Managing Disaster with Wireless Sensor Networks

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Abstract - **Global climate change is increasing the occurrence of extreme climate phenomenon with increasing severity, both in terms of human casualty as well as economic losses. Authorities need to be better equipped to face these global truths. An efficient disaster detection and alerting system could reduce the lost of life and properties. In the event of disaster, another important issue is a good search and rescue system with high level of precision, timeliness and safety for both the victims and the rescuers. This paper reviewed technological solutions for managing disaster using wireless sensor networks (WSN) via disaster detection and alerting system, and search and rescue operations.**

Keywords – Alerting system, detection, disaster management, monitoring, search and rescue, wireless sensor networks (WSN).

I. INTRODUCTION

A wireless sensor network (WSN) is a group of low cost, low power, multifunctional and small size wireless sensor nodes that cooperate together to sense the environment, process the data and communicate wirelessly over a short distance [11]. The sensors are commonly used to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at areas of interest [22]. Some of these sensor nodes are able to move on their own, this is achieved by mounting the sensors on mobile platforms, as achieved in the Robomote project [9].

The development of WSN was originally motivated by military application such as battlefield surveillance. However, WSN are now used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, disaster management, healthcare applications, home automation and traffic control [22] & [35]. In this paper we will review the applicability of WSN in improving and assisting disaster management operations.

II. NEED FOR DISASTER MANAGEMENT

Studies over the recent years have gathered evidences indicating that the global climate is changing. The changes include the occurrence of extreme climate phenomenon that may have disastrous consequences to us human. The Intergovernmental Panel on Climate Change (IPCC) identified a number of extreme climate phenomenon with high level of likelihood to occur [14];

i. heat waves;
ii. floods;
iii. landslides;
iv. avalanche;
v. soil erosion;
vi. tropical cyclones,
vii. drought and
viii. storms.

The effects of the global climate change are clearly felt by many around the globe.

Malaysia

In Malaysia floods and landslides are the most common natural disaster as well as haze and forest fire [2]. Monsoon flood and flash flood are two types of the most frequent floods that hit Malaysia [19]. The northeastern monsoon during the end of the year to early of the next year often causes floods in peninsular Malaysia. Rapid development and poor drainage system have also cause frequent occurrence of flash flood in Malaysia. The floods bring damages to private and public properties. The lost often reaches to millions of dollars. Floods also caused lost of life, 33 perished in the 2007 flood, 19 in 2006 and 20 in 2005 [2]. Occasionally, Malaysia also suffers from mud floods, like the Pos Dipang tragedy on 29th August 1996. Heavy rain had triggered the mud flood that hit the Pos Dipang settlement, an aborigines' settlement in the state of Perak, killed 44 people and destroyed 30 homes [1].

Figure 1. Flood in Johor, 15th January 2007 [24]

Development on hillsides and heavy rain fall bring threats of landslides. On 6th December 2008 a massive landslide at a housing area in Bukit Antarabangsa, Selangor destroyed many houses and killed 5 people [25]. Many of the residence in the area were evacuated and search and rescue operation was initiated.

Figure 2. 2008 Bukit Antarabangsa Landslide [25]

Malaysia also suffers from haze caused by “slash and burn” activities and wild fires in its neighbouring country during the dry months [33] & [27]. In the most recent haze during the end of October this year an Air Pollutant Index (API) of 432 was recorded over the southern part of peninsular Malaysia [27]. An API index of 0-50 is considered good, 51-100 is moderate, 101-200 is unhealthy, 201-300 is very unhealthy and >301 is hazardous [10]. The haze reduces visibility and causes health problems.

Figure 3. Haze over Kuala Lumpur, 17th October 2010 [26]

The extreme climates together with uncontrollable human activities increase the frequencies of disastrous events which affect higher numbers of people with increasing levels of life threatening damages. Thus there is the need for more comprehensive regional and local risk reduction strategies [29]. Thus, it is important for authorities to ensure their risk reduction strategies include effective prediction, detection, monitoring, alerting, and, search and rescue systems. The Malaysian National Security Council (NSC) had laid out its total disaster risk management strategy into four parts [28];

i. prevention and mitigation,
ii. preparedness – prediction and early warning system, awareness
iii. response – search and rescue, relief, medical
iv. recovery – analysis, rehabilitation, reconstruction.

The first two parts of the strategy are to be implemented before a disaster occurs while the other two are implemented after a disaster happens.

An efficient disaster prediction, monitoring and alerting system could help the authorities and public to be better prepared to face an incoming disaster thus reducing the lost of life and properties risks. Another crucial aspect for reducing the amount of casualties is the search and rescue operation. We believe that WSN can play an important role in enhancing these two aspects of disaster management. A number of studies had shown the applicability of WSN for functions suitable for these kinds of systems [4], [6], [8], [17], [15], [20] & [31].

