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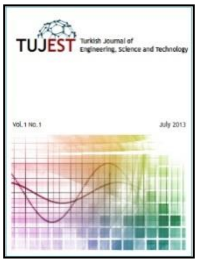

Water Powered Sensors In Water Distribution Systems

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Abstract

With the parallel developments of both sensor and wireless communication technologies in recent years, wireless sensor networks (WSN) has become a so popular study area in computer science and preferred to use on different areas and applications such as military, health, industrial controls, fire brigade, greenhouse and so on. Water distribution systems are one of these. WSN based monitoring systems implemented on water distribution systems are used world-wide. Its main advantages are real-time monitoring and detecting leakages to prevent resource loss. But WSN have some challenges like power consumption (finite energy sources), storage area, coverage, security. All WSN systems have to face these problems. The aim of this work is to solve energy problem in WSN used in water distribution monitoring systems by generating energy from the water flow in the pipes.

1. Introduction

Nowadays, Wireless sensor networks (WSN) are composed of many small and cheap sensors that can communicate in various ranges wirelessly. As the WSN have the advantage of monitoring the environment remotely with low costs, many applications based on WSN are used at different parts of life such as military, health, process control, wildlife monitoring, fire brigades, energy monitoring.

On the other hand WSN have some restrictions like power consumption, communication range, security, self-organizing, routing.

In this paper, we proposed a system based on wireless sensor networks which aims to detect and localize leakages in water transmission pipelines. While implementing this system, we have solved the energy problem of the sensors used in the system by harvesting energy from the flow of water in the pipes by a specific application developed. The monitoring system includes a set of sensors which perform the tasks such as measuring the water pressure and water quality parameters. Data collected by sensors will be sent to the data management center and the center uses data to monitor the system and to decide what to do.

2. Wireless Sensor Networks

A wireless sensor node has basically four parts that are sensing, processing, transmission and power units as shown in Figure 1. According to the requirements of the specific system, a mobilizer or power generator can be added [1].

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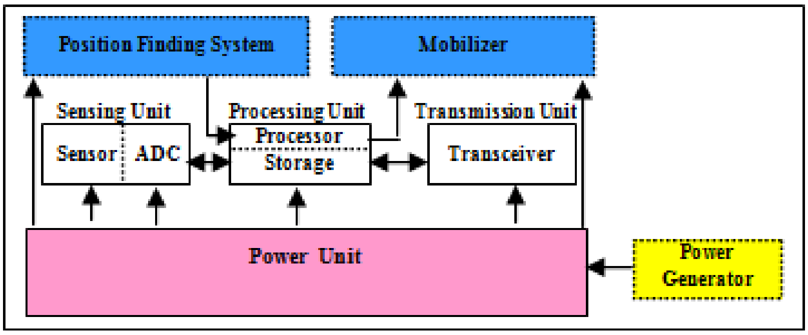

Figure1. A typical wireless sensor structure [1]

Even though a basic node has the units above, the dimensions of the nodes are not so big; they vary from a coin to a matchbox size.

The combination of many wireless sensors in a planned or random order in an environment to collect data about temperature, humidity, pressure etc. and transmit them wirelessly either among each other or directly to the base station is called wireless sensor network.

If the data transmitted to the base station is needed to be analyzed again according to different criteria or will be used for other purposes, the transmission needs to be directed to those systems.

The hardware architecture of a sensor node is shown below in Figure 2 [2]. The sensor nodes have some components. Each component perform specific workload and described as following:

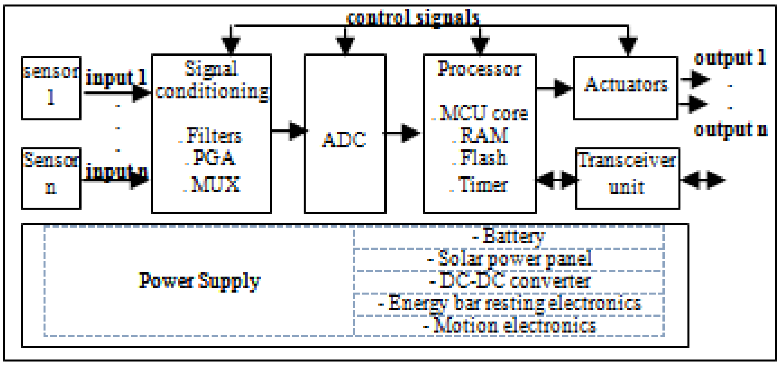

Figure 2. Parts of a wireless sensor node [2]

- Sensing Unit: The unit where the nodes are connected to environment and sensors sense the data from the environment.
- Computing Unit: In this unit, a microprocessor or a microcontroller is included and the sensed data is processed.
- Transmitting Unit: The unit where the processed data is transmitted to the neighbour nodes or base in a range.
- Power Unit: The unit where the necessary power for the units above is stored.

