Development of Self Powered Wireless Sensor for Air Temperature and Velocity Measurement

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ABSTRACT

Air temperature and velocity measurements are important parameters in many applications. A transmitter module is powered by a dc tachogenerator scavenging energy from the airflow has been designed. It transmits the measured air temperature and velocity to a receiving unit. The system consists of a self-powered wireless sensor and the receiver unit. The self-powered sensor has a section for energy harvesting. The self-powered sensor consists of integrated devices, including microcontroller, an integrated temperature sensor, and a transmitter in low-power technology. The data transmission is realized with amplitude-shift-keying modulation, in Manchester encoding, covering a distance between the sensor and the reader up to 4–5 m, which depends on the power supplied in transmission. The velocity of air is measured using the rotor frequency of the dc tachogenerator, whereas, a commercial low power sensor is used for the temperature measurement. A system has been designed experimentally and fabricated, which demonstrates that the airflow harvester can power the self-powered wireless sensor permitting measurements of air temperature and velocity. The system is used for real-time monitoring of temperature and velocity of air. The sensor module placed into the common environment with continuous flow of air does not require any batteries.

General Terms

Self Powered, Power Generation, Charging Circuit, Transmission, Wireless.

Keywords

Energy Harvesting, DC Tachogenerator, Arduino, ZigBee

1. INTRODUCTION

1.1 Overview of Energy Harvesting

Energy harvesting has been around for centuries in the form of watermills, windmills and solar power system. In recent periods, technologies such as hydro-electric generators , wind turbines and solar panels have turned harvesting into a small but growing contributor to the world's energy needs. This technology offers certain significant advantages over battery-powered solutions, virtually little or no adverse environmental effects and unfailing sources. Macro-scale energy harvesting technologies differ in many ways but have one thing common, they feed the grid, adding megawatts or kilowatts to the power distribution system. As studied, they are not the game changers of electronic designers whose mission in life is to snip the wires – including power cords and even battery-powered systems where the perpetual device is the ultimate design goal.

Energy harvesting's new frontier is an array of micro-scale technologies that scavenge milliwatts from solar, vibration, biological and thermal sources. A few years back, micro-harvesting could have been termed to be scientific curiosity. But the design community's search to ultra-low-power (ULP) technology has had the unexpected result of pushing micro-scale energy harvesting out of the lab and onto the designer's bench.

Now, designers are sizing up ULP not just from the consumption side but from the production view as well. Understanding ULP from sourcing side will be every bit as challenging as it was from the consumption side. Harvested power is derived from ambient sources so it tends to be unregulated, intermittent and small. The most promising micro-harvesting technologies extract energy from vibration, temperature differentials and light. Another possibility scavenging energy from RF emissions is interesting, but the availability of energy is at least an order of magnitude less than that of the first three.

Micro-harvesting provides power at the same order of magnitude that carefully designed ULP circuits typically consume. The most promising technologies based on motion, light and thermal scavenging has various characteristics.

Large solar panels have made photovoltaic harvesting a well designed technology. Average power of approximately 1 mW can be harvested from each 100-mm2 photovoltaic cell. Efficiency is typically, roughly 10 percent and the capacity factor of photovoltaic sources, the average power ratio produced to power that would be produced if the sun was always shining is about 15 to 20 percent.

Commercially available kinetic energy systems also produce power in the range of milliwatt. Energy is to be generated by an oscillating mass (vibration). But electrostatic energy harvested by piezoelectric cells or flexible elastomers is also classified as kinetic energy. Vibration energy is available from structures such as bridges and in many automotive and industrial scenarios. Kinetic harvester technologies basically include a mass on a spring; devices that convert linear to rotary motion; and piezoelectric cells. An advantage is that voltage is not determined by the source itself but by the design of conversion. Electrostatic conversion has the capability to produce voltages for about 1,000 V or more.

Thermoelectric harvesters exploit the Seebeck effect, which explains that voltage is created in the presence of a temperature difference between two different metals or semiconductors. A thermoelectric generator (TEG) consists of thermopiles connected electrically in series and thermally in parallel. The latest generators are characterized by an output voltage at matched load of 0.7 V, which is a familiar voltage for engineers designing ultra-low-power issues. The generated power depends on the ambient temperature, the size of the TEG, and the level of metabolic activity in the case of harvesting heat energy from humans.

According to the Belgian-based research corporation IMEC, at 22˚C a wrist-watch type TEG delivers power of 0.2 to 0.3 mW on an average for normal activity purpose. Generally, a generator continuously charges a battery or super-capacitor and requires advanced power management to optimize efficiency. Despite their differences, motion, photovoltaic, and thermal harvesting also have a few things in common.

