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Research Article

Development of a Low Cost Wireless Temperature Monitoring System for Industrial & Research Application

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Abstract

The proposed paper focus on developing a low cost and easy handling temperature monitoring system, based on radio frequency for wireless data transmission. The wireless system module architecture consists of a power supply, a sensor and a main node system mainly based on wireless radio frequency (RF) technology. The benefits of this system are low cost, high range of temperature sensing, management of data, response to temperature alert, and accuracy of required documentation. The system uses a low-power and gives high-performance. With this utilization, it is possible to design a cost efficient, reliable and accurate system which is perfectly suitable for monitor parameters in harsh environment as required in the outdoor solar application. This device has been tested in a solar NABL lab (Indore, India), for temperature monitoring and compares data with the calibrated monitoring system used in the laboratory. The collected data were used to evaluate the system workability. Data has been taken for the whole year. Also data shows that the system can measure and monitor the temperature at given distance ranges.

Keywords: *Wireless sensor network; Radio Frequency Identification; thermocouple; temperature monitoring; solar equipment.*

1. Introduction

Temperature sensors have a wide array of applications, from household electric appliances to industrial process controls. Many other physical measurements, such as, humidity, pressure, flow, *etc.*, often times depend on the ambient temperature and require simultaneous temperature measurement to improve their accuracy. There are many different types of commercially available temperature sensors (Childs *et al.*, 2000; Magison, 2001), among them the most popular temperature sensors include thermocouples (Kinzie and Rubin, 1973), resistive temperature detectors (RTD) (Baker, 1998; Kim *et al.*, 2001), thermistors (McGee, 1998) and semiconductor temperature sensors (Szajda *et al.*, 1996). Non-contact temperature measurement can be achieved using infra-red thermometers or pyrometers (DeWitt, 1988). Various optical sensors for high temperature applications have been developed, including remote pyrometers (radiation thermometers) (Dils, 1983; Adams, 1992), thermal expansion thermometers (Xiao, 2003), fluorescence thermometers (Zhang *et al.*, 1992; Wickersheim and Sun, 1987), and thermometers based on optical scatterings (Murphy and Farmer, 1992). Fast response temperature measurement can be performed using techniques such as Coherent Anti-Stokes Spectroscopy, Laser-Induced Fluorescence and Infrared Pyrometry (Kee and Blair, 1994; Hung *et al.*, 2005). However, these are expensive, difficult to calibrate and maintain and are therefore not used for wide-scale deployment outside the laboratory (Seidel *et al.*, 1990). The traditional system adopts wired way wiring, which makes the system complex and expensive. It has been estimated that typical wiring cost in industrial installations is US$ 130–650 per meter and adopting wireless technology would eliminate 20–80% of this cost (Sensors Magazine, 2004). For an office building, wiring costs (labour plus material) make up approximately 45% of the installed cost for a new building and nearly 75% of the installed cost for a retrofit application (Yang *et al.*, 2005). In 2002, the estimated cost to the signal cable ranged from $ 2.20, per meter for new construction, to U.S. $ 7.19 for existing buildings (Kintner *et al.*, 2002). Another example of the costs involved in wired systems can be found in a recent structural monitoring system, where up to 75% of total testing time and 25% of system cost involves the installation of signal wire (Akyildiz *et al.*, 2002). Performance evaluation is a problem due to large wired connection, large number of wires creates problem for data transmission, greatly affected by environmental conditions also if the wired get suddenly broken up data collection gets hampered. Using different thermocouples (Duff & Towey, 2010), it is possible to measure temperatures a very wide range

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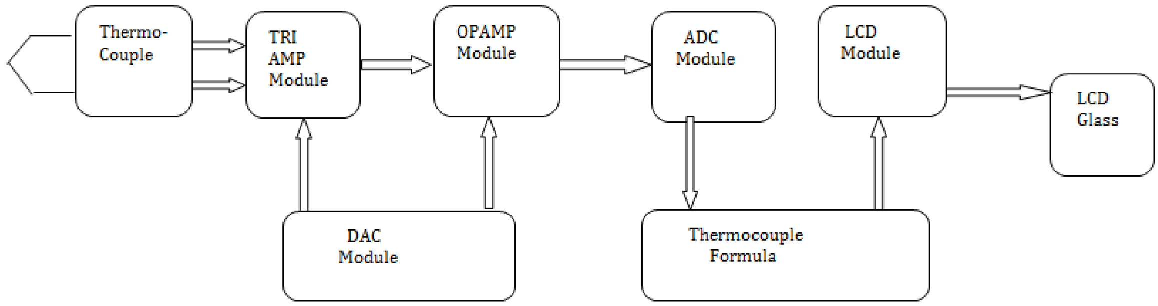

