Deployment of an Early Warning Fire Detection System

Abstract – Wireless sensor networks are the result of interaction between intelligent sensors and pervasive computing. Many applications of the resulting technology are being designed, tested and deployed everyday. This paper presents the deployment of WSN based system for fire detection. The goal is the early detection of wildfire fire using tiny wireless sensors, organized in an ad-hoc network, equipped with humidity, temperature and light sensors, and to inform fire fighters of areas where risk of fire is present. A first deployment as already been done with good results in terms of routing and range. Dense trees, rocks and the terrain roughness are main constrains for deployment of WSNs in the wild. The components of the system, including the MonSense application, are also discussed.


INTRODUCTION

The last decade has witnessed unprecedented interactions between technological developments in computing and communications, which have led to the design and implementation of robotic and automation systems consisting of networked vehicles, sensors, and actuator systems. These developments enable researchers and engineers not only to design new robotic systems but also to develop visions for systems that could have not been imagined before.

A concrete example is the interaction of intelligent sensors and pervasive networking technology which gives wireless sensor networks a new kind of scope that can be applied to a wide range of uses: environmental and habitat monitoring, precision agriculture, indoor climate control, surveillance, treaty verification, and intelligent alarms [1].

This paper addresses the design, development and deployment of a system for wildfire detection based on wireless sensor nodes capable of measuring specific environmental parameters (temperature, humidity and light). The wireless sensor nodes are composed of environmental sensors collecting temperature, relative humidity, and light attached to a wireless, networked MOTE. The motes communicate with each other forming an ad-hoc wireless sensor network capable of monitoring the evolution of these parameters on a pre-determined forest area.

A first pilot experimentation of this system was deployed this summer in a national park in Portugal. This pilot was deployed over an area of approximately 12 hectares and used 20 wireless nodes and a base station. This pilot experiment was designed to help study aspects of each deployment which lead to specific solutions namely in what concerns routing with known geographic locations and mixed initiative interactions to enhance and validate existing models and optimal sensor placing.

Experienced heat waves in Europe in the last years were one of the major causes of the unprecedented magnitude of forest fires that devastated the southern countries and, in particular, Portugal. Preliminary estimates indicate that over 10% of the Portuguese forest was devastated in only 3 weeks in the summer of 2003. In Italy, in 2002, 22 outbreaks in the same day damaged 1.000 hectares of forest. And in Sweden, in 1997, a 10-day outbreak consumed 450 hectares of forest and costs €350.000.

Several studies were conducted at the European level (see [2]) and from all the lessons learnt the most important was that “the best way to fight a forest fire is to prevent it”. Moreover, study of typical forest fires determined that there are three important events in the evolution of a fire: initiate fire (IF); detect fire (DF); and fight fire (FF). The time to detection TD is the time elapsed between IF and DF. The time to intervention TI is the time elapsed between DF and FF. The reduction of both TI and TD may be crucial to prevent the propagation of the fire and to limit its action. The factors affecting TD are: Time of the day; Location; Type of terrain. The factors affecting TI are: Time of the day; Location and accessibility; Distance from sources of water.

By reducing the time to detection, the early warning fire detection systems will contribute to restrict the propagation of forest fires. Moreover, associated with autonomous fire fighting capabilities (see [5]) may be able to reduce fire propagation and to prevent the occurrence of situations where a fire may run unattended for hours, specially in the case of remote locations.

WSN APPLICATIONS AND STATE OF THE ART

The ability to connect sensors to a microcontroller and communicate gathered data by radio frequency has been available for a long time. But only to do it cheap, and in a size and power consumption small enough to enable the deployment of large networks of wireless devices is very recent.

We are now able to create sufficient dense and flexible wireless sensor networks. There are many people thinking in different kinds of applications (civil engineers, biologist, etc), mostly to solve problems that they deal every day.

