The Environmental Applications of Wireless Sensor Networks

Ima Ituen*
Faculty of Environmental Studies
Gunho Sohn
Faculty of Science and Engineering
York University, Toronto, ON M3J 1P6, Canada

ABSTRACT

There has been increased interest in wireless sensors in the last few years. This paper provides insight into the properties that make these sensors so attractive, specifically considering their efficiency, data reliability, and the ability to verify the data generated. Some advantages a wireless network presents over traditional information sensing are discussed as well. The paper considers how the environmental field can benefit from using these networks. Some of the possible challenges this industry will face in adopting this new method of data sampling and collection are also considered. A project we conducted raised concern over measures needed for the integrity of the communication system to be maintained, thus ensuring the integrity of the data being collected. From results of an experimental project conducted in York University, the reliability and usefulness of a sensor network is discussed.

Keywords*: Sensor Network; SenseWeb; Sensors; Network Application; Environmental applications.*

1. INTRODUTION

ADVANCES in wireless technology in recent years has allowed researchers and practitioners to sojourn in areas that were unthinkable a few short decades ago. Wireless technology has been useful in industries interested in topics such as cellular phones, GPS units, satellite television, remote sensing, and the internet. One of the tools that have been introduced in remote sensing of late is a sensor called the Mote. A mote is an abbreviation for 'remote' node and refers to the individual sensing units that form a wireless sensor network [1]. The nodes of the network – the motes - are tiny microcomputers that employ wireless media to communicate with other motes [2]. Because it is thought that motes are intended to be microscopic, or as small as dust, these sensors are sometimes referred to as "Smart Dust" [3].

Motes range in size from a few centimetres to a matter of millimetres; as a result, they can be placed in the most space-constrained area. [2] Mote architecture typically comprises a processor, transceiver, and a sensing unit. Optional components of a mote are a location finding system e.g. GPS, and a mobilizer when it is necessary for the motes to move on their own [1], for instance when they are following an object of interest. The objective of the motes is to extract pertinent information under several constraints such as low computational capabilities, limited arithmetic precision, and the need to conserve power [4].[1]

Each mote has the capability of providing various sensor measurements, ranging from measuring the surrounding magnetic field and sound level, to measuring temperature and acceleration. With a variety of sensor types, applications for these motes can include enemy detection for military uses or monitoring machines for failure in industrial applications. These applications require another feature inherent in every mote namely the ability to self-form an ad-hoc wireless network with other motes [2].

Sensor nodes can able to collaborate among themselves to establish a sensing network, showing their self-configuration ability. There can be hundreds or thousands of tiny sensor nodes spread across a geographical area. They can then form a network such that the network can provide access to information anytime and anywhere, by collecting, processing, analyzing, and disseminating data. Thus, the network actively participates in creating a smart environment [5].

These sensors are very useful for environmental applications also. As a network, they have been used to detect environmental hazards such as earthquakes and floods. One of the main attractions to the motes is their ability to gather data from remote areas. Since the sensor nodes have wireless communication capability for disseminating the data they collect, researchers can monitor remote terrain from the comfort of an office. Some have even deployed the motes to analyze remote locations, observing the motion of a tornado, or detecting fire in a forest. It is possible to make sense of the data gathered when a sensor network covers a large area because each node can be georeferenced.

As an individual component, a mote has limited benefits yet as part of a network, a mote becomes much more powerful and provides more advantages [2].

* Corresponding author
Email addresses: {iituen, gsohn}@yorku.ca

2. MOTIVATION

With access to the internet being so ubiquitous in the city, there seemed to be no logical reason for the residents of Toronto and beyond not to enjoy the benefits of a sensor network in their daily lives. Some of the more widespread functions the public uses online sensor networks for involve monitoring traffic flow on a particular route, checking the local gas price, or even seeking the current wait-time at a restaurant. The most common form of sensors that appear on Microsoft's SenseWeb website is the thermometer, however. This may be due to demand, or because temperature sensors are cheaper than some other sensors that gather more delicate data.

Following the trend, this project was introduced as a pilot endeavour to see if the temperature at York University could be uploaded to Microsoft's SenseWeb website, and later to add cameras to monitor traffic. What it evolved into was much more than the initial goal, and we envision it bringing not only the intended publicity to York University and by extension Toronto (since no temperature sensors from the city has yet been on the SenseWeb website), but it could also help rectify an internal problem in York University.