They generate erratic voltages instead of the steady 1.8 V or 3.3 V design engineers sometimes take for granted; they also provide intermittent power and sometimes there won't be any power. Technology of conversion is only part of the solution. As micro-harvester tends to generate alternate power, the common system architectures are called hybrids because they include energy storage in thin-film batteries.

A typical energy-harvesting system includes temporary storage, conversion and a heavy dose of sophisticated power management circuits, ULP MCUs and analog converters. To move ULP to the next level, it is desirable to integrate as many of these circuits as possible on a single chip.

1.2 Significance of the Project

The measurement of airflow contributes to determine the indoor air quality and it provides healthy environments for the occupants of the building. The commercial airflow measurement system commonly requires a battery, but, recently, an alternative system supplied by power-harvesting modules is proposed. The elimination of battery adoption has many reasons: the size and weight of the devices and the unwanted maintenance burdens of replacement. As these batteries contain toxic chemicals, the disposal of the increasing number of batteries is creating an important environmental impact. It outlines a self-powered sensor that, without any battery, autonomously performs the measuring functions and transmits data to an external receiving unit. The sensors proposed are powered by a harvesting system that exploits the mechanical energy coming from the velocity of airflow. Since particular power supply is not required, the self-powered sensor can easily be installed at any point of a building.

The airflow harvesters are evaluated for their potential utilization in autonomous measurements. An airflow harvester can be a promising technological solution for producing electricity in different applications. In general, it is necessary for the power consumption of the harvesting electronics to be less than the available power for harvest, which varies as a function of airflow velocity.

In recent years, several groups have demonstrated small airflow harvesters based on the wind turbine principle. For this purpose, a properly sized small airflow turbine is required to exploit the available airflow potential for producing electrical energy. In urban areas a wind energy system is evaluated for their potential utilization. The life cycle assessment and the techno-economic analysis of such energy system is reported.

The design, fabrication, and testing of small-scale piezoelectric windmill are reported. The windmill was tested at an average wind speed of 4.47 m/s, and it provided 5 mW of continuous power. A 100mm diameter airscrew rotor is combined with a brushless dc motor operated as a generator that could deliver up to 28 mW at 5.1m/s flow rate or 8 mW at 2.5 m/s. More recently, a smaller device with a 4.2-cm-diameter rotor is described. At flow rates of 5.5 and 12 m/s, The device delivers powers of 2.4 and 130 mW respectively.

A small scale airflow harvester is reported. This device was developed using MEMS technology and was aimed at higher flow-rate. It consist of a 12-mm-diameter axial-flow turbine integrated with an axial flux electromagnetic generator. The autonomous sensor measures the air velocity and in the non-volatile memory of the microcontroller the data measured is saved. At a later stage the measurement data is downloaded, near the sensor module reading unit is positioned, a few inches away, and the sensor module is supplied by the magnetic field generated by the reading unit.

The system presented here does not require a battery; it can be used in areas where the power source is absent, such as open field, but does not allow real-time measurements since only post process monitoring is possible. An airflow measurement system for velocity higher than 4 m/s with power harvesting capability is proposed for short-range application for monitoring purposes. A self-powered wireless sensor is proposed for online measurements of air velocity and temperature. Temperatures and velocity are important indicators of operational efficiency in the regulation of industrial implants or in air conditioning. The wireless sensor does not require any battery since it uses the power harvested from the mechanical energy of the air flow.

The self-powered wireless sensor sends the measured data to an external receiving unit. The sensor continuously operates for airflow greater than 3 m/s. For slower flows, the sensor is off, and the receiver assumes that the velocity of air is below the threshold. The measurement data are acquired every 2 s, but this time interval can be reduced. The system has been improved, its functionality has been modified, and the air velocity sensor requires less power. The air velocity is measured through the rotor frequency of the electromechanical generator using a magnetoresistor coupled to a magnet.

The transmission at 125 kHz has been substituted with another at 433 MHz, increasing the distance between reader and sensor up to 4–5 m. The receiving unit is kept always on and ready. The system allows real-time measurement. For internal flow, such as ventilation ducts, the air velocity can reach 12 m/s in large ducts, down to 1–2 m/s. For internal air duct applications, tiny windmills have significant advantages. Considering these aspects, the self-powered wireless sensor has been designed to be powered with low airflow velocity.

2. SYSTEM DESCRIPTION

2.1 Block Diagram of the Project

The Figure. 2.1 illustrates the block diagram of the self powered wireless sensor and receiving unit.

