce 3.6 to 3.7 Volts per cell, they are the most expensive and are dangerous if punctured or damaged.

Lead-acid batteries were developed in the late 1800s, they were the first commercial practical batteries. These batteries have remained popular because they are relatively inexpensive to produce. The most widely known uses of lead-acid batteries are as automobile batteries.

Lead-acid batteries remain popular because they can produce high or low currents over a wide range of temperatures, they have good shelf life and life cycles, and they are relatively inexpensive to manufacture. Lead-acid batteries are usually rechargeable. Lead-acid batteries come in all manner of shapes and sizes, from household batteries to large batteries for use in submarines. The most noticeable Short comings of lead-acid batteries are their relatively heavy weight and their falling voltage profile during discharge. Lead-acid batteries can be further categorized as sealed or flooded.

Flooded types of batteries lose water produced from electrolysis to the air. In sealed batteries, however, the generated oxygen combines chemically with the lead and then the hydrogen at the negative electrode, and then again with reactive agents in the electrolyte, to recreate water. The net result is no significant loss of water from the cell [12].

2.3. Wireless Communications Overview

Over the years there has been an increase in new communication device due to the reduction in cost of components. Both wireless and wired networks are becoming more reliable and faster.

Wireless technologies have been under rapid development during recent years. Types of wireless technologies being developed range from simple IrDA that uses infrared light for short-range, point-to-point communications, to wireless personal area network (WPAN) for short range, point-to multi-point communications, such as Bluetooth and ZigBee, to mid-range, multi-hop wireless local area network (WLAN), to long-distance cellular phone systems, such as GSM/GPRS and CDMA.

Most people feel the strong impact of wireless technology mainly due to the astonishing growth of cell-phone market. However, not many people have realized that the demand of bandwidth for wireless, interpersonal communications, such as cellular phones, will soon become a minority share of the total available bandwidth, perhaps only 3% by the end of the decade [13].

The main task of the system is to use low power devices. Low-power Wireless Solutions are based on three components; a micro controller, GSM modem, and software. Atmel offers a well-balanced blend of micro controllers, transceivers and firmware for wireless applications. With certified IEEE 802.15.4, ZigBee, and 6LoWPAN standards-based technologies the design will address the unique needs of low-cost, low-power, low data rate wireless control and sensor network applications. Atmel's high performance RF transceivers offer industry best range and robustness adding cutting edge technology and performance from the low power micro controllers.

To reduce the costs on infrastructure we are using a GSM network to communicate. We will be sending the data to the hyperlink terminal using a GSM modem either by SMS or by a GPRS connection. The data from the sensors is read into a micro controller and this goes on to store the data in a way that will not require much power consumption. The data is then sent to the modem for transmission through the GSM network.

In this work a G900/1800 WAVECOM GSM modem was used. The GSM/GPRS Modem comes with a serial interface through which the modem can be controlled using AT command interface. An antenna and a power adapter are provided. The modes of functionality may be as follows:
• Voice calls;
• SMS;
• GSM Data calls;
• GPRS.

Voice calls are not an application area to be targeted. In future if interfaces like a microphone and speaker are provided for some applications then this can be considered.

SMS is an area where the modem can be used to provide Pre-stored SMS transmission. These SMS can be transmitted on certain trigger events or interrupts in a microcontroller based control system. The SMS can also be used in areas where small text information has to be sent. The transmitter can be an automation system or machines like vending machines, collection machines or applications like positioning systems where the navigator keeps on sending SMS at particular time intervals. This mode can be a solution where GSM data call or GPRS services are not available, this is the preferred mode of operation for this system.

GSM Data calls can be made using this modem as well. Data calls can be made to a normal PSTN modem/phone line also (even received). Data calls are basically made to send/receive data streams between two units either PC's or embedded devices. The advantage of Data calls over SMS is that both parties are capable of sending/receiving data through their terminals.

Some notable disadvantages of data calls are that the data call service doesn't come with a normal SIM which is purchased at shops but has to be requested with the service provider (Vodafone or Telecom). Upon activation of data/fax service you are provided with two separate numbers i.e. the Data call number and the Fax service number. Data calls are established using Circuit Switched data connections. Right now the speed at which data can be transmitted is 9.6 kbps. The modem supports speeds up to 14.4 kbps but the provider give a maximum data rate of 9.6 kbps during GSM data call. Technologies like HSCSD (high Speed Circuit Switched Data) will improve drastically the data rates, but still in pipeline.

Typical applications for the data call mode of transmission can be found in devices that have communication on serial port either on PC or in the embedded environment, also useful in devices that want to communicate with a remote server for data transfer, this capability of data transfer can help in reducing processing requirements of the device. The basic aim is to provide a wireless solution keeping the existing firmware intact.

The clients firmware continues to work without any modifications (no changes in the existing software required), GSM data calls can be a good solution where data has to be transmitted from a hand-held device to a central server. The interface on two sides can be between PC's as well as embedded devices. Calls can be established by the terminals at either side to start data calls. The Modem remains transparent during data transfer after the call is established. Call establishment needs to be automated in case of embedded terminals. GSM converter can be an option where intelligence of establishing calls has to be put in case of embedded devices.