The sensor network initially comprised of only two sensors to perform preliminary tests. When it proved workable, more sensors were added to the network, finally reaching the current total of thirteen sensors deployed around York's campus.

The first challenge to be addressed was verifying the scalability of the sensors since the intention was to add as many sensors as possible to the network. Scalability indicates the ability of a system to either handle growing amounts of work in a graceful manner, or to be readily enlarged [3]. We needed to ensure that the communication between the motes, and that between the motes and the gateway could be maintained as we increased the nodes of the network. Another concern we wanted to address before launching the sensor readings on SenseWeb was the accuracy of the temperature values. Our project included a mote to act as a Control to test the accuracy of our sensor readings.

A third aim of the project was to test the viability of operating a sensor network. Would it be feasible financially? Was the data generated as useful and reliable as to warrant further investment? Although many of a sensor network's uses are not so obvious, we believe that the community would be interested in it when the concept is introduced to them. Because it potentially can be a time-saver, like when it is used to indicate which route has lower traffic volumes, it can draw a large part of the North American market. Time saving appears to be very important to citizens in this demographic.

3. CURRENT APPLICATIONS OF SENSOR NETWORKS

3.1 Background: Anatomy of a Sensor Network

The first level of the sensor network is the sensor mote. A sensor board needs to be attached to the mote to gather the data, and the combination of the two is normally referred to as a sensor node (a node of the network) or a mote (the shortened form of 'remote node'). Each of the nodes is autonomous and gathers data reflecting its immediate environment. The temperature, ambient light, pressure, vibration, or the photographic image of its environment is among the data sensor nodes gather. The motes form an ad hoc network that relays the sensor data to a specified destination for processing. It is possible for the nodes to form a multihop network also, enabling them to forward each other's messages [6]. The multi-hop capability of the network allows it to be scalable.

The sensors regularly send updates of its health status, recorded as 'Node Health' by the software. This allows the user to monitor attributes such as each sensor's battery voltage, the percentage of dropped packages, and the quality of transmission and reception. The frequency at which health messages are transmitted can be adjusted by the user.

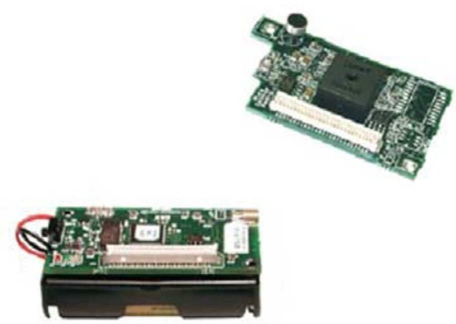

Fig. 1. Picture of sensor used in project. At the front is the MICA2 mote, at the back is the MTS300 sensor board.

All motes include a fully programmable microcontroller, two-way ISM band radio transceiver, and flash memory for over-the-air-programming and data logging of up to 100,000 measurements. The motes we used in this project had a 433MHz radio transceiver frequency. Motes with higher frequencies also exist, such as those of 868/916MHz, or 2.4GHz. There are a variety of sensor suppliers in the market. Those used in this project were from Crossbow Inc's MOTE-KIT 4000. The mote is powered by two 1.5V AA industrial batteries which typically supply between 3.1V to 3.4V when new. The sensors require at least 2.8V to provide reliable data.

One can select from an assortment of sensor and data acquisition boards for the MICA motes. The sensor board we used was the MTS310. This sensor has a sounder or "buzzer", a microphone, thermistor, x-y accelerometer, x-y magnetometer, and photoresistor. Thus, our network was able to acquire data in its environment such as the sound level, temperature, tilt, magnetic fields, and ambient light. The accelerometer can also be used for movement, vibration, or seismic measurement. The microphone could be used for acoustic recording and measurement. Audio files can be recorded in the logger flash memory of the motes to be downloaded and analysed at a later time. Used with the sounder, the microphone can be used for acoustic ranging. This application requires two nodes, as one will be listening for the sounder from the other mote, and then the 'time-of-flight' value of the sound is converted into an approximate distance between the two motes [10].

Sensor boards, combined with a wireless mote, have capabilities to sense such parameters as ambient light, barometric pressure, GPS, magnetic field, sound, photosensitive light, humidity and temperature. All of these boards connect to the MICA2 via the standard 51-pin expansion connector. Custom sensor and data acquisition boards are also available. An attractive feature of these sensor boards is that they can be reprogrammed remotely.