Figure 1 Block diagram of the wireless temperature monitoring system

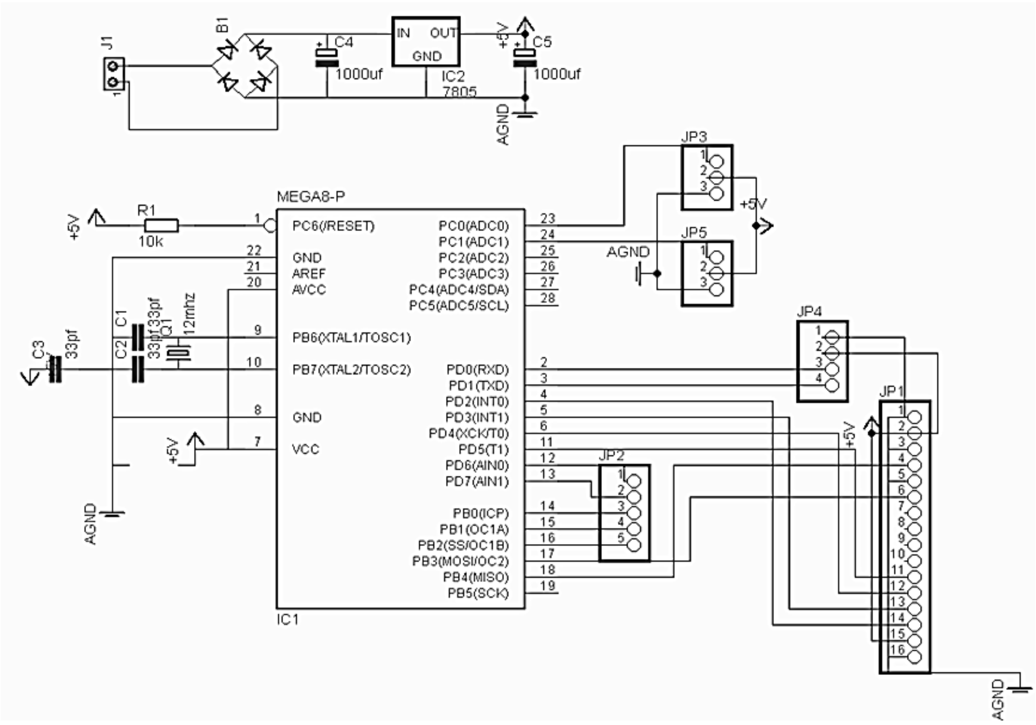

Figure 2 Schematics circuit diagram of wireless sensor network

of temperatures, from below -200 ^{0}C to above 1200 ^{0}C. Time response is about (< 6 sec) very less In this paper, an effort has been made to develop a low cost wireless temperature monitoring sensor system with RF communication module by using k type thermocouple for a location(Indore, India) consisting of composite climate. Data has been taken for the whole year.

2. Methods and materials

With the view to develop sophisticated electronic instrument for temperature monitoring, it is proposed design for the Wireless Sensors Network. The block diagram of sensor node, at a glance, is depicted in Figure 1.

2.1 Wireless temperature monitoring

The heart of wireless sensor network (WSN) is the sensor node. AVR Atmega328 and the detail designed are described. This is a system which is basically used to monitoring the temperature parameter. It comprises k type thermocouple, microcontroller, display unit and power supply section. Moreover to ensure the wireless communication the RF module is employed. Through the design tool called Easily Applicable Graphical Layout Editor (EAGLE), we made a connection scheme in order to realize the connection over the test bed.

2.2 Thermocouple

Most practical temperature ranges, from cryogenics to jet-engine exhaust, can be served using thermocouples. Due to their low cost and ease of use, thermocouples are popular means for measuring temperature. In this prototype we use K type thermocouple having temperature range of -270 ^{0}C to 1370 ^{0}C by combination of Chromel (alloy of Nickel -Chromium) and Alumel (alloy of Nickel-Aluminium).