The other mode of data transfer mode is Dial-Up Networks Using GSM Data Calls. Dial up networking is a utility available with Windows through a person can dial the Data call number of this modem from any PC and share the file system on either PC's. This can be a good utility where both terminals are PC based. Sharing the file system remotely enables monitoring of devices remotely. Thus the modem can act as a piece of device which acts as a spy in the system. Can be a good debugging utility wherein a person can configure/monitor a remote PC based system and even rectify it. Some companies do sell their products with a GSM modem inside it just for this handy feature which allows them to configure the machines sitting anywhere in the world. Since the connection can have upper layer protocols like TCP/IP in this connection it becomes more reliable and useful.

The GSM modem can be used to make a GPRS connection for internet connectivity of devices handheld or wireless embedded devises. In this application, the PC/Embedded device dials the Service Provider and then the data is routed through the ISP. GPRS is basically Packet Oriented service. Protocols like TCP/IP are inherent characteristics in GPRS, we talk in terms of IP addresses here not phone numbers the implementation is more useful where PC's want to communicate over GPRS, the data transfer is done from embedded devices too but with reduced features. Since there is either on monthly flat rates or amount of data transfer taking place GPRS is a cheaper option as compared to GSM data call. The data rate rates in GPRS can go up to 40 kbps. Typical applications are found where mobile devices want to upload data to a central server and also in monitoring devices that are continuously logged on to the server.

2.4. Data Storage and Testing

Archiving sensor readings for off-line data mining and analyzing is essential. The reliable offloading of sensor logs to databases in the wired, powered infrastructure is an essential capability. The intention is to interactively "drill-down" and explore individual sensors, or a subset of sensors, in near real-time complement log-based studies. In this mode of operation, the timely delivery of fresh sensor data is key. Lastly, nodal data summaries and periodic health-and-status monitoring requires timely delivery [14].

In field devise control monitoring the ultimate goal is data collection; sampling rates and precision of measurements are often dictated by external specifications. For every sensor we can bind the cost of taking a single sample. By analyzing the requirements we can place a bound on the energy spent on data acquisition. We trade the cost of data processing and compression against the cost of data transmission.

We can estimate the energy required by data collection by analyzing data collected from analogue inputs. By considering an experiment where a microcontroller collects an analogue sample every minute. The sample is represented as an 8-bit integer, but it contains a 10-bit ADC reading. The control scheme performs well when applied to a long run of data [14].

2.5. Overview of Microcontroller Based Control System

Nowadays, a microcontroller includes not only memory and processor, but non-volatile memory and interfaces such as ADCs, UART, SPI, counters and timers. In this way, it can interact with sensors and communication devices such as short-range radio or modems. There are many types of microcontrollers, ranging from 4 to 32 bits, varying the number of timers, bits of ADC and power consumption.

The EM6603 from EM microelectronic, is a 4-bit, is ultra-low-power microcontroller but its computational power is also very limited, it draws 0.3 micro Amps in sleep mode and only 4 micro Amps in the run mode. Although Atmel AVR microcontrollers are commonly used, there are better choices for sensor node. Efficient wireless applications require high performance and low power components. With Atmel's transceivers you get the undisputed best link budget in the industry today. This means the best sensitivity and longest range for your products [15].

PIC controllers from Microchip are used for educational purposes, but they are not applicable where energy is crucial. The 8051 controllers are available from various manufacturers, but have low performance, being used only for historical reasons.

The DragonBall MC9328MXl is widely used in security applications because they are 16-bit and have a Bluetooth Accelerator radio interface. They also have an inbuilt time processing unit (TPU), a co-processor unit that seems to be able to perform various real-time control tasks (like sampling a pin). The shortcomings are performance (only 2.7 MIPS), no integrated memory or flash, relatively large footprint (TQFP 144, TQFP IOO), not ultra-low-power.

Microcontroller MSP430F149 from Texas instruments is a good option for sensor nodes since it is 16-bit 8 MIPS, providing more computational power, and also ultra-low power. It is equipped with a full set of analogue and digital processors. It has embedded debugging and in-system flash programming through a standard JTAG interface, and is supported by a wide range of development tools including GCC and IAR Embedded Workbench.

The ARM family has floating-point computational capabilities, being a possibility for devices demanding more computational power, such as a gateway or a robust sensor node, which can be the head of hierarchical wireless sensor network cluster. One common example is the processor module Intel StrongAnn SA1 100 embedded controller. The SA1 100 is a general-purpose, 32-bit RlSC microprocessor based on the ARM architecture that is rated the most efficient processor (in MIPSIWatt). The processor offers a 16KB instruction cache, an 8KB data cache, serial 110 and JTAG interface all combined in a single chip. Program and data storage are provided by IMB SRAM and 4MA of bootable flash memory.

Connection with the sensor modules is easily achieved using the 4-wire SPI interface. The processor has three states: normal, idle and sleep that can be controlled to reduce power consumption [15].

For this project the Amega64L microcontroller has been chosen mainly for its powerful instructions, low power capability and a lot of support literature is available in [16]. The microcontroller is characterized by 130 powerful instructions, 132 x 8 general purpose registers, 16 Million instructions per second execution time, 2 kb of EEPROM, 2 × 8-bit Timer/Counters, 53 I/O lines and an operating voltage between 2.7 and 5.5 V.