The next level for data acquisition is the gateway which connects the network nodes to the station storing the data. The gateway is connected to the computer system either by a USB port or by the RS-232 serial port. It is the standard interface between the PC and the motes. Following the specifications of the motes used in this project, the gateway could be over 500m away from them and still acquire data. This was a key feature of the sensors as the area that was mapped out to be monitored on the University campus was large.

Fig. 2. Picture of MIB510 gateway which uses a serial port with base board attached.

A base board allows the aggregation of sensor network data onto a PC or other computer platform. Any MICA2 Mote can function as a base board when it is connected to a gateway board and programmed as such. Fig. 2 shows the mote used as a base board for this project.

The final component of the sensor network is the end-user's computer system. The user needs to communicate with the sensors using a software program. It is possible for the sensor network to be monitored by more than one person at a time, thus each observer can access the network's activities from their own computer terminal, connecting to the network either through a local intranet or the internet. Each user that is not using the computer directly connected to the gateway would connect to the network setting the software's Acquisition Type to 'Remote'.

Some of the software programs that can act as an interface between the end-users and the sensors are SerialForwarder, MoteView, and TinyOS. For the purpose of this project, MoteView 2.0 was used.

3.2 Applications of Sensor Networks

1) **Habitat Monitoring**: One of the foremost advantages of using a sensor network in obtaining data is its ability to acquire data unobtrusively. There have been many studies done on the anthropogenic effect on plant and animal behaviour when someone is physically present monitoring their habitats. It is suspected that the effects of human interruptions on sensitive animal populations manifest in reduced breeding success, or an increase in stress. One research result indicated that a fifteen minute visit to a cormorant colony could result in a mortality rate of up to 20% among the eggs and chicks in a breeding year [6]. Plants on the other hand may suffer from the trampling of the researchers, the introduction of exotic elements through frequent visitation, and changes in local drainage patterns through path formation [6]. A researcher can solve such problems by setting up a sensor network prior to the breeding season, for instance. That way, the data can be obtained without disrupting the ecosystem significantly and an observer can be a great distance away monitoring the data. It also ensures the data being gathered is more reliable, not considerably influenced by stimuli foreign to that environment.

2) **Serving Multiple-goal Project**: Once it has been determined that a network is scalable, vastly different purposes can be achieved by the sensors in the network. More and more sensors can be added to the network, depending on the purpose of the data collection. A wireless sensor networks can provide a wide array of sensing information – for instance seismic data, acoustic data, and high-resolution images – displaying its interoperability. With the sensors networked, they can aggregate the data to provide a rich, multi-dimensional view of the environment [7]. The University of California, San Diego, set up a network of video cameras originally intended to generate images of an area of interest. However, even though it was not the intention when deployed, the cameras were situated in a position to capture footage of Hurricane Isabel in 2003. When the researchers and students noticed this, they were able to increase the sensor's sampling rate to watch as the hurricane unfolded. That same camera was used to count fiddler crabs, monitor fish during high tides, and then to observe colonies of nesting herons [9].

The flexibility of operating a sensor network can be harnessed when challenges such as battery power conservation are at hand. Instead of linking each sensor directly to a central communication point, the nodes can save power by having nodes send their data to a "Captain" (the aggregate node) which gathers the data in that section and forwards it to the gateway. The software coordinates which sensor 'talks' and at what time. The nodes then 'listen' for each other and follow a schedule to time when to share data [8]. The aggregator nodes are sometimes termed 'Parent nodes' when data is displayed, as seen in Fig. 6. Aggregator nodes that cache, process and filter the data are useful in case of data redundancy, to compensate for sensor nodes' failing [5].

3) **Agricultural Uses**: Sensors deployed in agricultural settings are normally used to monitor such qualities as soil moisture, temperature, and nitrogen content. Depending on the sensor type, it is also possible to track pests on the farm land. Because vineyards are so sensitive, the properties most often monitored by the sensors have to do with the micro-climate. Thus the heat, humidity, and soil moisture are measured regularly.

4) **Seismic Sensing**: A team of researchers at the University of California, Los Angeles, are studying seismic activity on a much smaller scale than is normally done, investigating the effect of earthquakes on individual building components [8].

They have deployed sensors on different parts of buildings spacing them 100m apart. They envision that this will generate a resolution surpassing current seismic sensors, which are spaced apart by kilometres [8]. The researchers will be able to discover how structures respond to localised variations in an earthquake's strength. Also, they can compare how the vibrations measured by their sensor network compare with the data gathered by the U.S. Geological Survey (U.S.G.S.) inside a campus building wired by the U.S.G.S.