2.3 AVR Atmega328

The microcontroller AVR Atmega328 is used as the computing device. It is easy available, low cost for easy programming of the microcontroller, and having better

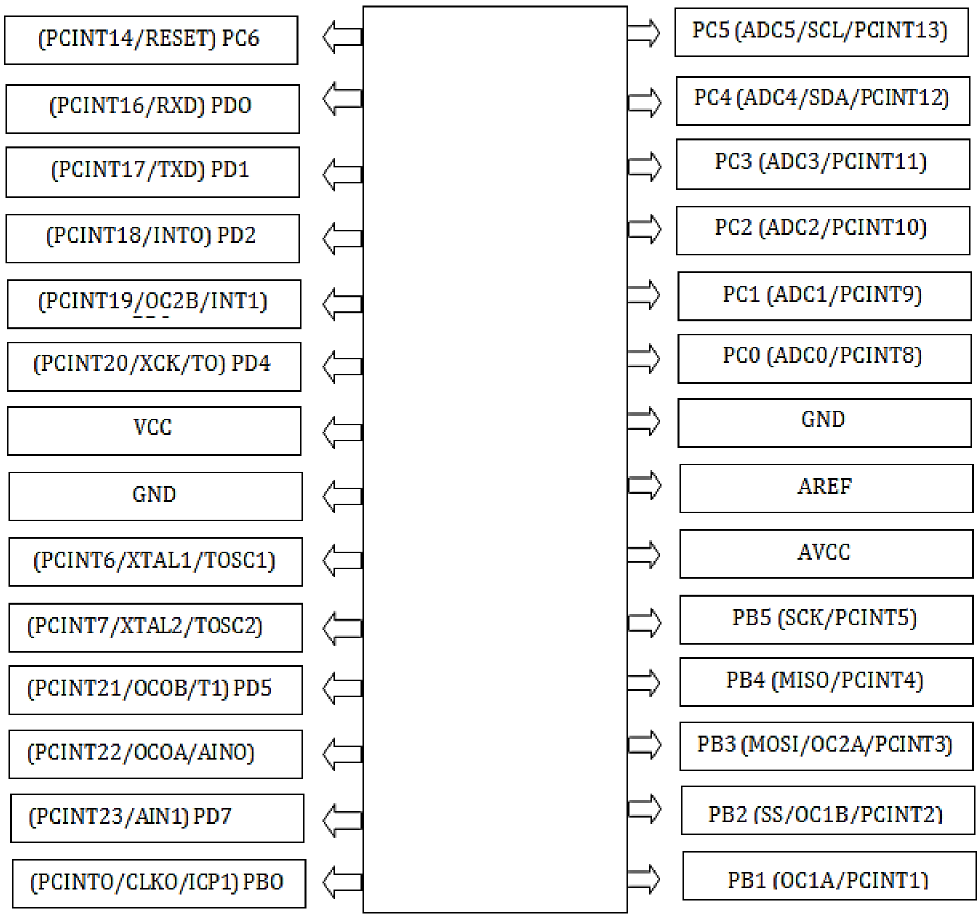

Figure 3 Show the pin configuration of AVR Atmega328

performance over others. The ATmega8L provides the following features: 512 bytes of stands for Electrically **E**rasable **P**rogrammable **R**ead **O**nly **M**emory (EEPROM) and is a type of non-volatile memory used in computers and other electronic devices to store small amounts of data that must be saved when power is removed. The high-performance Atmel 8-bit AVR RISC-based microcontroller combines 32 KB ISP flash memory with read-while-write capabilities, 2 KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes.

2.4 The RF Module

In general, a lower frequency allows a longer transmission range and a stronger capability to penetrate through walls and glass. However, due to the fact that radio waves with lower frequencies are easier to be more easily absorbed by various materials, such as water and trees, and that radio waves with higher frequencies are easier to scatter, effective transmission distance for signals carried by a high frequency radio wave may not necessarily be shorter than that by a lower frequency carrier at the same power rating. The 2.4 GHz band has a wider bandwidth that allows more channels and frequency hopping and permits compact antennas. The RF module is designed for operation in the world wide ISM frequency band at 2.400 - 2.4835GHz. An MCU (microcontroller) and very few external passive components are needed to design a radio system. The module is configured and operated through a Serial Peripheral Interface (SPI.)