2.6. Real Time Clock (RTC)

In this system the real time clock is used to provide time stamped data at the user interface. This functionality of the circuit is essential because most quality control procedures require a specific time stamp to accompany any process data.

There are a wide range of real time clocks available, with different functions. Many real time clocks only keep time and upload this time to the system. Other real time clocks have features like programmable alarms, multiple power supply connections and trickle charging. The selection of real time clock is important as the different features available allow for different implementations of the data logging system. In our system, the real time clock functionality is embedded in the micro controller on-chip software.

Programmable alarms for pressure and temperature allow the RTC to send a signal to the microcontroller on certain times. This feature allows for the design of a system where the real time clock controls the timing of data requests and data acquisition through interrupts generated when a data requisition flag is activated. The selection of a real time clock is important as the different features available allow for different implementations of the data logging system.

To enable correct and reliable functionality a separate crystal oscillator is provided to give the required clock signals at 4 MHz. When the microcontroller goes into sleep mode the real time clock wakes it up when it wants to initiate a data transfer.

3. Implementation

3.1. Communications Using the G900/1800 GSM Modem

Data is sent in text format from the GSM modem to a dial up modem which then uses hyperlink terminal to store the data on the PC. The G900/1800 GSM MODEM consists of 12 volt power supply, a SIM card slot, an optional phone line connection and a communications cable. There are two ways of sending and receiving SMS messages: by text mode and by PDU (protocol description unit) mode. The text mode is just an encoding of the bit stream represented by the PDU mode.

To edit AT commands while connected to the modem the online character command +++ preceded by the specific command was used. The following lines of commands were use to send and access data from the GSM modem:

****

AT+CSMS?
+CSMS: 1,1,0
OK // enable gsm modem
AT+CMGR=2
+CMGR: 0,68 <64 byte pdu>
OK// read data from SD card
AT+CMGW=128<CR><128 byte pdu><CTRL-Z>
+CMGW: 2   // send a high bit to SD card to confirm that data has been received

+CME ERROR: 0 //GSM Modem failure.
+CMS ERROR: 322 // SD card Memory full.
AT+CBC?
+CBC: 0,50
OK // gsm modem battery ok
AT+CMGF = 1 //Set TEXT mode
AT+CSMS = 0 //Check if modem supports SMS commands
AT+CMGS=23 //Send message, 23 octets (excluding the two initial zeros) values of temperature first
****

3.2. Atmega64L Microcontroller

The Atmega64L microcontroller was chosen mainly because it is compatibility with a voltage range of 2.7 to 5.5 Volts, coupled with low power consumption and the availability of six programmable sleep modes. Fig. 2 shows Atmega64L microcontroller interfacing peripherals.

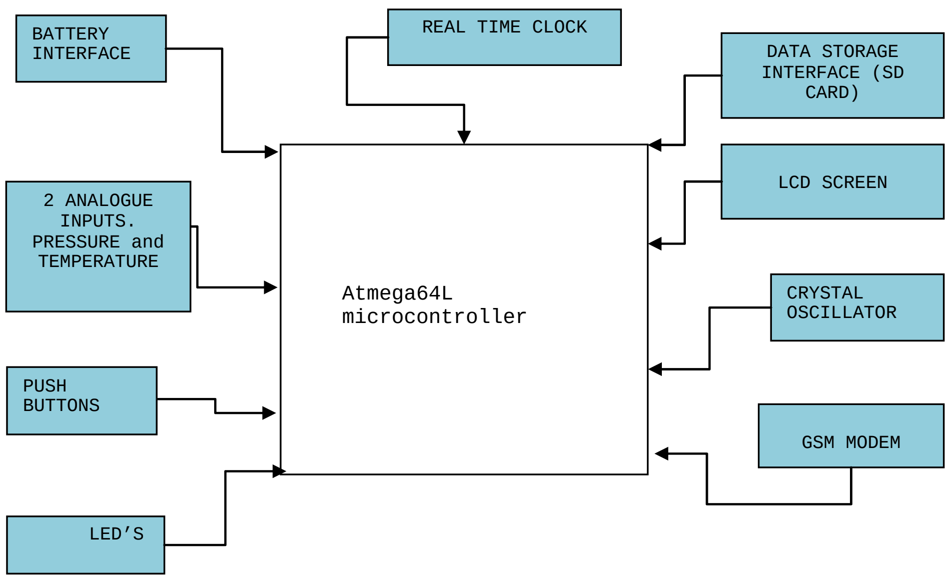

Fig. 2. Atmel Micro-controller Interfacing peripherals.

3.3. Control Strategy for Analogue Inputs (Temperature and Pressure)

The analogue sensors use 12 Volts in a 4-20 mA current loop, 50 ohm resistors were used to drop the voltage down to the required 2.56 Volts as stated by the Data sheets. The power for the sensors is derived directly from the battery terminals. Fig. 3 shows the connection of the analogue inputs.

3.4. Sampling Rate

The sampling rate refers to period between each pair of temperature and pressure measurements. The decision on the device’s sampling rate was taken in conjunction with the operators who would use such a product, as the sampling rate is an important criterion during data acquisition. One of the tasks of the implementation was to select a sampling rate which achieved a balance between power consumption and data integrity. Using an iterative process based on individual power consumptions, it was found that an hourly sampling rate would provide the optimum balance.