5) **Motion Tracking**: Movement in a room can be tracked using sensors that sense motion. Some of these sensors can be leveraged for more intelligent purposes such as detecting when no person is present in a room and turning off a light switch. Some networks anticipate the destination of the occupant of the room and relays messages to the motes ahead to prepare them for the person. That might entail switching on a light or enabling a security feature, perhaps. The MTS310 sensor board we used in this project can be used for vehicle detection also. Successful test have detected disturbances from automobiles at a radius of 4.5 meters [10].

6) **Security, Surveillance and Force Protection**: A very important social application of sensor motes is their use for surveillance activities. The trends in technology bode well for such security activities since surveillance appliances are getting smaller and smaller. As it becomes the "smart dust" that it is projected to be, sensor networks can become the more preferred choice to spy on the unsuspecting [7]. Sensor networks are good for providing security in a shopping mall, parking garage or other facility. For the Military, sensor networks can detect, locate or track enemy movements, and even increase alertness to potential terrorist threats. [5]

3.3 Environmental Uses of Sensor Networks

Wireless sensor networks have opened up an opportunity previously unavailable for environmental monitoring. They save a vast amount of time also where traditional methods required setting up a lot of equipment, or monitoring a site demanded one to be physically present. Remote sensor networks perhaps even extends researcher's range of monitoring because more sampling is possible in less time. For instance, where it would have taken three days to survey a 200 hectare plot, it can be done in a few minutes if a many sensors are deployed over the area. Reference [9] gives an example of a wildlife biologist being able to conduct a spring bird survey using over one hundred acoustic sensors covering twenty listening posts in five forest types. It is anticipated that the increased spatial extent made possible to be covered for environmental monitoring will definitely pay off to more discoveries in the coming years.

The data gathered by the sensors can be used to generate maps of ecosystem distribution. This will reveal the distribution and diversity of ecosystem types. It is important to know the ecosystem distribution so as to improve models on the ecosystem's diversity [11]. The sensor network can be a major part of conducting remote sensing of ecosystems.

A very important use of sensor networks in the environmental arena is for monitoring rare flora or fauna species. Monitoring for environmental purposes which focuses on the effects of climate change entails monitoring biological diversity and ecosystem functioning, or biogeochemical cycles. Also chemical vapours, gas concentrations, relative humidity, and barometric pressure need to be detected. Sensing the data relevant to these ecosystem properties can be done using an interoperable wireless sensor network.

Many ecological systems are subject to processes that are not linear. Thus a combination of factors affects the system, such as a physical/biological combination. This makes finding a solution to a troubled ecosystem that much more difficult. Coupled with the fact that different monitoring tools or techniques may be used on a particular site, and the data generated from the multiple tools is not uniform, could cause more difficulty to environmental analysts. For instance, some of the tools may be set to sample once a week, while others are gathering data every hour. Whichever way this problem is resolved, using a wireless sensor network or not, it is imperative that for more progress and faster development in the environmental arena that an interdisciplinary approach be taken. There are many phenomena that interact in the physical environment, and expertise from a variety of disciplines is needed to accurately analyse the situation, and subsequently propose proper remedial action to problems [12].

3.4 Advantages of a Wireless Sensor Network

Highlighted below are a few advantages of using wireless sensors deployed in a network over collecting data manually from work sites at determined intervals from different locations. (The manual data collection is usually done by data loggers.)

- Data loss is reduced because the remote sensors can be constantly monitored. When something goes wrong, it will be evident more quickly than if the observer waited until the end of the study period (like the mating season perhaps) to collect the data.
- It is possible to have a high sampling rate over large spatial scales. This high sampling rate enables changes to be seen clearly.
- Phenomena can be observed unobtrusively. As discussed earlier, anthropogenic interference can be quite harmful to sensitive environments.
- Negative weather conditions do not affect a researcher's work. A researcher can monitor a site from the comfort of a remote computer. This advantage is especially welcome in hostile environments.
- It is possible to have many users viewing the data simultaneously, and also manipulating it. The multiple users do not have to wait for the data to be downloaded to them a week or a month after the event as is often the case if a data-collector retrieves data from a remote work site.
- Real-time data can be accessed and analysed, as the students and instructors did seeing the effects of Hurricane Isabel described above [3]. If a phenomenon of interest occurs, one can increase the sampling rate to gather more data, reducing the risk of missing an important event.
- The sensor networks are self-healing, so a node can be added or removed without having to restart the network. This is especially useful if one or more of the nodes die during operation. The network will

reconfigure itself and then determine which route to use to send the messages to the base station.