3. The Software

ARDUINO the microcontroller on the board is programmed using the Arduino programming language and the Arduino development environment. Arduino boards are relatively in expensive compared to other microcontroller platform. The Arduino software runs on windows, Macintosh OSK, and Linux operating system. Most microcontroller system is limited to windows. The Arduino software is published as open source tools, available for extension by experienced programmer. Arduino projects can be stand-alone or they can communicate with software running on a computer (e.g. Flash, Processing, and Max MSP). The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of

Table 1 Various Configuration based on wireless data transmission

Technology	MCU system	Monitoring system	Module Interface	Programming Code	Reference
GSM-WSN	8051	PC, Mobile	Siemens,TC35,CC1100	C 51	Dursun & Ozden, 2010
PV SYSTEM	MSP430	Mobile	GM862QUA D-PY CC2430	C, Pythan	Xijiun *et al.*, 2009
WSN	PIC16F877	PC	LCD	Mikro C	Peijiang & Xuehua, 2008
Zigbee	Jn5121	PC	RS232	Java, interactive C	Jin *et al.*, 2007
RF	PIC18F452	PC	Sony ericsson	Visual C net 2008 editor	Banerjee & Singhal *et al.*, 2010
Fuzzy logic	STC12C5A32S2	PC	STC12C5608	C++	Bhutada *et al.*, 2005
GPRS	C8051F310	PC, Mobile	CC1020	PYTHON	Healy *et al.*, 2011
GSM	8051 FAMILY	PC, Mobile	Nokia FBUS	C,JAVA	Ahmed & Ladhake, 2010
Zigbee-WPAN	ATmega168	PC	MySQL, PHP	Aurdino	Boonsawat *et al*
4214A-Xbee	ARM 7	LCD	UART	KEIL,IDE LPC 2000	Patil *et al*
Bluetooth	MSP430G2553	PC	UART	C	Sainz *et al.*, 2013
Zigbee-GSM	ATmega2560	PC	GUT,UMTS	CC-SD	Boquete *et al.*, 2010
GSM-RF	PIC16LF872	PC	LCD	JAVA	Crowley *et al.*, 2005

which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

4. Analysis of Existing Systems

All these systems given below in Table-2 are well suited for remote control and monitoring depending upon the requirements. PC, LCD and Mobile based technologies are explained. From the paper (Purnia & Reddy, 2012), PC or LCD is the remote monitoring station and microcontroller is the controlling device. Special hardware and software installation is required to control the devices. Bluetooth based solutions are also used for this purpose (Sainz *et al.*, 2013) although Bluetooth eliminates the usage cost of the network to a great extent, its range of operation is limited to a few meters. One cannot remotely monitor and control devices using this technology. Also it is desirable for each home device to have a dedicated Bluetooth module but due to the fiscal expense of this type of implementation, a single module is shared by several devices which have a disadvantage of access delay. Interference is also a problem when using this technology.(Boquete *et al.*, 2010; Ahmed & Ladhake, 2010; Crowley *et al.*, 2005) are examples of GSM based remote monitoring and control systems where the monitoring and control unit is PC. It can provide the real time data and information with the help of internet access but again requirement of PC incurs additional implementation cost and it also restricts the mobility of the user. The systems where both PC and Mobile act as monitoring and control unit are given in (Dursun & Ozden, 2010; Healy *et al.*, 2011). PC acts as home monitoring station and mobile control everything remotely. Although these systems eliminates one of the drawback of real time monitoring using internet and WSN but again increased fiscal cost due to PC is again a drawback.The paper (Boonsawat *et al*) reported that the range of the Zigbee is more as well as expensive. The MCU system is having less Pin therefore we cannot use more interface. The distance between the Coordinator and End device should not exceed 140 meters from the location of monitoring.

On the other hand, if there are any blockages, the distance should not be greater than 40 meters. For the sensor, it can measure the temperature to the accuracy of only one decimal point, i.e., the resolution is in 0.5 degree Celsius. MySQL and PHP code have to run on client computer in the same LAN network because Arduino cannot run MySQL by itself. In prototype (Patil *et al.*, 2007) the system is very accurate and efficient in all manner as the ARM 7 used but the only disadvantage is that this prototype is expensive. In system (Sainz *et al.*, 2013) range is a major issue from bluetooth, the PWM is used in MCU system ,the microcontroller is having 40 pins so if all pins are not used it increases the complexity of the circuit. Secondly, the power consumption is more. If circuit is using 8051 microcontroller, the Analog to digital converter (ADC) is unbuilt due to which the complexity increases, response is also slow and power consumption is less.PIC16LF872 is also having large EEPROM and also high time response but it is not user friendly. The technique which is based on GSM is highly dependable on the coverage area (Peijiang & Xuehua, 2008) (Ahmed & Ladhake, 2010) (Boquete *et al.*, 2010). Hence the presented prototype having some silent feature of low cost , optimum range and technical advantage of the having fine coordination between the programming language and the MCU system, also the language used for MCU is free version, no need of coverage area as in the GSM.