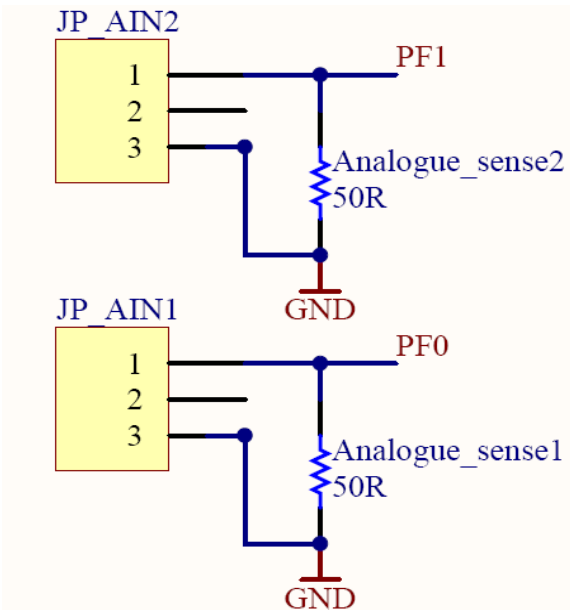

Fig. 3. Analogue connections.

3.5. Data Storage

Data storage refers to the process in which data is stored in order to provide 6 months of time stamped measurements. There are two types of data used in the system, time stamp data and measurement data i.e. temperature and pressure data. Selection of an optimum data storage process would not only reduce power consumption but would also minimize the total memory required to store 6months of time stamped data. Memory is an expensive commodity and its efficient usage will minimize the system costs.

The temperature and pressure sensors provide data in a 10 bit format. However, this caters for a range of -50°C to 50°C, which is suitable for the specified range of the parameters. Since the efficient use of memory space is integral to the design of the device it was decided that this 10 bit format will be reduced. This is possible because the raw data output of the sensor is already scaled up by 25. Thus to obtain the actual temperature it is required that the output of the sensor be divided by 25. However, division in the microcontroller requires a large amount of processor power which is not very efficient as well as the fact that division will result in floating point numbers, requiring more than 10 bits of space and thus defeating the point of reduction. Instead a shift operation will be implemented that will involve a shift left of 5 bits resulting in a final data length of 4 bits, as bit 10 is ignored since the temperature of the unit measures a maximum of 50 °C. This results in a resolution of 1.28 °C and a worst case accuracy of 1.4 °C at 25.4 °C. The pressure data is received by the microcontroller in an 8 bit format. Similarly to the temperature data this is reduced to 5 bits which results in resolution of 2 % and a worst case error of 4 %, which is within specifications.

Thus during every hourly cycle 10 bits of data would be saved. Over a period of 6 months (180 days) with an hourly sampling rate, 6588 bytes of memory would be required. Although this requirement is high and compression methods exist to reduce this number it has been decided not to do so. The reasons for this decision are as follows: the sampling rate is low by design decision and further degradation of this may reduce the integrity of the data. Use of compression methods often result in a memory requirement which varies depending on the researched environment. In order to guarantee 6 months of operation we would have to implement a worst case approximation of the memory requirement. This would nullify the effect of the reduction process. Further, a variable memory system would not allow for the simplistic method of time stamping.

PSEUDO CODE

- Run hourly Interrupt……
- Start conversion
- If sample size is 1 ……then store data in Buffer
- Else Download Pressure and Temperature values and wait for conversion to complete
- Increment sample size

CODE SNIPPET

```
*****************************************************************

Void ADCstart (void)
{
        ADCSRA |= (1<<ADSC);      //start conversion

        While (!(ADCSRA & (1<<ADIF)));  //wait for conversion to complete
}
*****************************************************************
```

3.6. Calibration Switches and Status LED's

The following switches and LED's are illustrated in Fig. 4:
SW1 ------ Start Calibration
SW2 ------ Increase Value
SW3 ------ Decrease Value
SW4 ------ Accept Calibration
LED1 ----- Flashes when analogue input 1 is open circuited
LED2 ----- Flashes when analogue input 2 is open circuited
LED3 ----- Flashes when The SD card data is full
LED4 ----- Flashes when there is a loss of communication with the GSM Modem

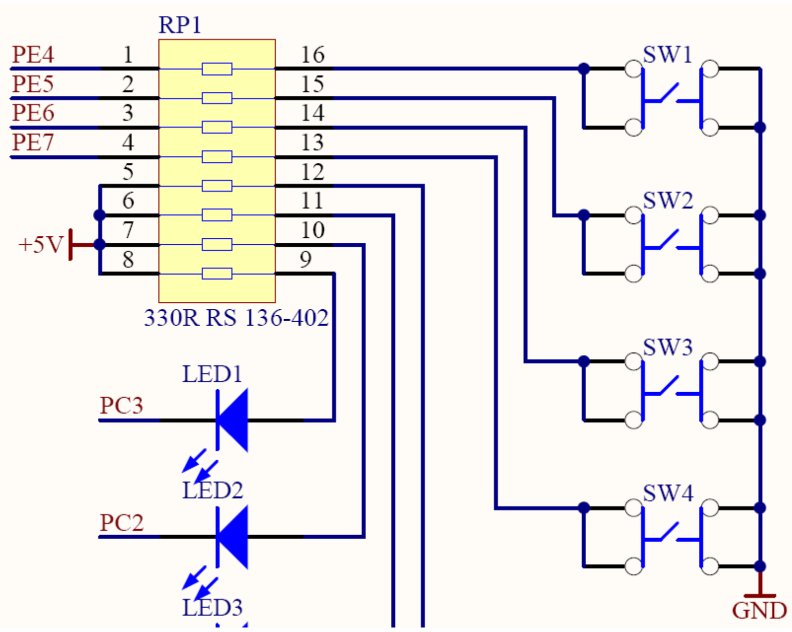

Fig. 4. Push button switches and LED's.

