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LOW COST WIRELESS SENSOR NETWORKS FOR ENVIRONMENT MONITORING

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ABSTRACT

Wireless Sensor Network (WSN) is one of the emerging technologies which combine sensors and tiny embedded devices over a wireless communication medium nowadays. WSNs gather information from the environment by measuring mechanical, thermal, biological, chemical, optical or magnetic incidents and transmit the collected information from sensor nodes to a sink node. However there are many sensors nodes which can be commercially sold in the markets, these nodes cost high prices and low cost and easy to build up sensor nodes are needed in low budget applications. The aim of this study is to create a low cost wireless sensor network for environment monitoring by using Arduino Platform. In accordance to this aim, Arduino Uno R3 modules are used as wireless sensor network nodes. Moreover, to collect data from nodes and communicate between our sensor nodes, a low cost radio transceiver called NRF24L01+ is used for the wireless communication. In to monitor environment, four kinds of sensors (temperature, humidity, carbon monoxide and methane) suitable for Arduino platform selected. In addition, the collected sensors data is displayed to users with a developed windows application by using Visual Studio.Net Platform.

Key Words: Wireless Sensor Networks, Sensor Motes, Arduino.

ÖZET

Kablosuz Algılayıcı Ağlar (KAA) almaç (sensör) ve küçük boyutlu gömülü aygıtları kablosuz bir iletişim ortamında birleştiren ve günümüzde gelişmekte olan teknolojilerden biridir. KAA mekanik, termal, biyolojik, optik veya manyetik olayları ölçerek ortamdaki bilgi toplarlar ve topladıkları bu bilgileri kablosuz iletişim ortamı aracılığıyla yönetici aygıtı aktarırlar. Günümüzde çok sayıda ticari olarak satılmakta olan kablosuz algılayıcı aygıt olmasına rağmen ticari olarak bu cihazların satın alma maliyetleri yüksek ve düşük maliyetli ve kolay oluşturulabilir kablosuz algılayıcı aygıtlara ihtiyaç vardır. Bu çalışmanın amacı, çevrenin izlenmesi için Arduino platformu kullanılarak düşük maliyetli kablosuz algılayıcı aygıtlardan oluşan bir ağ oluşturulmasıdır. Bu amaç doğrultusunda, Kablosuz algılayıcı aygıtları oluşturmak için Arduino Uno R3 modülleri kullanılmıştır. Aygıtların kablosuz olarak birbirleri arasında iletişim kurması ve aygıtlardan gelen verilerin toplanması amacıyla, düşük maliyetli NRF24L01+ radyo modülü kullanılmıştır. Çevrenin izlenebilmesi için dört çeşit (sıcaklık, nem, karbon monoksit ve metan) Arduino uyumlu almaç seçilmiştir. Almaçlardan toplanan bilgilerin kullanıcılara gösterilmesi amacıyla Visual Studio.Net platformunda bir bilgisayar programı geliştirilmiştir.

Anahtar Kelimeler: Kablosuz Algılayıcı Ağlar, Sensör Aygıtları, Arduino.

1. INTRODUCTION

In recent years, Wireless Sensor Networks (WSNs) are getting popular in observing the physical world, monitoring the hostile environment and tracking systems. WSN implementations are used in various applications in the literature for instance monitoring habitat, volcanic eruption, battlefield surveillance, vehicle tracking and detection, and monitoring inaccessible or wild environments (Akyildiz, I.F. et al., 2002). WSNs gather information from the environment by measuring mechanical, thermal, biological, chemical, optical, and magnetic phenomena (Yick J et al., 2008).

A WSNs consist of sensor nodes and one or more manager nodes (Hussain F. B., 2008). The number of the sensor nodes varies based on the WSN applications. There are two main steps in WSNs. First, sensor nodes sense the environment with their sensors. After the sensing process the collected sensor data is delivered from the sensors nodes and directly sends to the sink nodes. The network topologies are depended on the WSN applications. A WSN example is given in Figure 1.