All units above need for a specific amount of energy to perform its function properly. Therefore, enough energy must be supplied to the system by the power unit. One of the biggest challenges of a WSN is finite energy sources [3]. This paper is aimed at to bring a solution to this problem.

As the batteries are commonly used finite energy sources and are usually difficult to replace them especially in harsh conditions, energy problem should be solved by energy harvesting via renewable energy sources. Hence, lifetime of the WSN will be longer, energy supplies will not be a problem and energy costs will decrease.

2.1. Energy Harvesting Methods

Today, there are many alternative ways in harvesting energy; solar energy, thermal energy, and mechanical energy. But some of them are more efficient than others in terms of cost and efficiency. Mostly used energy harvesting methods in WSN based systems are:

1. Solar methods: Energy harvesting from sun is the most common method in the world for many applications. But it has a disadvantage of being able to generate energy only in sufficient sunlight or artifical light [4]. To ensure that energy is not lost during the transfer -from the harvester to the wireless sensor- a low-power maximum power point tracker (MPPT) circuit [3] has been added. With the help of this circuit harvested solar energy sent to rechargeable batteries even in non-

optimal weather conditions without any loss. The Heliomote project [5] focused on developing a plug-and-play solar energy harvesting module for using with Crossbow/Berkeley motes.

2. Mechanical methods: Vibrations are very common resources and especially prominent in bridges, roads and rail tracks [4]. In [6], a vibration-based micro-power generator is used to exploit environmental vibrations to support a sensor node. Traffic sensors can also be solely powered by the short vibrations when a vehicle passes over the sensor [7]. Experimental results have shown that when a piezoelectric pushbutton is depressed, sufficient energy is harvested to transmit two complete 12-bit digital word information wirelessly [8]. In [9], a new energy harvester for harvesting energy from the Kármán vortex street behind a bluff body in a water flow has been proposed. It converts flow energy into electrical energy through oscillation of a piezoelectric film.

3. Thermal methods: Electrical current is generated when there is a temperature difference between two junctions of a conducting material. Due to the lack of moving parts in thermal energy harvesting devices, they tend to last longer than vibration-based devices [4]. Devices having direct contact to the human body can harvest the energy radiated from the human body by means of thermogenerators (TEGs) [10].

2.2. Energy Harvesting in Fluid Dynamics[11]

1.Power Harvesting Using Mechanical Parts: In [12] energy harvesting from wave and water tides using hydraulic turbine inside the pipeline has been proposed as a solution of sensor power and the same technique has been used in [13]. The advantage of this technique is that it generates enough power for wireless sensor nodes. The disadvantages of this technique are mounting the mechanical parts into the system can be sometimes so difficult and the potential of problems depending on the rotating parts in the system in long time.

2. Power Harvesting Using Non-Mechanical Parts: In [14], Pobering presented a promising technique for harvesting power from fluid in general without using any rotating parts. It consists of bluff body contact with piezoelectric cantilever to generate vibration on the cantilever by flow disturbing. Other piezoelectric based energy harvesting applications have been presented in [15] and [16]. This technique has advantage of using non-mechanical parts but has disadvantage of instantaneous power generated is small and it can not be the only source of power sensor node in active mode.

3. Energy Harvesting In Water Distribution Systems

In order to bring a solution for WSN energy problem in a water distribution monitoring system, a specific application is developed. In this application, we developed a monitoring and management system for urban drinking water pipelines. The system includes a set of sensors which perform the tasks such as measuring the pressure and water quality parameters. Data collected by sensors are sent to the management center to make decisions by the system.

WSN based monitoring systems implemented on water distribution systems are used world-wide both to monitor the system real-time and to detect and locate the leakages to prevent many resources loss like water, money etc. But WSN have some challenges in terms of power consumption, storage area, coverage... All systems based on WSN told above have to face these problems. The primary aim of this work is to develop a novel approach to solve energy problem in WSN especially in water distribution systems by generating energy by the water flow in an urban drinking water pipeline.