3.7. Coding RS232

The system has two serial connections, one is for connection with the PC and the other is used a s the communications port for the GSM Modem. The computer interface has been supplied only for future use.

PSEUDO CODE
- Initialize USART
- Calculate Baud rate
- Enable receive and transmit bits
- Set frame format

CODE SNIPPET:

```
*****************************************************************
#define FOSC 8000000// Clock Speed
#define BAUD 9600
#define MYUBRR FOSC/16/BAUD-1
void main( void )
{
...
USART_Init ( MYUBRR );
.../
}
void USART_Init( unsigned int ubrr )
{
/* Set baud rate */
UBRRnH = (unsigned char)(ubrr>>8);
UBRRnL = (unsigned char)ubrr;
/* Enable receiver and transmitter */
UCSRnB = (1<<RXENn)|(1<<TXENn);
/* Set frame format: 8data, 2stop bit */
UCSRnC = (1<<USBSn)|(3<<UCSZn0);
}
---------------------------------------------------------------------
```

3.8. LCD Screen

The type of LCD screen used for the PCB is a 16 character X 2 lines screen from Computronics Pvt Ltd. The mode of operation is 8 Bit mode, which has been chosen to achieve faster data transfer as compared to the 4 Bit mode.

The LCD is used as a GUI to display the temperature and pressure values when the switch SW1 (calibration start) is pressed, otherwise it stays off.

CODE SNIPPET

```
*****************************************************************
#define     RS      16      // RS Signal
#define  RW        32       // RW Signal
#define ENABLE          64          // ENABLE Signal
#define LCD_PORT PORTD              // LCD data port
#define LCD_DDR DDRD                // LCD port data direction register
```

```
#define LCD_PIN PIND                          // LCD port input pins
void LCD_sendstring (char *str) {             // sends the whole string to LCD
 while ((*str != 0) && (*str != 10)) LCD_sendchar (*str++);
}
void LCD_sendconststring (char *str) {         // sends the whole string to LCD
 char value;
 char nr = 0;
 value = PRG_RDB(&str[nr]);
 while ((value != 0) && (value != 10)) {
 LCD_sendchar (value);
 nr++;
 value = PRG_RDB(&str[nr]);
 }
;
}
*****************************************************************
```

3.9. State Based Control

The microcontroller will be used to control the use of the functions described in the previous section. Since the system will only sample data hourly the microcontroller can remain in a power down mode for the majority of the system operation. The power down mode is a low power mode where all unused modules of the microcontroller are shut down thereby saving power. However, in this mode the external interrupts are enabled allowing the microcontroller to enter active mode on command. Thus the microcontroller will operate in 3 modes; initialization, active mode, and power down mode. In order to use the microcontroller in a power down mode an entirely interrupt driven system is 24 Hourly, thus allowing the microcontroller to carry out the tasks required to achieve an hourly sampling rate.

The initialization process will be carried out each time the system is powered up. It involves the setting of all ports and the required interrupts as well as setting all counters to the desired initial condition. On completion of this process the device enters power down mode. The device will enter active mode hourly and execute the interrupt routine. In this routine all the required tasks are performed.

Functions for the requesting and download of temperature and humidity are then called. Once this is achieved a counter is incremented which indicates that the tasks of sampling temperature and humidity data have been completed. This counter is then checked to determine if its value is equal to 43933. If so, then 6 months of samples has been completed and the system is disabled, otherwise normal operations commence. This is done in order to prevent the overwriting of stored data in EEPROM as the power supply is designed to operate for periods in excess of 6 months, in order to ensure the desired system requirements.

The manipulation and storage of data only takes place after two samples have been taken. Thus if the sample counter is exactly divisible by two the process of manipulating and storage of the temperature and Pressure data will commence. On completion of this task the sample counter is tested for divisibility by 8. This test allows for the process of time stamp synchronization to take place every 8 hours. Once all processes are completed the system will also return to power down mode. Fig. 5 shows the overview of the system broken down into different functions as part of the complete system state machine. Table 2 provides definition of the various states.