A sensor node device also known as sensor mote is a node in a sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network

(Wikipedia, 2011). A wireless sensor mote consist of a power unit, communication subsystems (receiver and transmitter), storage and processing resources, analog to digital converter (ADC) and sensing units (Kalaycı, T.E., 2009), as shown in Figure 2. The sensing unit observes the environment. After that the collected analog data are converted to digital format by ADC and analyzed by a processor then transmitted to nearby sensor nodes.

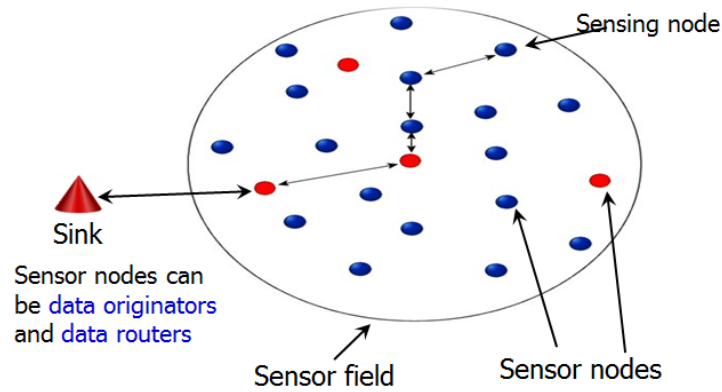


Figure 1: A WSN Example.

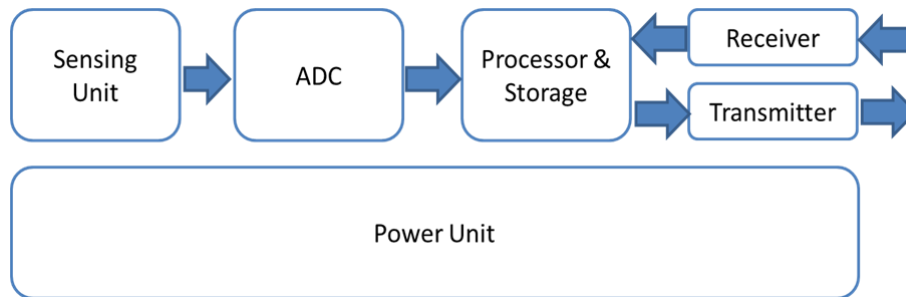


Figure 2: Components of a sensor node.

Nowadays, well-known semiconductor producers develop various types of microcontrollers suitable for WSN motes. However, there are many sensors motes which can be commercially sold in the markets some of these motes cost high prices. Because of the higher prices researchers and electronic prototype developers looking for a low cost and easy to build up sensor nodes. Some of the sensor mote examples are given in Table 1.

Table1: Examples of some commercially sold sensor motes in the internet.

Name	Manufacturer	Price	Release	Device
G-Node G301	SOWNet Technologies	68 euros	2010	TI MSP430F2418
MTM-CM3000-MSP	AdvanticSys	80 euros	2011	TI MSP430F1611
TMote Sky/TelosB	MEMSIC	N/A	2005	TI MSP430F1611
Wasp mote (starter kit)	Libelium	199 euros	2011	Atmel ATmega1281
MICA	Memsic	N/A	2003	Atmel ATmega 128L

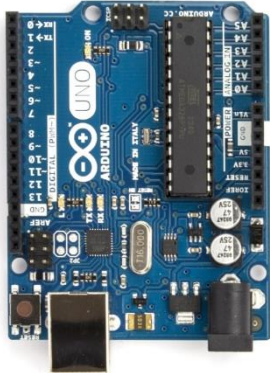
The aim of this study is to create a low cost WSN for environment monitoring by using Arduino Platform. In accordance to this aim, Arduino Uno R3 modules are used as WSN motes with NRF24L01+ wireless modules for the wireless communication. In order to monitor environment four kinds of sensors (temperature, humidity, carbon monoxide and methane) suitable for Arduino platform selected.

2. THE STUDY

The main idea of our study is to set up sensor nodes for environment monitoring system. For this aim, Arduino Platform is selected to develop our sensor nodes. Arduino is an open source prototyping platform for developers. Arduino provides easy to use hardware and software for developers, supports rapid development platform for beginners and flexible enough for advanced users (Arduino Web Site, 2015). Moreover, Arduino runs on Windows, Linux and Mac operating system which allows cross-platform development. These properties make the Arduino platform popular in electronic applications.