3.1. Prototype Design

Energy problem in WSN is a very popular research field. Some researchers have focused on increasing the efficiency of energy usage while others on energy harvesting methods such as solar, thermal and mechanical approaches.

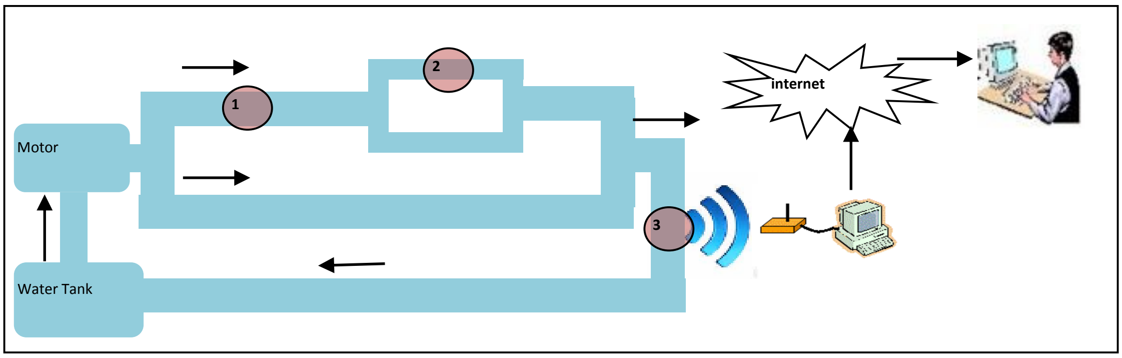

Figure 3. The Structure of The Whole System

We designed a small prototype model of water pipeline structure of a city and deployed wireless sensors at three points to obtain pressure an water quality data from the pipes. Obtained data is sent to the base by system and changes can be observed both by the user having a base-connected computer and remote users by internet (Figure 3). By the way, the pressure values can be seen on the computer as a graph by a specific programme written for this purpose. The pipeline monitoring can be done real-time, without any cabling, any costs like GSM based systems.

Electrochem PS-1 model wireless pressure sensors(Figure 4), which is powered by a AA (3.9 V Lithium) battery [17], is used. Operating Frequency is 2.4 GHz. Life time of batteries may vary from 2 months to 1 year (on default 10 seconds signal period) according to the transmitting period. Standard range for signal transmitting distance varies from 30 meters indoor to 100 meters outdoor. The relation of this system about solving the energy problem of WSN is that we have managed to harvest energy from the mechanical energy of water flow in the pipes and then recharged the batteries of these wireless pressure sensors with the harvested energy.

Figure 4. PS-1 Wireless pressure sensor [18]

On WSN based systems like the one implemented here and many others, replacing the batteries can be very difficult. (even sometimes impossible in harsh conditions). This is an important problem for the systems to survive. But it has to be solved to extend the system's lifetime no matter what it costs.

The sensors used by system can only be powered by batteries. And they have another problem afterwards – signal loss- . It also effects the lifetime of the system.

Pressured water flowing through the pipes is the source of the solution. Never ending water flow through the pipes will charge the batteries by a recharge unit. And the system will continue to run till sensors' have any hardware problem.

The energy harvesting method of the system is shown in Figure 5.

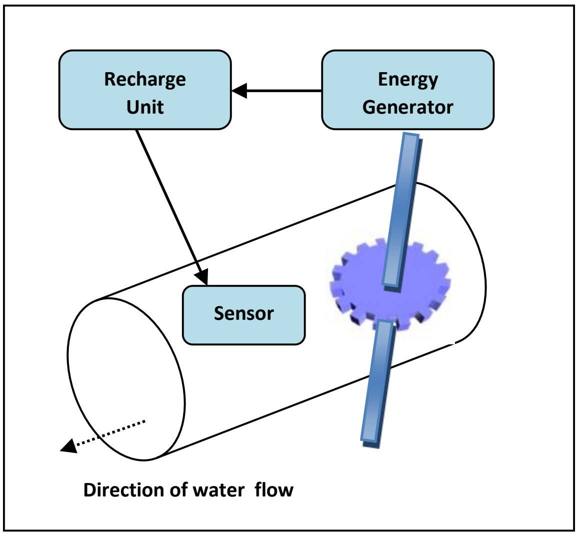

Figure 5. The structure of 3rd sensor in this system that the energy harvested

As it can be seen from the Figure 5, a rotor is rotated by the flow of pressurized water. Then the rotating motion is being transferred to a dynamometer by a bar. Harvested energy from the dynamomoter (we have used a 12 Volt DC motor with 3500 rpm as a dynamometer that we had at the laboratory) is used to recharge a 3.9 V AA battery.