- The reliability of the data being acquired can be verified from the constant monitoring of the nodes' health status. The user can program the sensor to send their health status to the gateway as frequently as they choose.
- Fewer personnel are required to perform data collection from remote sites. A researcher does not need to hire a horde of data loggers to gather data from each work site.
- Sensors connected in a network have very good redundancy. Thus, when one node of the network fails, the others can continue to send data to the collection hub. The network simply self-organizes and there is no loss of data from the remaining nodes that still function.

3.4 Challenges in Operating Wireless Sensor Technology

Unfortunately, the wireless network system is not yet cost-effective for all applications. So though it has wonderful advantages over traditional methods of monitoring phenomena, for the most part the business case for employing a sensor network cannot yet be made. One sensor node costs about $130 (from Crossbow Inc.). For some industries, the sensors can be considered cost-effective as they monitor multi-million dollar equipment, so on balance, it is cheaper to install a sensor network than repair the expensive equipment. Unfortunately, on smaller scales, traditional methods would be chosen even though they may be less efficient to operate.

When building a sensor network for a particular operation, the sensors have to be chosen carefully because their radio range is limited. If a field to be covered is quite large, the user may have to set up multiple networks to monitor the entire area. Crossbow's 868Mhz or 916MHz motes have an outdoor range of only 165m, while the 433MHz motes we used can transmit at twice that distance outdoors. The 2.4GHz motes have an outdoor range of only 75-100m. The transmission range for motes is normally much lower indoors, depending on the number of obstacles present.

Another important challenge that faces sensor technology is the struggle to extend the lifetime of the sensor network. [5] The power supply is the part of the system that comes to mind most readily when thinking of system failure for the network. Numerous tests have been done to estimate the average battery lifespan. No definite time has been concluded, but Crossbow Inc's tests have reported Mica2 motes worked for 172 hours when transmitting data every four seconds. By then, the battery level was at 2.1V. They also recorded five more hours of life for the motes when an 85% efficient battery booster was used. [13]. Other researchers' experience was slightly different, however [14]. For them, the battery was unable to supply enough current to power the node when the voltage went below 2.3V. With a boost converter on the mote, they were able to extract 15% more energy from the battery when the voltage went below 2.5V. [14]

Finally, even though deploying sensors on a remote field is normally seen as a benefit to a cash-strapped researcher, it could be seen as a social ill: the loss of a person's livelihood to technology. Whereas traditionally a team of students might have taken field trips to download data from remote sites, the entire team's services are not required when wireless sensor networks are installed instead.

4. YORK PROJECT OVERVIEW

As mentioned above, a range of wireless sensors have been used for a variety of purposes. One of the uses they have been put to is for an intelligent building management. In this capacity, sensors have been used for building systems such as HVAC, lighting, environmental, and security applications. Generally, when such technology as the sensors is used to monitor building properties, it is termed a "smart building". These low-power wireless networks give smart-building systems distributed sensor nodes to optimize control algorithms [19]. So they can be used for climate control, security, or fire protection. Our intent in the project was to leverage the sensor technology for smart building management. We wanted to investigate the potential of the sensor network replacing the traditional methods for setting temperature in the building.

York's Chemistry Building is one of the more recent buildings, opened in 1993. It adjoins the Petrie Science and Engineering building which was opened five years earlier. They are connected by a 25m hallway. The experiment entailed determining if there was a significant difference in temperature between these two buildings. We would then be able to propose having the temperatures in the buildings monitored by our network to maximize the comfort of the occupants, at the same time perhaps making it easier to handle the building management. For instance, temperature adjustments could be made more rapidly in response to weather changes, as the network can provide real-time data.

First of all, to start the project, the thirteen sensors were programmed. They were programmed with XMTS310CB_433_lp, indicating that they were being programmed with XMesh for an MTS310 sensor. XMesh is a full featured multi-hop, ad-hoc, mesh networking protocol developed by Crossbow for wireless networks [18]. The mote programmed as a base board had XMeshBase_433_lp uploaded to it, assigning it an ID of zero. We placed sensors at different parts of both the Chemistry building and the Petrie building, and the corridor connecting both buildings.