In the first step, Arduino Uno R3 kit is selected for the sensor mote microcontroller. Arduino Uno R3 board is using ATmega328 microcontroller with 16MHz clock speed. Technical details about Arduino Uno R3 development kit is given in Table 2.

Table 2: Properties of Arduino Uno R3 development kit (Arduino Web Site, 2015).

	Microcontroller	ATmega328
	Operating Voltage	5V
	Input Voltage	6-20V
	Digital I/O Pins	14 (of which 6 provide PWM output)
	Analog Input Pins	6
	DC Current per I/O Pin	40 mA
	DC Current for 3.3V Pin	50 mA
	Flash Memory	32 KB (ATmega328)
	SRAM	2 KB (ATmega328)
	EEPROM	1 KB (ATmega328)
	Clock Speed	16 MHz
	Weight	25 g

Arduino Uno kit does not have any wireless communication module in stock. In order to support wireless data transmission we prefer NRF24L01 RF Transceiver Module suitable with the Arduino platform. NRF24L01 module supports 2.4 GHz wireless data transmission with low energy consumption (Semiconductor, 2009). The properties of the 2.4 GHz NRF24L01 transceiver module is given in Table 3.

Table 3: Properties of the 2.4 GHz NRF24L01 RF Transceiver Module (Semiconductor, 2009).

	Power supply :	1.9V~3.6V
	Working current:	13.5mA at 2Mbps / 11.3mA at 0dBm output power
	Sensitivity :	-85dBm at 1Mbps
	Emission distance	:70~100 meter at 256kbps
	Data rate :	256Kbps / 2Mbps
	Communication mode :	Enhanced ShockBurst TM / ShockBurst TM
	Working mode :	Power Down Mode / Standby Mode / RX Mode / TX Mode
	Temperatures :	Operating:-40°C ~ 85°C / Storage:-40°C ~ 125°C

Sensor selection is the other important task for environment monitoring applications. For this purpose, at the first glance we decided to sense temperature, humidity values, methane and carbon monoxide values. In the second step, Arduino suitable sensors are supplied. MQ-4 Methane gas sensor module used for methane and lpg gas detections as shown in Figure 3a. MQ-7 Carbon monoxide sensor module is used for air quality and CO detections as shown in Figure 3b. DHT11 sensor is used for temperature and humidity monitoring. DHT11 supports 0 to +50 °C temperature measurement range and $\pm 5.0\%$ RH humidity measurement with low power consumption as shown in Figure 3c (DHT11 datasheet, 2015).

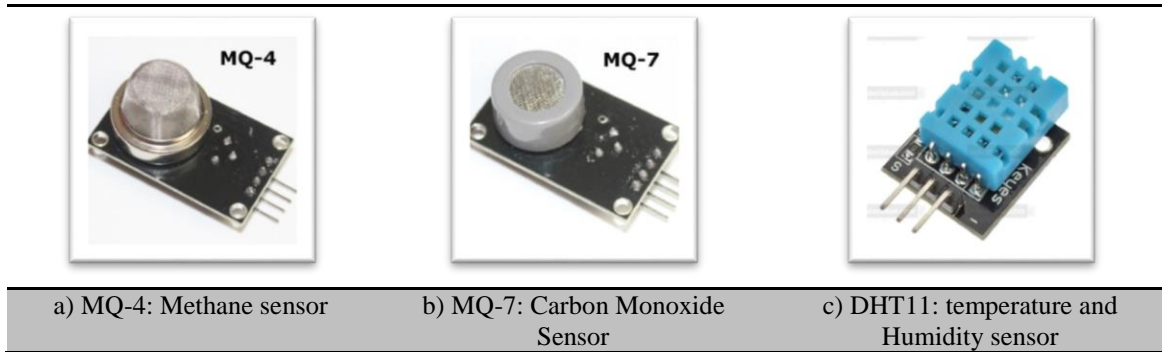


Figure 3: Arduino suitable sensors.

In the third step we combine these modules to each other and make our first prototype as our sensor mote as shown in the Figure 4. NRF24L01 module works with 3.3V DC voltage and supports 2Mbps data rate at 2.4GHz ISM band (Semiconductor, 2009). NRF24L01 module supports 125 different channels between 2.4GHz and 2.525 GHz frequencies and each channel has 6 data pipes for data communication (Semiconductor, 2009).