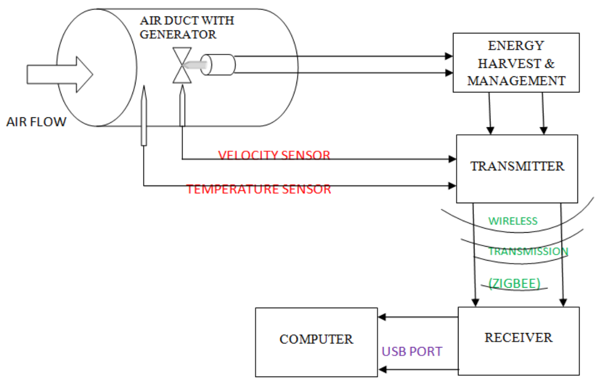

Figure 2.1 Block diagram of Self powered wireless sensor

The goal of the process is to design a system for energy harvesting. A commercial air screw is connected to an electromagnetic generator. The electronic circuit is supplied for the measurement of air temperature and velocity through harvested power, using air motion energy. The microcontroller, which coordinates the operation of the self-powered wireless sensor, initially is in an idle state. Every 2 s, it wakes up and switches on the sensor modules to execute measurement of temperature and velocity. The microcontroller turns on the transmitter module and sends the package; after the transmission, it returns to the idle state. On the other hand, when the transmission power consumption is high, the energy storage system is recharged during the interval in which the sensor module is off.

The interval of 2 s is considered sufficient to allow proper operation of the system since the measured quantities (temperature and velocity) have a slow dynamic. Finally, the microcontroller switches off the transmitter and returns to the idle state. A typical problem of a wireless network is encountered, since the self-powered sensor is a wireless device. In this application, a point-to-point communication has been implemented. Point-to-point communication avoids managing the complexity of a saving power, network protocol and making the system compatible with the available low energy. For these reasons, the self-powered sensor implements a simple communication at 433 MHz; other wireless protocols such as Bluetooth or Wi-Fi are more expensive in terms of power consumption.

The air flow is used for energy harvesting. The air duct in industries will always have some amount of air flow in it. The flow of air might not be constant, as it may increase or decrease according to the process. This air can be utilised for energy harvesting as per our system configuration but earlier it was not utilised anywhere. The DC tacho generator is placed inside an air duct. The exhaust air from the process stations will be flowing through the ducts. The generator is placed in such a way that the fan of the generator attached to the screw starts rotating with the air flow. The design of fan should be very efficient that it should rotate easily.

When the generator rotates there will be a voltage generated. This voltage generated will be stored in a super capacitor. The temperature and velocity of the air is measured at certain interval of time and it is transmitted to the control room. For the transmission of signal, batteries were used. But in this system we use the harvested energy. This stored energy is used for the activation of the micro-controller and to transmit data for the time interval set. The receiver kit is activated by the external power. The energy harvested would be utilized for different purpose in small scale.

2.2 Temperature Sensor

LM35 is the temperature sensor proposed. The temperature sensors, LM35 series are precision IC. The output voltage of the sensor is linearly proportional to the Celsius temperature. The sensor has an advantage over linear temperature sensors calibrated in ˚ Kelvin, as it is not required to subtract a large constant voltage from its output to obtain convenient scaling in Centigrade. The LM35 does not require any trimming or external calibration to provide typical accuracies of ±1⁄4˚C at room temperature and ±3⁄4˚C over a full −55 to +150˚C temperature range. At the wafer level low cost is assured by calibration and trimming. The LM35's linear output, low output impedance, and precise inherent calibration make interfacing to readout or control circuitry easy. It can be used with plus and minus supplies or with single power supplies. It has very low self-heating, as it draws only 60µA from its supply, of less than 0.1˚C in still air. The LM35 is operated at a rate of over a −55˚ to +150˚C temperature range.

2.3 Microcontroller

The controller used is ATmega16. The ATmega16 is based on the AVR enhanced RISC architecture with a low-power CMOS 8-bit microcontroller. The ATmega16 achieves throughputs approaching 1 MIPS per MHz allowing the system designer by executing powerful instructions in a single clock cycle, to optimize power consumption versus processing speed.

2.4 Arduino

Arduino is an open-source electronics prototyping platform based on easy-to-use software and hardware, flexible. It is intended for hobbyists, artists, designers, and for the one interested in creating interactive environments or objects. When arduino receives input from a variety of sensors it can sense the environment and can affect its surroundings by controlling motors, lights, and other actuators. On the board the microcontroller is programmed using the Arduino programming language based on Wiring and the Arduino development environment based on Processing. These projects can communicate with software running on a computer such as Flash, Processing, MaxMSP or they can be stand-alone. The Arduino module is shown in Figure.2.3

The hardware consists of a simple open hardware design for the Arduino board with on-board input/output support and an Atmel AVR processor. The software consists of a compiler which is the standard programming language and the boot loader that runs on the board. The hardware is programmed using syntax and libraries, Wiring-based language, similar to C++ with some slight modifications and simplifications, and an integrated development environment based on processing.