To do an approximate check that the data being generated was accurate, we tested the ambient light intensity. Mote 3 was put under a table in an unoccupied office in the Petrie building so it would detect as little light as possible (even though some light was coming in through the window). It acted as a Control in the experiment for the ambient light data.

A look at the distribution of the sensors as they appeared in the network is shown below.

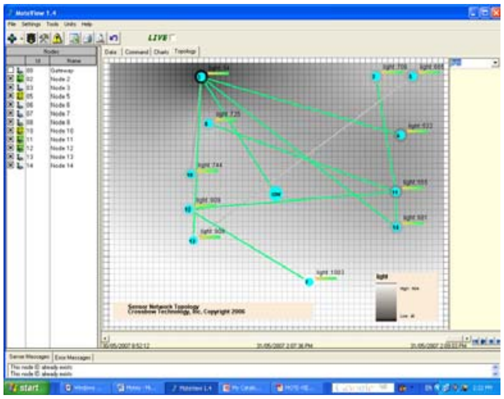

Fig. 3. A depiction of the sensor network. The blue circles are the nodes (sensor motes) and the middle circle depicts the gateway,

The sensors in the Chemistry building were Motes 6 and 8. Some of the sensors in the Petrie building were Motes 10, 14, and 11. We placed one in the hallway between the two buildings also. This was Mote 7.

Mote 3 showed a significantly lower light intensity reading. While the other motes recorded ambient light values that were between five hundred and nine hundred , Mote 3 recorded values between twenty and sixty . Mote 7 gave higher readings however, since it was placed right beside a window in the hallway adjoining the two buildings. Its light intensity values averaged at one thousand.

The data gathered in MoteView can be exported to a spreadsheet. Table 1 is a sample of the data generated during this project. Two of the sensors that were in the same lab were nodes 12 and 13. The similar data they gathered is evidence of the motes' data reliability.

The Chemistry building consistently had a higher temperature than the Petrie building. They were monitored over a morning to late afternoon one day and the temperature difference was between 1° to 2º over the entire monitoring period. A building about 200m away from the Chemistry building was monitored two weeks later, and the chemistry building was still warmer than that one.

We found out from York University's Maintenance, Utilities, & Energy Management that optimally, the temperature in a building should range between 20-23°C, and the office temperature can sometimes be set individually in an office. Other times, the temperature was remotely controlled as it is in hallways.

Although no final conclusion has been drawn from the project, it enabled us to verify that the Chemistry building is warmer than the buildings around it. This was also an opportunity to use the motes for an environmental application: detecting the temperatures of buildings.

ID	TIME	PARENT	VOLTAGE [V]	TEMP [C]	LIGHT	MIC
8	5/30/07 9:51 PM	5	3.2112	23.292	941	192
14	5/30/07 9:51 PM	3	3.1076	23.292	142	177
12	5/31/07 12:41 PM	0	3.3396	22.227	771	186
11	5/31/07 12:42 PM	12	3.3219	21.736	506	167
6	5/31/07 12:42 PM	11	3.2277	23.620	558	171
7	5/31/07 12:43 PM	12	3.2194	23.456	762	163
6	5/31/07 12:43 PM	12	3.2194	21.736	518	185
14	5/31/07 12:44 PM	7	3.1231	21.818	699	181
10	5/31/07 12:44 PM	12	3.2957	21.573	725	181
3	5/31/07 12:44 PM	8	3.1231	22.718	32	193
12	5/31/07 12:44 PM	0	3.3131	22.063	778	195
11	5/31/07 12:45 PM	12	3.3219	21.573	524	169
14	5/31/07 12:50 PM	7	3.1153	21.736	743	190
10	5/31/07 12:50 PM	12	3.2784	21.818	759	181
5	5/31/07 1:03 PM	12	3.2784	22.063	614	165
6	5/31/07 1:03 PM	11	3.2112	23.374	480	171
13	5/31/07 1:04 PM	12	3.2529	22.554	911	176
7	5/31/07 1:04 PM	12	3.2029	23.456	686	163
6	5/31/07 1:05 PM	12	3.1948	21.900	432	183
14	5/31/07 1:05 PM	7	3.1231	21.736	636	183
10	5/31/07 1:05 PM	12	3.2698	21.900	676	181
3	5/31/07 1:05 PM	12	3.0999	22.718	18	177
12	5/31/07 1:06 PM	0	3.3219	21.982	411	202
11	5/31/07 1:06 PM	12	3.3044	21.573	435	173
8	5/31/07 1:06 PM	12	3.2194	23.210	654	181
7	5/31/07 1:07 PM	12	3.1948	23.620	722	165
3	5/31/07 1:11 PM	12	3.0999	22.800	22	192
7	5/31/07 1:13 PM	0	3.2029	23.456	725	163
13	5/31/07 1:13 PM	7	3.2529	22.391	908	171
3	5/31/07 1:14 PM	7	3.0999	22.718	19	184
6	5/31/07 1:16 PM	11	3.2112	23.292	466	171
7	5/31/07 1:16 PM	0	3.2029	23.456	723	163
12	5/31/07 2:52 PM	3	3.3219	21.900	925	195
13	5/31/07 2:53 PM	3	3.2444	22.554	961	162
6	5/31/07 2:53 PM	3	3.1545	21.982	920	184
3	5/31/07 2:53 PM	0	3.0695	22.882	26	185
14	5/31/07 2:54 PM	3	3.1153	21.982	925	177
5	5/31/07 2:55 PM	0	3.2698	22.063	912	165
7	5/31/07 3:47 PM	14	3.2029	27.863	994	164
8	5/31/07 3:47 PM	11	3.2112	24.114	944	176
3	5/31/07 3:47 PM	0	3.0545	22.964	26	183