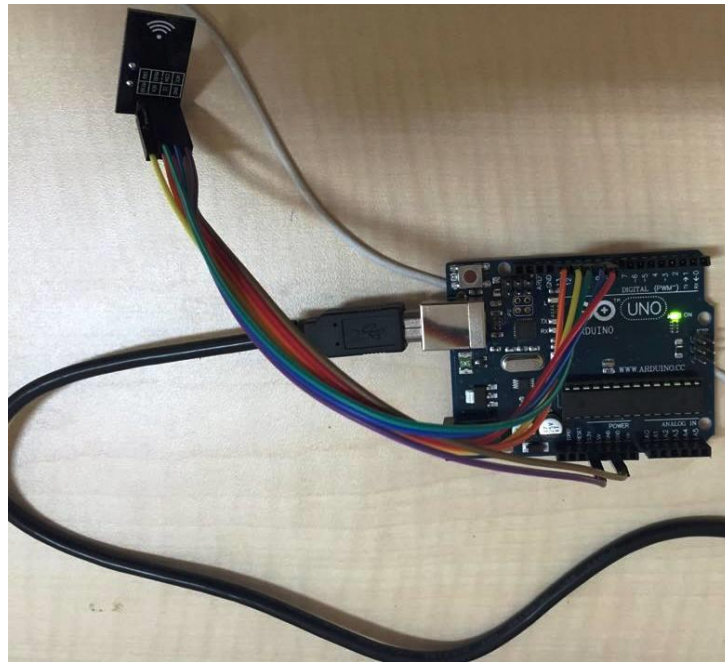


Figure 4. Arduino Uno R3 with NRF24L01 module

There are several libraries for Arduino wireless applications. One of this called MySensor library developed by Henrik Ekblad and his team mates is used in our study (MySensor, 2015). MySensor library allows Arduino users to build up wireless networks with Arduino modules. MySensor library allows 64516 sensor nodes in a network in theory as far enough four our experiments.

3. EXPERIMENTS AND RESULTS

Experimental studies are done in the Embedded Laboratory of Dokuz Eylül University, Computer Engineering Department. In the first experiment we build two sensor motes and test our NRF24L01 wireless modules radio signal ranges for data transmission. One of these modules work in a sender and the other one works in receiver mode.

Radio signal test are done in two different scenarios. In the first scenario range test are done in open area without any obstacles. Two sensor nodes are used for this test. One of the sensor nodes work as a sender and the other one is in receiver node. The NRF24L01 modules can transmit data up to 75 meters in open area tests. In the second scenario we test the RF modules in a closed place, its range is highly reduces and the data cannot be transmitted far than 25 meters behind 50 cm concrete wall. The signal strength reduction is too much which means you cannot place sensor nodes far than 25 meters between them that makes our sensor network coverage in a 50m diameter circular area. This range is not enough for wide area environment monitoring applications. In order to widen our RF signal coverage area of our network we need to implement multi hopping wireless sensor networks.

In the second part of our experiment a multi-hop wireless sensor network is implemented to cover wide areas. In order to achieve this issue, four new sensor nodes are added into sensor network. The Wireless sensor network schema is given in the Figure 5.