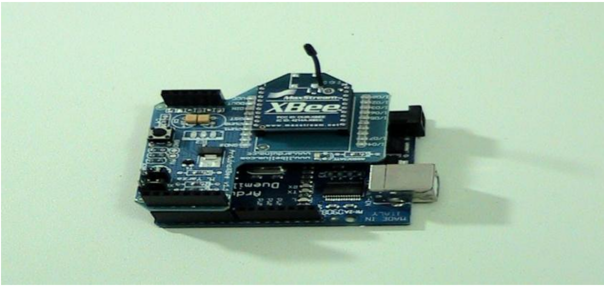

Figure 2.3 Arduino Module

An Arduino board consists of an 8-bit Atmel AVR microcontroller with incorporation into other circuits and complementary components to facilitate programming. An importance of the Arduino is the standard way of exposure of connectors that allows the CPU board to be connected to shields which are variety of interchangeable add-on modules. Communication of some shields takes place with the Arduino board over various pins directly, but many of them are individually addressable using an I²C serial bus, allowing many shields to be used in parallel and stacked.

Arduino have used the mega AVR series of chips, specifically the ATmega2560, ATmega1280, ATmega328, ATmega168, and ATmega8. Arduino compatibles use a handful of other processors. Most boards include a 16 MHz crystal oscillator or ceramic resonator in some variants and a 5 volt linear regulator, although some designs such as the LilyPad dispense with the onboard voltage regulator due to specific form-factor restrictions runs at 8 MHz. An Arduino microcontroller simplifies uploading of programs to the on-chip flash memory as it is also pre-programmed with a boot loader, compared with other devices which need an external programmer.

When using the Arduino software stack, at a conceptual level, all boards are programmed with respect to RS-232 serial connection, but the implementation varies by hardware version. A simple inverter circuit to convert between TTL-level signals and RS-232-level is contained in serial Arduino boards. Arduino boards currently used are programmed via USB, such as the FTDI FT232, implemented using USB-to-serial adapter chips. Some variants, such as the unofficial Board and the Arduino Mini, use a Bluetooth, detachable USB-to-serial adapter board or cable or other methods. Instead of the Arduino IDE when used with traditional microcontroller tools, standard AVR ISP programming is used.

The Arduino board exposes most of the microcontroller's I/O pins for use by other circuits. It gives 14 digital I/O pins, six analog inputs and six of which can produce pulse-width modulated signals. On the top of the board these pins are found, via female 0.1 inch headers. There are many plug-in application shields also available commercially. The Arduino-compatible Bare Bones Board, Arduino Nano, and Boarduino boards may provide male header pins on the underside of the board to be plugged into solderless breadboards.

The Arduino IDE is a cross-platform application which is derived from the IDE for the Wiring project and for the Processing programming language, written in Java. It is designed to introduce programming to newcomers unfamiliar with software development and the artists. It contains a code editor with features such as automatic indentation, brace matching and syntax highlighting, and is also capable of uploading programs to the board with a single click and compiling. There is typically no need to run programs on a command-line interface or to edit make files. If required with some third-party tools such as Ino, building on command-line is possible.

2.5 Design

Using Arduino, the purpose in the project is to acquire signal from the sensor and control the system according to requirement. The Arduino module is in the transmitter end. The air velocity and temperature is sensed by Arduino at its input port. These signals have to be transmitted wireless to the control room.

For the transmission of signals from transmitter to receiver a Zigbee module is used at both the ends in the transmitter and the receiver. At the receiver end the signal is received using Zigbee and then it is displayed in the computer through RS232 port. For the transmission a set of program is downloaded in the Arduino so that the microcontroller allows the signal to be detected and transmitted for a particular interval of time. At the receiver end for receiving signals through Zigbee, LabVIEW is used. In LabVIEW there are Arduino configurations, So that the signals are obtained with good accuracy.

For testing purpose the transmission is done using Wifi. The components used here are computers with Wifi and the LabVIEW set up with Arduino controller. It includes a server block and a client block. In the server block the Arduino module is connected and the temperature is sensed. The temperature sensed by Arduino is then sensed by LabVIEW software. The com port setting is done accordingly. The block diagram and front panel of server is Shown in Figure. 2.4(a), 2.4(b).