We can divide the wireless sensor network application in three types, depending essentially from the kind of objective to be monitored. In this way we can find the first type applications, with the goal to monitoring space, including environmental monitoring, habitats monitoring, security monitoring, agriculture monitoring, and the application discussed in this paper – EWFDS – is of this type. There is a
second type of applications for monitoring things, like buildings, bridges, medical diagnostics, machine parameters for detect fails and malfunction, and all other king of things that people find interest in monitoring. Lastly we find, probably the more interesting and complex applications with goal to monitor complex interactions between space and things, including natural and environmental disaster management, healthcare, emergency response, wildlife habitats, ubiquitous computing environments, goods tracking and manufacturing process flow.

Wildlife monitoring

There are several works done is this area using the most recent technology available on wireless sensor networks. The work done in Great Duck Island to monitor the nesting habitat of seabird’s colonies is a good example [4]. The main objective is to enable researchers all over the world, a new way to do long term studies from a non-intrusive manner. In this particular case, the Wireless Sensors are deployed in the Leach’s Storm Petrel nest, existing in the island, and the readings are sent over the sensor mesh network to a ground station where the researchers can access over a wireless internet link. This is a new, more flexible and cheaper, way to obtain live and continuous environmental data without the need to affect the normal bird life.

Structure monitoring

Civil engineers and urban planners must know the condition of structures and their need for repairs and applied efforts and forces. Deploying tiny wireless sensors near critical structural points creating a large network to monitor the entire status of the main structures is a good and economic solution. The deterioration of structures can now be evaluated during the entire life of the building, by these tiny sensors, reporting continuously the location and kinematics of the critical structural points. The civil engineers actions can now be more precisely taken, to correct the structure faults.

San Francisco Golden Gate Bridge is a real example [9], where the entire vibrating structure are being monitored by two hundred tiny wireless sensors, organized in an ad-hoc wireless sensor network. The goal is tracking the stress on the bridge caused everyday by traffic. With this new technology, low cost monitoring is possible without interfering with the operation of the structure.

Emergency response

Code Blue project is a good example how many complex these applications could be [5]. This project from Harvard University, is exploiting applications of wireless sensor network technology to range of medical applications, including pre-hospital and in-hospital emergency care, disaster response, and stroke patient rehabilitation. Adding vital sign sensors to the wireless nodes, and collecting these data automatically next to the patient, we can use them for real-time triage, correlation with hospital records, long term observation and better study of resuscitative care.

They have already developed small wearable sensors, including pulse oximeter and 2-lead EKG. These devices can collect heart rate (HR), oxygen saturation (SpO2), and electrical recording of the heart (EKG) and send them over a wireless short link to a base station, including PDAs, laptops, or ambulance-based terminals. The data collected can be displayed in real time and integrated into the developing pre-hospital patient care record. The devices can be programmed to alert the patients or any nearby paramedic if for some reason any parameter is outside the normal.

WSN FOR FIRE DETECTION – EWFDS

The proposed architecture for the pilot demonstration system is arranged in three levels – wireless sensor nodes, base station (BS), web server (WS) – with increasing computer power and storage capacity but with decreasing mobility (see figure 1). For larger forest areas, future deployments may include contiguous areas of 2000 hectares, the systems scales well with an additional level in the architecture (see figure 2) – the sensor network server (SNS).

System breakdown structure

The architecture of the system is composed of the
following components:

- Wireless Sensor Network (WSN)
- Base Station (BS)
- Sensor Network Server (SNS)
- Command Center Server (CCS)
- Operator Console (OC)

The wireless sensor network is in turn composed of sensor nodes. These nodes gather data autonomously, and the network passes this data to one or more base stations, which forward the data to a sensor network server. The sensor network server publishes the data to a web server through a GSM/GPRS link.

The network communicates with a base station which is responsible for storing, processing, and relaying gathered information. This information is locally available at the base station or can be accessed through any wireless device (laptop, PDA) if the base station is equipped with standard wireless WiFi communication.