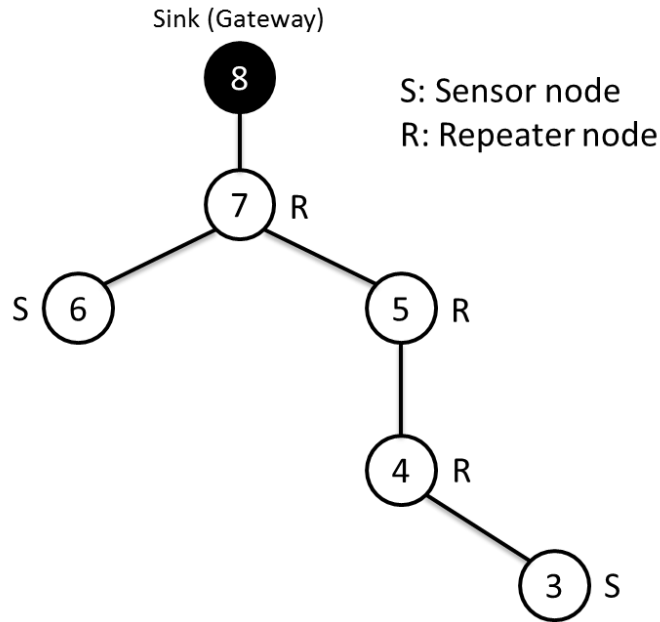


Figure 5: Multi-hopping Wireless Sensor Network schema

The WSN consist of 6 sensor nodes. The numbers given in Figure 5 represent the sensor identification numbers (IDs). Each sensor node in the network has a unique ID number. ID numbers are static and given to each sensor node before the adding them into network. Moreover each node knows its higher nodes sensor ID for data transmission. Nodes with ID 3 and 6 are working as sensor nodes which collect data from environment and transmit its sensor data to its higher node. Node 8 is the sink node, all the sensor data coming from sensor nodes are collected from sink node. Sink node is also connected by a computer via USB port to collect and monitor the data flow coming from the WSN. Nodes 4, 5 and 7 are used as repeater nodes which are used for collecting sensor data from far nodes to the sink. Repeater nodes can also support multiple sensor nodes and transmit their data. The developed sensor nodes are given in Figure 6a.

In the third part of our experiment temperature humidity and gas sensors are tested for suitable for environment monitoring applications. The sensor node with the DHT11, MQ-4 and MQ-7 sensors is given in Figure 6b. DHT11 sensor supports 0 to +50 °C temperature measurement range. The accuracy of the sensor is $\pm 5.0\%$ RH humidity for ± 2 °C for temperature (DHT11 datasheet, 2015). Response time of the sensor is lower than 5 seconds with low power consumption. However, the properties of DHT11 is adequate for environment monitoring, DHT22 is

recommended for more sensitive applications. The MQ-7 can detect carbon monoxide gas concentrations between 20 to 2000ppm (MQ sensors datasheets, 2015). The MQ-4 methane gas sensor can detect natural gas concentrations between 200 to 10000ppm. Both MQ-7 and MQ-4 gas sensors are sensitive enough for monitoring applications (MQ sensors datasheets, 2015).

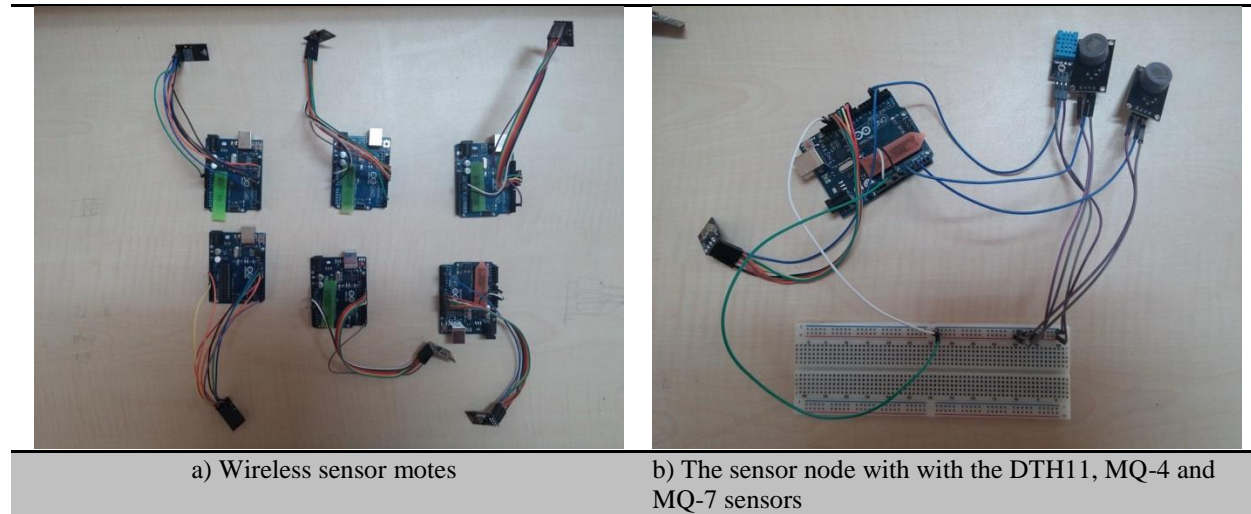


Figure 6: Wireless sensor nodes and sensors.