Table 2 Various parameter of thermocouple

Thermocouple Type	Measurement Junc. Temp. Range	Reference Junc. Temp. Range	Power Consumption
K	-25 ^{0}C to 1100 ^{0}C	0 ^{0}C to 50 ^{0}C	1.25 μW

5. Result and discussion

5.1 Experimental analysis

For Examine the prototype, the commercial solar box type cooker is used in location of Indore (India).data are taken for six month of 2013. The aim of this experiment was to confirm that data measured with the RF measurement system are consistent with data measured with the current procedure. The thermocouple used here is K type thermocouple. And the whole circuitry is set in a compact box. Now give power supply to the circuitry of the temperature sensor and the probes of the thermocouple is attach to the surface of the solar cooker where the temperature in account. The reading is taken at every 2 minutes and shown in the PC.

Basic junction temperature range is given in below Table 2. The power consumption is calculated also mention in the table. The setup of solar cooker is placed in exact position according to the solar radiation coming towards the surface and reading is checked on the PC for whole year from January 2013-December 2013.

Reading of whole month has been taken and average reading is calculated by help of the software, and different graph is plot according to the parameter in the Microsoft Excel. Reading has been taken from morning 10.00am to 4.00 pm at every 2 min which again depends upon the user to set the time interval. Variation on reading is due to rise in the radiation level of the Sun. The other data logger of the NABL lab is placed against the temperature sensor. Both the reading is shown on the PC by the help of the software Hyperlink. Below graph is shown the comparison of temperature reading between the sensor and the NABL lab data logger. From above the correlation factor of the graph is 0.99 which is very near to accurate. Temperature Sensor measures temperature and displays the information in the voltage form. The output from the temperature sensor is analog but is then sampled and quantized (A/D converted) by the Arduino. Hence, we can realize the temperature in degree Celsius by calibrating it by using the equation derived from an experiment if we use reference temperature is X degree Celsius and sampling value at reference temperature is Y as shown in equation (1)

$$y=0.996* x+ 0.284 \quad (1)$$

Figure 5 shows the radiation of the day and the temperature range varying the whole day of both the temperature data logger. The faint (Dim) line graph is for the NABL lab data and the dark line is for the prototype using here. The database is maintained in computer for the offline future analysis.

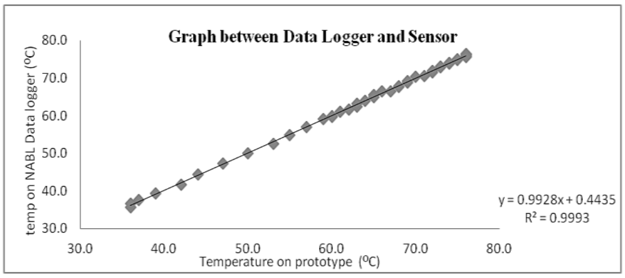

Figure 4 Graph plotted between the temperature range of the NABL Data logger and the Thermocouple sensor

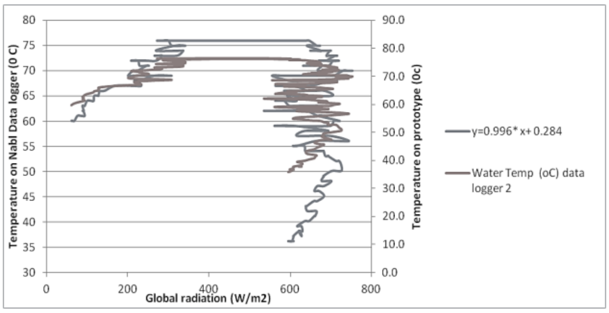

Figure 5 Variation on both temperatures monitoring system with the Global radiation (W/m^2)

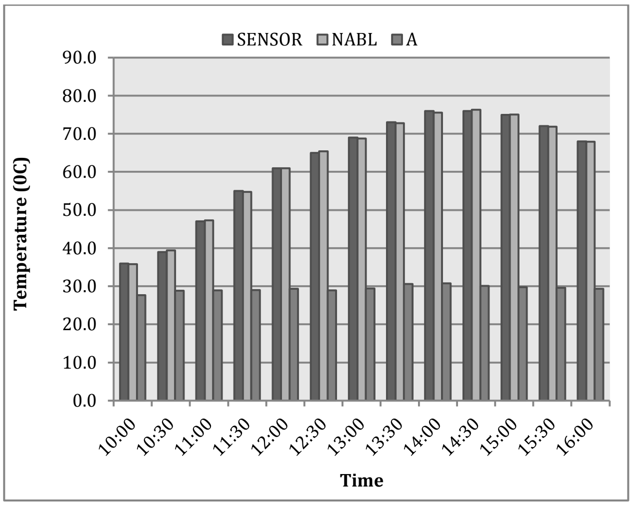

Figure 6 Variation on temperature taken by the Temperature sensor, NABL lab sensor and the ambient temperature with different time interval