![Fig. 3 – EWFDS System Breakdown Structure](image)

The base station relays the collected data and analysis results to services running on a web server through a GSM/GPRS uplink. This web server makes the information available to authorized users, which can view and manipulate the data with a browser using a specific web application. Web publishing through Web services and other interfaces gives researchers and civil protection authorities seamless access to information.

When the level of threat, defined in terms of environment parameters, reaches a pre-defined level the base station sends a warning message to the forest guard or directly to the local fire department.

Using the Operator Console, remote operators can diagnose network node failures and react accordingly by changing the network setup.

**WSN node**

The Wireless Sensor Network is made from nodes with the ability to collect data from where they are deployed. Data like humidity, temperature and luminosity can be collected by the built in sensors and sent to the base station using the radio transceiver. The nodes run on Ni-MH batteries so, it is very important to use low power devices to perform the needed tasks.

To fill these requirements we use a hardware platform called Tmote Sky [6] which has the following main features:

- 250Kbs 2.4GHz IEEE 802.15.4 Chipcon Wireless Transceiver with the capacity to interoperate with other IEEE 802.15.4 devices
- 8MHz Texas Instruments MSP430 microcontroller (10k RAM, 48k Flash)
- Integrated ADC, DAC, Supply voltage monitor, and DMA controller
- Ultra low current consumption and fast wake up from sleep (<6µs)
- Programming and data collection via USB
- Tiny OS [7] support: mesh networking and communication implementation
- Integrated onboard antenna with 50m range indoors / 125m outdoors

Because the nodes are deployed in harsh environments, all the WSN node components are protected. To do this a weather plastic container was used. The digital humidity and temperature sensor are located outside the plastic container to avoid wrong readings of these parameters. The transparent plastic container lead guarantees the correct readings of the two luminosity sensors (Partial Active Radiation and Total Solar Radiation). We still have readings from the WSN node battery pack and the ability to collect other kind of readings using the expansion connector. We can see aspect of a WSN node in the figure 4.

![Fig. 4 – EWFDS Node Container](image)

In order to have better ranges and, as a result, lower power consumption, a 5dBi external antenna is used. A series of tests conducted with these antennas in line of sight (LOS) ranges up to 250 meters were achieved.

Now that the hardware is ready the TinyOS support capability to program WSN nodes to collect sensors data and forward this data to a base station using multihop routing can be used. The TinyOS framework is open source so we have the chance to change the application running on the WSN node, in order to find the better way, or other ways to answer the requirements that vary from application to application.

**WSN MonSense**

When dealing with Wireless Sensor Networks with nodes distributed over vast areas of irregular terrain, some problems and requisites arise.
It is fundamental to have the exact world location of all nodes in order to obtain useful data and to be able to successfully recover the deployed devices later. Also very important is the ability to relate the local topology with the network quality and to be able to relate the geographical and sensorial data in an easy and comprehensible way.

The application MonSense was created to respond to these requirements and is already at a stable state, it has been tested in a real life demonstration where it showed to be very useful for the deployment, monitoring and recovering of the WSN.

The application is being developed in the Java language, due to its portability, communications APIs, and allows the reutilization of some of the components included in the TinyOS software. This application is integrated in the Neptus framework [8].

The application has two different modes: Edition mode and monitoring mode, being possible to switch between these modes even while receiving (and processing) data from the WSN.

In Edition mode, it is possible to create a geographical map of the WSN environment by the inclusion of raster images and vector data like points of interest, roads, trees or rivers. These objects can be inserted into the map by providing its real world coordinates in the form of latitude and longitude values.

In the Monitoring mode, the user has visual access to the WSN environmental map and the data that is being collected.