In order to visualize environment monitoring application a computer program is developed to monitor sensors data collected from the WSN. The program is a windows application developed in C# programming language in Visual Studio.net 2013. The screenshot of the developed WSN monitoring program is shown in Figure 7.

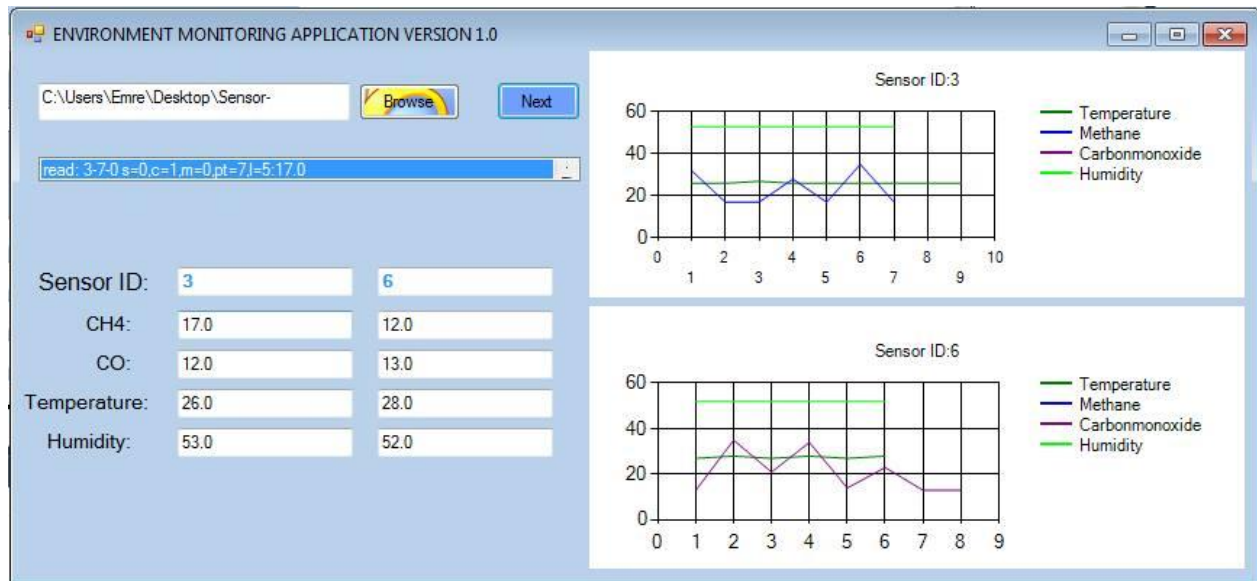


Figure 7: Environment monitoring application.

In the last part, we calculate the cost of our sensor mote. The total cost of a wireless sensor mote is about 12 American dollars with all sensors and other parts which can be affordable for various environment monitoring applications.

4. CONCLUSIONS

WSNs are one of the significant topics in the literature. Real world implementations of WSN and sensor motes are discussed compared in this article. However, there are many sensors nodes which can be commercially sold in the internet most of them have high prices and there is a need for low cost and easy to build up sensor nodes. In this study, low cost WSN network design and implementation is presented for environment monitoring applications. For this aim, a low cost alternative sensor mote is developed by using Arduino platform for environment monitoring system using four different sensor parameters. In order to enlarge sensing filed of the WSN, multi-hop based sensor network application is implemented. Moreover, environment monitoring application with our sensor motes is implemented and a windows application is developed to monitor sensor's data collected from the WSN. The cost of the sensor mote is suitable for small budgets and prototype studies. In order to enlarge sensing filed of the WSN, multi-hop based sensor network application is implemented.

Energy efficiency is one of the most important tasks for WSNs. In the next studies, in order to extend sensor network life time, we are going to focus on energy consumption of sensor motes and network traffic.

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