Solar variation is the change in the amount of radiation emitted by the Sun. All matter in the universe that has a temperature above absolute zero (the temperature at which all atomic or molecular motion stops) radiates energy across a range of wavelengths in the electromagnetic spectrum.

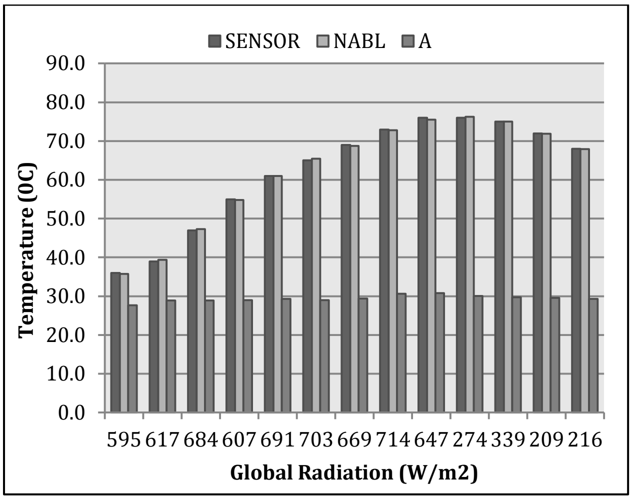

Figure 7 Variation on temperature taken by the temperature sensor, NABL lab sensor and the ambient temperature with different Global radiation (W/m^2)

The hotter something is, the shorter its peak wavelength of radiated energy is. The hottest objects in the universe radiate mostly gamma rays and x-rays. Cooler objects emit mostly longer-wavelength radiation, including visible light, thermal infrared, radio, and microwaves. The proposed sensor node has the features of low power consumption and deal with minimal number of components with larger distance coverage

5.2 Cost analysis

From the graph, it is concluded that the thermocouple are small and have low thermal capacity, thermocouples respond rapidly to temperature changes, especially if the sensing junction is exposed and has high time response of about (<6 sec). Because thermocouples require no excitation power, they are not prone to self-heating and are intrinsically safe ideal for monitoring in flare, kiln etc.

Table 3 Cost economics of component

Component	Cost In INR (Rs.)$
Thermocouple	50/-
RF Sensor	1250/-
Capacitor(1000 uf)	10/-
Capacitor(paper capacitor)	2/-
Resister	1/-
Transformer(12 V,AC)	60/-
Buzzer	10/-
LCD	120/-
Connecting wire	20/-
Port, battery	20/-
AVR Microcontroller(ATmega328)	200/-
Voltage Regulator	10/-
Crystal oscillator	1/-
Bakelite sheet	80/-
TOTAL	1834/-($ 29.39)

*1$=62.39 INR

In general, a lower frequency allows a longer transmission range and a stronger capability to penetrate through different materials. To obtain a long effective transmission communication range with high penetration capability, 433MHz was selected as the communication frequency in this application. And from the cost analysis table it is also clear that the cost of the system is very low by using low cost thermocouple.

Conclusion

The designed system is tested in solar lab and it is found that RF operates properly. Small size, low power consumption makes RF an indispensable option to develop a system, which is compact, reliable and flexible. In this prototype, an environment monitoring system based on WSN and thermocouple technology is developed successfully. The system has been used and tested in a lab. The improvement of data efficiency has been noticed. the presented prototype having some silent feature of low cost, optimum range and technical advantage of the having fine coordination between the programming language and the MCU system, also the language used for MCU is free version, no need of coverage area as in the GSM. Specially, the proposed system architecture brings the following benefits:

(1) Thermocouples are the best choice for extreme condition, shock or vibration, very less time response, and low cost.
(2) Using WSN technology to monitor the environment helps one to solve the problems of deployment difficulty, high costs, and realizes unmanned monitoring.

Future work will focus on the security issues of this system.

Notes

The authors declare no competing financial interest.

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