We made use a circulation pump of a combi boiler which is easily obtainable (Figure 6) in order to deploy a rotor into the pipes as it has a same structure that we want to design. But we needed to customize some parts of it to extend the length of the axes to connect the dynamometer. All parts can be seen in Figure 7 and 8. Figure 9 shows the connection of the DC motor to the combi boiler pump. Figure 10 shows the complete system of the model pipeline structure. Figure 11 shows the recharge circuit used to recharge the battery. By the pressure adjusting unit (hydrophore), we have an opportunity to run the system on the different pressure values varying from 0 to 10 bars. The pressure in city pipelines is normally 3 - 6 bars.

By adjusting the pressure between 3-6 bars we have measured 5-6 volts in the output of the DC motor connected over the pump. After that by using the circuit shown in Figure 11, we have filtered the voltage and used that voltage to recharge the 3.9 V battery with a current 30-40 mA.

Figure 6. The circulation pump of a combi boiler

Figure 7. The inside of the pump, rotated by the water flow

Figure 8. The picture of the DC motor used to generate electricity

Figure 9. The system designed to test the energy harvesting

Figure 10 Waterpipeline model of a city deployed wireless pressure sensors

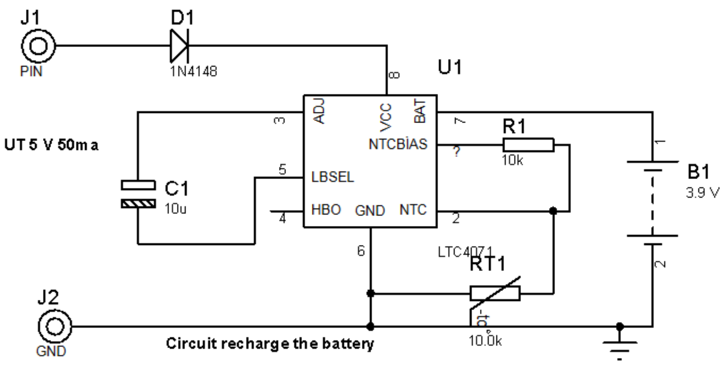

Figure 11 Circuit used to recharge the battery

4. Conclusions

WSN based water distribution systems are used world-wide both to monitor the system and to detect and locate the leakages to prevent water, money, resources. The success of these systems about monitoring the water distribution system or detecting and locating the leakages can be discussed. But all the WSN based applications implemented for this aim have the same problem- the finite energy sources commonly used batteries-. Batteries are used as power supplies to power the sensors used in the systems. Finite energy sources (batteries) is also one of the challenges of WSN and have to be faced to extend the lifetime of the system as replacing batteries especially in harsh conditions is a big problem and sometimes impossible. Finite energy sources is another challenge in the success of these systems as some sensors stop sending signals after a period of time when the batteries run out of energy.

As told above, a model of water distribution monitoring system based on the pressure values measured from three wireless pressure sensors at three different points has been implemented. By the system, the anomalies in the pressure values can be remotely analysed on the computer to detect the leakages in the pipelines. A new solution to the energy problem of the WSN has been presented which is the main purpose of this study. The solution is based on harvesting energy from the mechanical energy of water-flow through the pipes. A rotor rotated by the water flow transmits the motion to out of the pipes to a motor used as a dynamomoter and an energy of 5-6 volts DC is harvested. After filtering the voltage, a battery of 3.9 V is recharged with a current 30-40 mA at 3-6 bars water pressure. A special charging process supervision integrated circuit (LTC4071 [19]) is used in recharge circuit. It also has battery overcharging protection, which is very important for Li batteries. The circuit also has better power processing efficiency against classical charger circuits based on LEDs, resistors and linear regulators.

As the flow of pressurized water in a water distribution system would never stop, the energy need for the system will be meet forever. The same energy problem in some similar projects designed for the same purposes about the water distribution systems are faced in literature, the energy harvested by the way described above would be an efficient alternative energy source for the sensors which are used in this type of systems. The system works continuously. Recharging the battery takes –approximately- 4 hours and 22 minutes. The recharge circuit also has battery overcharging protection which is very important for Li-ion batteries.

As to find a solution to the energy problem of the sensors and to extend the lifetime of the monitoring system by supporting the batteries with this harvested power is the main point of the paper, the power processing efficiency or the harvested power levels under various conditions are ignored.

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