Fig. 4. Table showing some of the readings taken from sensor network. Ambient light, temperature, microphone, and battery voltage are among values recorded by sensors.

5. LOOKING AHEAD: FUTURE PROJECTS

We want to expand on the network used for the project discussed here. We look to cover with sensor nodes each of the the four floors of the Chemistry and Petrie buildings. The network might not exhibit a problem with regards to scalability, but more gateways may be needed due to the range specifications of the motes. We then want to publish on Microsoft's SenseWeb the sensor data we gather of our physical environment at York University. This website allows network operators to publish their sensor data on the internet so that many others can benefit. Information has been used to provide information about a city by providing distances and best route to travel to avoid traffic congestion; the local gas price; the temperature in a city; wait-time in restaurants. The information on the website is always fresh and updated, at least by the hour. The data is displayed on a map, called SensorMap. When there is more than one sensor in a particular area, the average result is displayed. The maps are interactive, based on Geographic Information system technology. Thus, the maps can be queried by any user in any part of the world.

There have been challenges though in the publishing and use of data on SenseWeb, such as privacy and data ownership concerns for sharing the real-time physical data [14].

6. CONCLUSION

Sensor motes are low-power smart sensors that are extremely multifunctional. They can be georeferenced, and so even when deployed en masse, the data analyst can know the origin of data each mote reports. These miniature devices are also very attractive in terms of logistics because they can fit in tight spaces. They are reliable and very easy to manipulate. They have proven to be scalable and interoperable and very useful for environmental monitoring. Even though the cost may seem prohibitive in some arenas, it is very affordable for some industries as the monetary problems they prevent far exceed their costs. We do think that with more demand for these sensors, the cost may reduce even further. For instance, the motes that cost US$250 three years ago are now about half that price. This 'smart dust' should definitely be adopted for its present known uses, and for others that are being experimented on. For even further benefit, the sensor network's results can be shared on the internet.

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I. Ituen

She is a Master's candidate in Environmental Studies. She holds a B. Eng in petroleum engineering from University of Port Harcourt, Rivers, Nigeria (1998). She is interested in the applications of Geographic Information Systems for the furthering of environmental causes. As a student and research assistant, her main areas of focus lean towards industries adopting better techniques for their systems to be optimized, while doing less harm to their physical and social environment.

Gunho Sohn

He received the M.Sc. degree in Space Science from Yonsei University, Korea in 1994, and Ph.D. in Photogrammetry with remote sensing from University College London, U.K. in 2004. Since 2006, he was appointed as a faculty member of graduate studies at York University, Canada. His research works in airborne laser-scanning data processing was awarded as the best doctoral thesis from the British Photogrammetry and Remote Sensing Society in 2005. He is co-chairing the Softcopy Photogrammetry Committee at American Society of Photogrammetry and Remote Sensing (ASPRS) since 2006. His main research interests include 3D virtual city modeling from remote sensing data, artificial intelligence for urban and marine scene understanding and sensor web networking.