The WSN is presented to the user in the form of various objects (colored circles) located across the environmental map with positions associated with the real wireless sensor locations. These objects can be placed in the map by a drag and drop operation or also by introducing their latitude and longitude coordinates. The representation of the devices changes according to their current corresponding state. For instance, when a device loses its connection with the network, it is presented in grey, but when its connection is normal it turns blue. Whenever a message is received from a device, the correspondent object blinks and the routing that took place is showed.

With all these visual aids, the WSN state can be easily perceivable and any malfunctioning device or abnormal data is quickly detectable.

All the gathered data can be saved to a file for later revision, by using the same application. The stored data can be visualized in the form of an animation of all the messages that have been received. The user has then access to a timeline of the data, allowing him to pause, advance or move to a previous state of the animation. This feature gives the ability to precisely view any important WSN states or a quick glimpse over the various network configurations that took place.

**FIRST DEPLOYMENT**

The first deployment took place at Gerês Natural Park, in Portugal. It was a small deployment using only six nodes and a base station. The main goal for this test was to find the minimum number of nodes needed to monitor one hectare and to evaluate the communication behavior and range with obstacles. Radio frequency (RF) attenuation resulting from obstacles, including trees, rocks and terrain roughness was not known beforehand and that was also one of the objectives.

After arriving Gerês, the base station was setup and motes deployment was started. During these first mote deployments, link statuses were monitored, in order to obtain a working network. Using a GPS device to give the node locations and using this info to set the motes positions in MonSense software, the real network configuration was visible in MonSense, including current routes and relative position of each mote.

The first configuration was deployed and the reading quality RF signals indicators showed that is possible to try new configurations with more distance between the nodes. So, we tried to reach the maximum range for the network by displacing the nodes as far away as possible, without loosing its connectivity.

To locate the previously deployed sensors, we used the sensor GPS points that were recorded in the MonSense application but, given the roughness of the terrain and its thickly wooded forests, our GPS device was very inaccurate, reaching error estimations of 12 meters what turned the task almost impracticable.

At the end of the day we achieved a network configuration with sensors covering more than four hectares of terrain. In the meantime, we have also found various required improvements for the MonSense software, like being able to detect network failures, hide or show the info node label and the optional display of a dimensional grid.

We then prepared a new mission, with the new goal of covering an area of 12 hectares using 20 nodes. In this new deployment, we have used a signaling tape to simplify the nodes recovering task (see figure 6). Two teams were used to perform this task, being each team composed by two persons with one GPS device, sending real-time position information to the base station via rs232 radio link.

This new feature allowed us to see, from the base station, the current deployment teams’ positions informing them the better locations for the nodes deployment, achieving a greater efficiency during this phase.

We opted for a rectangular grid configuration for the nodes positioning and verified that, along the day, the routes changed various times. Some of the nodes actually lost their links for
long periods of time, maybe due to their long distance to the neighbor nodes.

CONCLUSIONS AND FUTURE WORK

This paper discusses the development of a wireless sensor network based application for wildfire detection and, with particular emphasis on the test deployments. Both deployments executed this summer, were successful given the fact that all desired goals were accomplished. The TinyOS MultiHop library used is stable and has proved its efficiency during the two missions. We will extend this library including our own needs and continue to test it in new networks with progressively more nodes.

The application MonSense proved to be efficient and stable and we will continue to develop this software to face the future mission requirements. One of the new features we foresee for the application is the ability to show the gathered data in the form of timed color maps, giving a better sense of the evolution of the world conditions.

It is important to be able to change the nodes network sampling rate after deployment or even turn off some of the nodes to increase power longevity.

In the near future we intend to add sensors external to the container in order to achieve more precise readings for temperature and humidity, which are crucial to the objective we pursue. We also want to create a new embedded system base that will stay on local, acquiring all data and storing it in a local disk. For that, it is essential that the hardware consumes a minimal amount of energy and to be weather resistant.

The deployment teams could use a PDA device with GPS capabilities and a connection to the base to see the current network configuration and status to further ease the deployment task.

REFERENCES