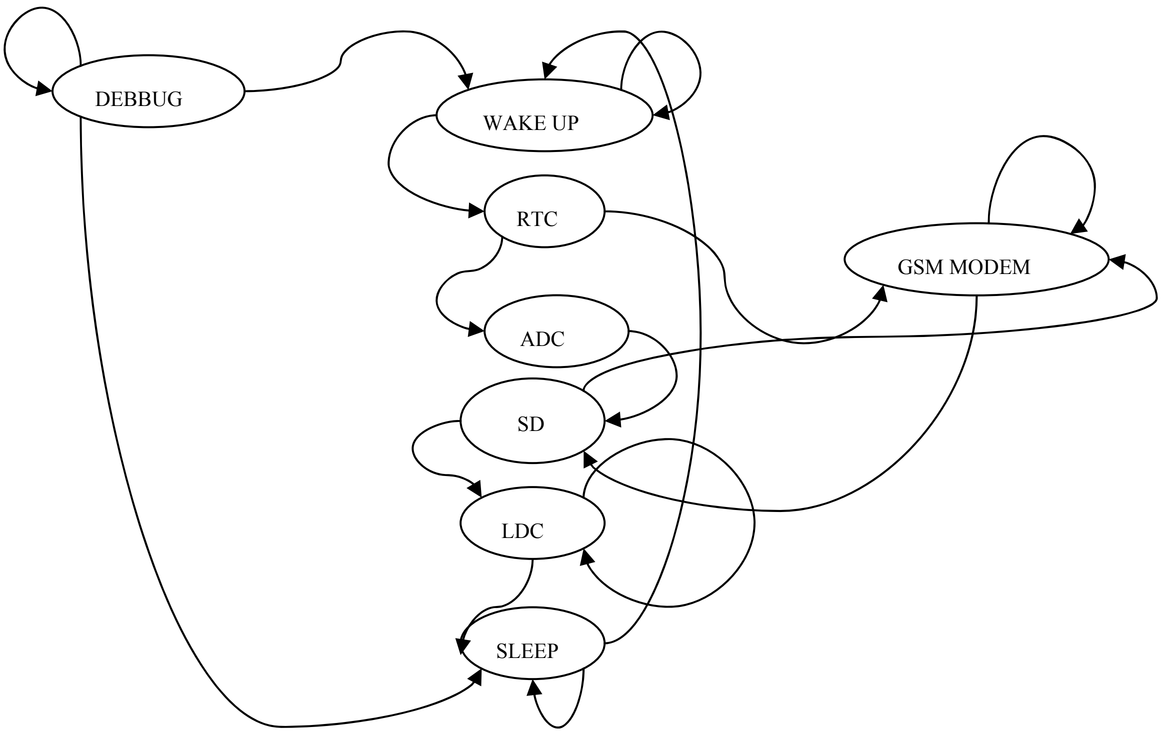

Fig. 5. State based control scheme for the GSM based transmitter.

Table 2. Definition of the various states.

SLEEP	WAKEUP	ADC	GSM	RTC	DEBUG	LCD	SD
Keep RTC clock running	PRESS WAKEUP SWITCH	RUN THE ADC ROUTINE	CHECK FOR COMMS WITH SD CARD, CLEAR TRANSMIT BUFFER	RUN ISR CONTINUOUSLY	ENABLE DEBUGG PIN	TURN ON BACKLIGHT	CONTINUOUSLY GET DATA FROM DATA REGISTER
Acquire data from ADC every 200sec	Turn on LCD AND ENABLE ALL I/O	UPDATE ANALOGUE DATA	ENABLE RECEIVE MODE	UPDATE ALL CLOCKS AND CURRENT TIME		ENABLE TO RECEIVE	CHECK COMMS WITH GSM MODEM
	ENABLE CALIBRATION ROUTINE	CHECK FOR SENSOR CALIBRATION	WAIT FOR 10SEC		DISABLE DEBUGG PIN	ENABLE TO TRANSMIT	ENABLE RECEIVE MODE
	CHECK GSM MODEM COMMS		ENABLE TO TRANSMITFFER, PLACE DATA IN TRANSMIT BUFFER			TURN OFF BACKLIGHT	ENABLE RECEIVE MODE

4. Power Management Control Scheme

In this system Sealed Lead Acid batteries are used. These batteries are popular in applications where cost is more important than space and weight, typically preferred as backup batteries for UPS and alarm-systems. The SLA batteries are charged using constant voltage, with a current limiter to avoid overheating in the initial stage of the charging process. SLA batteries can be charged infinitely, as long at the cell voltage never exceeds the manufacturer specifications (typically 2.2 V). The battery terminal voltage is monitored using an analogue signal going straight to the microcontroller's ADC input. Charging is provided by a 35 W solar cell.

To reduce power consumption, the microcontroller enters sleep mode, in which all On-chip modules are disabled except for the RTC. The microcontroller typically consumes less than 4 µA in this mode. The device will wake-up on the Timer Overflow Interrupt. The updates of the timer variables are performed during the active period. Then the AVR re-enters the sleep mode until the next Timer Overflow occurs. Below is a code snippet of achieving this task.

```
********************************************************************
_SEI(); /* set global interrupt enable */
_SLEEP(); /* enter sleep, waiting for interrupt */
/* note: will enter sleep before any pending interrupt(s) */
********************************************************************
```

5. Testing

The testing process is shown in an overview in Fig. 6.