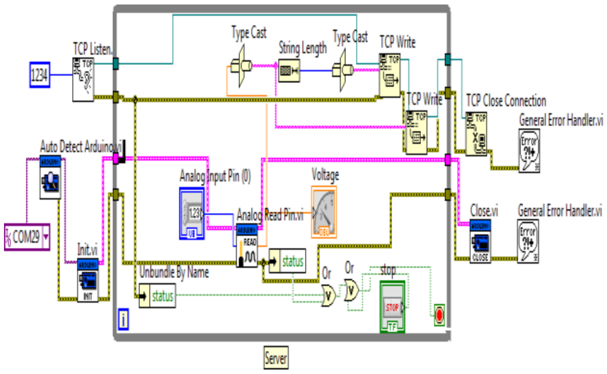

Figure 2.4(a) Block Panel of Transmitter

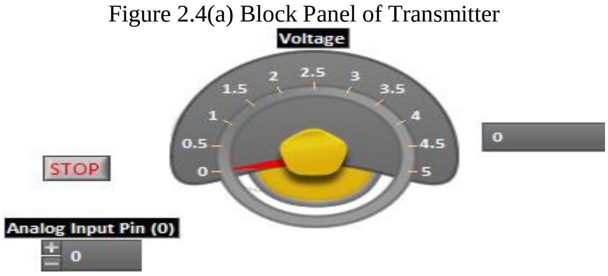

Figure 2.4(b) Front Panel of Transmitter

The Wifi configuration is done based on the IP address of the server. At the receiver end in the control room a client block is made in LabVIEW. This block is given an IP address. Therefore when there is a change in temperature in the server end the same temperature variation will be observed in the client end. The block diagram and front panel of client is Shown in Figure. 2.5(a), 2.5(b).

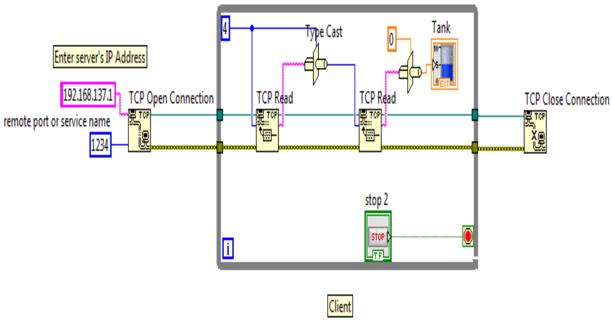

Figure 2.5(a) Block Panel of Receiver

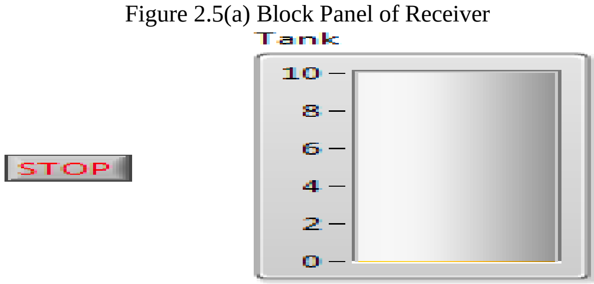

Figure 2.5(b) Front Panel of Receiver

2.6 DC Generator

To utilize the wind energy, a DC generator has to be used. The most common DC generator convenient is the computer fan because of its availability, price and light weight. For the testing purpose an SMPS fan is been utilized as shown in Fig 2.6.

Two fans are connected in series which is then connected in parallel with the two other fans connected in series. This setup will allow increasing the voltage and current by two times than the rated voltage of single fan. The output of DC generator is then connected to the DCDC converter and it is connected to a battery pack. For a single fan, when it is kept in front of the blower it is found to obtain a voltage of 3.3V up to 3.6V.

Figure 2.6 DC Brushless Fan

Wind module is tested by holding it outside of a air blower. Around 65 mph the module is producing a voltage around 3.5V and current around 110 mA. This current is not sufficient enough to charge a battery directly, but can be used for energy harvesting for back-up system.

3. CONCLUSION

The temperature measurement is done using a temperature sensor LM35. The measured signal is sensed through ATmega 16 and Arduino modules used as microcontrollers.The testing of transmitted signals from the transmitter to control room is done using Wifi network. A LabVIEW system is incorporated for the continuous parameter measurements.

SMPS fans are used to test the generation of power and the result is satisfactory for different speed of air. In extension of the project for the purpose of transmission, Arduino is proposed to be used with the help of Zigbee. The power generation using DC tachogenerator has to be done and it has to be stored in the super capacitor. This stored energy has to be harvested and should be utilized for powering the whole transmitter unit without the use of a battery.

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