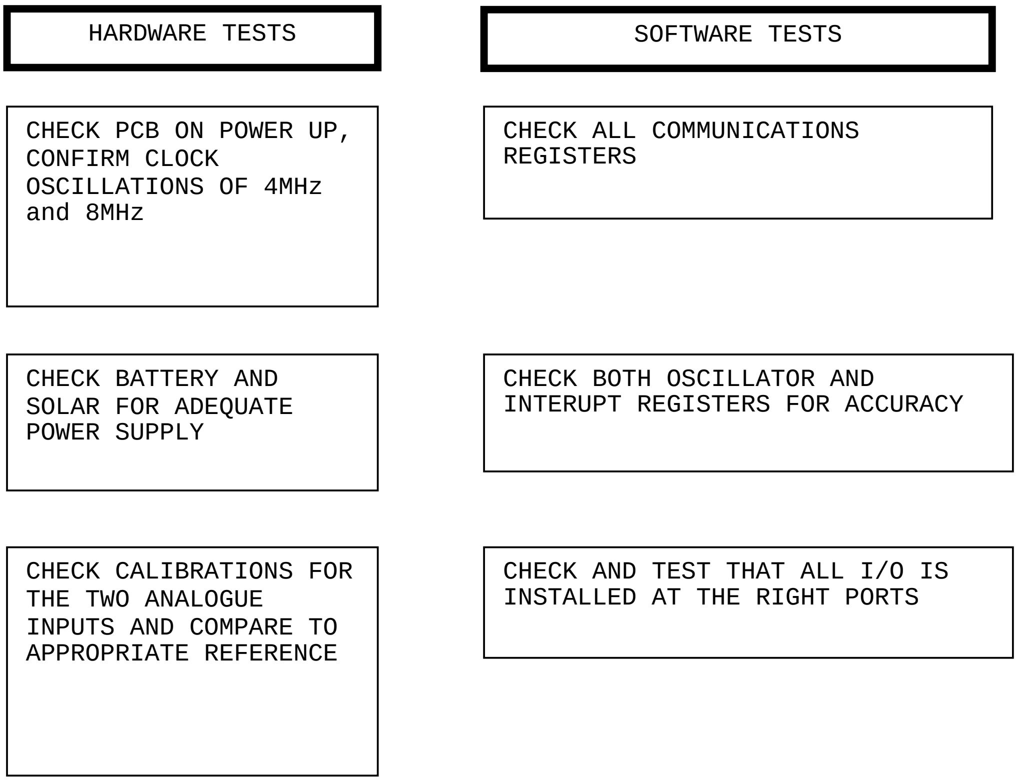

Fig. 6. Overview of required tests.

The debugging software used for this system is AVR studio. AVR Studio enables the user to fully control execution of programs on the Atmega In-Circuit Emulator or on the built-in AVR Instruction Set Simulator. The software creates an ease in debugging the code by the allowing the user to check or edit function files while online with the microcontroller.

Power failure tests were also done on the printed circuit board. The complete PCB of the transmitter, with all the components are labeled, is shown in Fig. 7. The battery and the solar cell were disconnected in order to check if the button battery can continue supplying sufficient power to the microcontroller and the RTC.

Testing of the complete transmitter circuit has shown that the system works according to the required specification. Fig. 8 shows the tested system while Fig. 9 shows a model of the complete monitoring system.

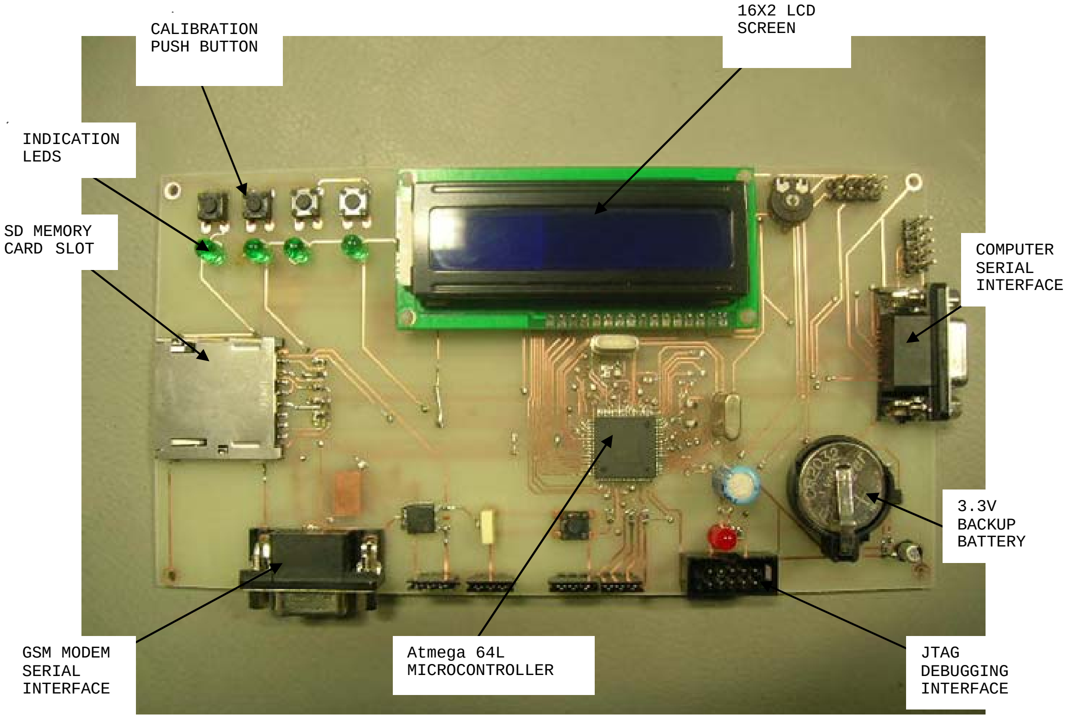

Fig. 7. PCB for the complete transmitter circuit.

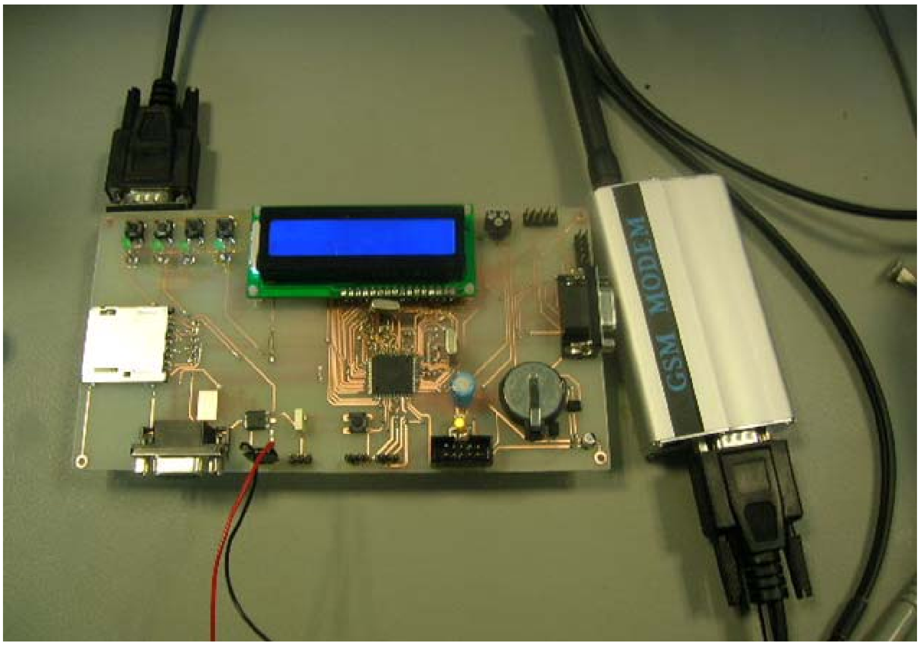

Fig. 8. The working system.

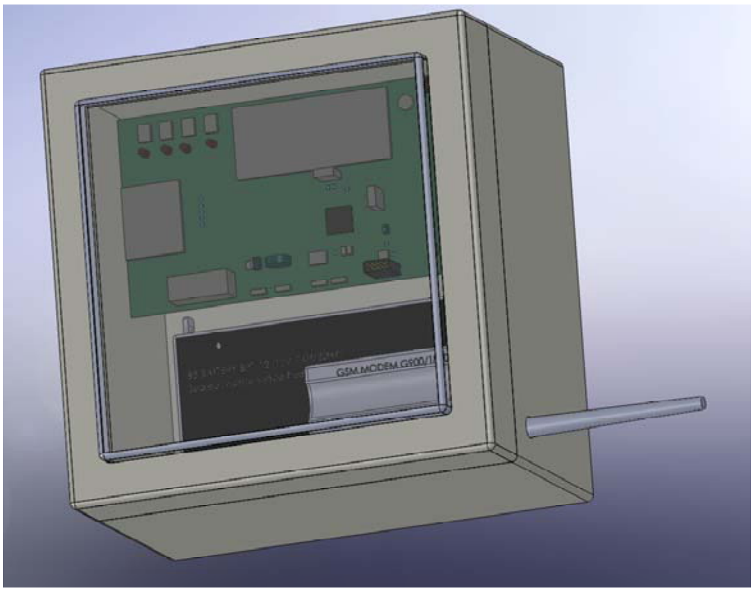

Fig. 9. Model of the complete system.

6. Conclusions

This paper presented the integrated hardware and software design of a dual channel analogue wireless monitoring system. The hardware design reflects the special demands for applying wireless sensing units in unattended environmental applications. The combination of the selected wireless modem and microcontroller, two of the major parts of the dual transmitter, served a balanced need between low power consumption and long-distance communication. To ensure high fidelity and flexibility in data collection, an embedded high-resolution analogue-to-digital converter is included within the control system. Software design of the system explored the state machine concepts to implement a robust communication link between the microcontroller and the user interface. A working PCB for the complete transmitter circuit has been produced and testing revealed the system has preformed according to the required specifications.

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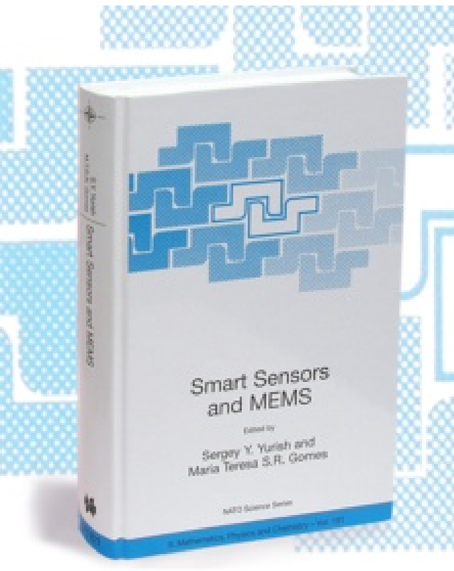

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