A WSN used for disaster detection and alerting system could sense for any significant changes in the environment and send an appropriate alert signal, for example sensors sensing water level at a river bank and tiltmeters at a hill side could alert the authorities and public for possible flood and landslide. In search and rescue application the deployed WSN scan the disaster area and locate the victims via the numerous sensing modes. The WSN can then provide the search and rescue teams with the identified locations of the victims needing rescue. The WSN can also provide the teams with crucial information such as the surrounding of the disaster site, obstacles that they need to overcome and avoid, etc. Thus, the search and rescue teams will be able to plan their operation with higher level of precision, timeliness and safety for both the victims and their members.

There are several important issues need to be considered in developing WSN for search and rescue application. These issues are the focus of the next section. In section 4 existing projects on WSN for disaster management operations are presented. Finally this paper is concluded in section 5.

III. Design Issues

There are multiple issues to be considered when designing WSN for disaster management. The first thing to be identified is the type of disaster to be handled. Different situation called for different system design, for example air quality monitoring requirement is not the same as search and rescue operation. Among the design issues are:

A) Deployment

Deployment is regarding on how the network is being installed. WSN is typically deployed in two methods predeterministic or randomly [11]. In predeterministic deployment the location of the sensors is decided first before the sensor nodes are deployed. In this method other issues like the degree of coverage and nodes connectivity are guaranteed [36]. Random deployment is simpler than the predeterministic deployment where the sensor nodes are randomly scattered in the region of interest. It allows the WSN to be deployed over hostile and unreachable environment, for example the nodes can be dispersed from an unmanned air vehicle (UAV) over a remote area for forest fire detection.

B) Coverage

In [11] three types of coverage are discussed; blanket coverage, barrier coverage and sweep coverage. This classification is borrowed from robotic system. Blanket coverage aims to provide maximum detection rate in a region of interest whereas for barrier coverage instead of providing coverage through out the region of interest the focus is now on ensuring that the perimeter of the region of interest is fully covered. Both blanket and barrier coverage can be achieve through static arrangement of the sensor. For sweep coverage the objective is achieved by moving the sensor nodes so that the region of interest is swept by the sensors sensing range.

There are other specifications of coverage, such as listed in [5]; area coverage, barrier coverage and point coverage. Area coverage is on how to cover an area with the sensors, where the objective is to maximize the coverage percentage. Coverage percentage is ratio of area covered by at least one sensor to the total area of the region of interest. Coverage problem can also be seen as a minimization problem [23]. From the minimization point of view, the objective is to make sure the total area of the coverage holes in the network is as small as possible. Area coverage is similar to blanket coverage. Point coverage is coverage for a set of points of interest. Basically this type of coverage is concern only on how to cover a set of targets or hotspots in an area, instead of the whole area as in area coverage.

Area, blanket and sweep coverage are suitable for disaster management applications. A disaster prone area can be thoroughly monitor using blanket coverage whereas sweep coverage can be used for a more active sensing.

C) Connectivity

Each sensor node in a WSN senses for occurrences of event of interest, this information need to be relayed to the base station. Therefore connectivity of the sensors to their base station and also connectivity among themselves is another important issue to be considered.

Typically in WSN, information is relayed to a base station using multihop communication, where the information is transmitted from a node to another node until the information reaches the base station. However this approach needs a connected network where at least a spanning tree exists to connect the nodes to their base station. The problem with this kind of network is that information would be lost if a link is broken, in addition to that in some environments obstacle such as a very dense rainforest or other obstruction will make it difficult to maintain connectivity. In [30] a moving base station is proposed. The mobile base station collects information by moving across the monitored area.

D) Mobility

Sensor mobility is another aspect to be considered in designing a WSN system. Mobility can be classified into two type; uncontrolled and controlled mobility. For uncontrolled mobility the movement is either caused by environmental influences such as wind and wave or the mobility is due to the sensor is embedded to a moving subject. In controlled mobility the sensor nodes are able to determined where and when to move themselves.

Controlled mobility is an attractive feature as it allows the sensors to self maintain the network [12], to harvest energy [21], to collect information using mobile based stations [30] and to compensate for lack of sensors in providing enough coverage by constantly moving the sensors so that the chance of target detection is improved [18]. It could also help to allow the WSN to provide sweep coverage thus minimizing number of missed detection [11]. On the other hand mobility usually will cause the sensor node to be bigger and bulkier thus limiting the movement of sensors in narrow or small spaces [13].

E) Type of sensors

The last issue to be considered here is the type of sensors to be used on the sensor nodes. Among the sensors used for disaster management are; motion detector sensor – sensing any sign of movement, camera – to obtain visual information, tiltmeter – for landslide monitoring, humidity sensor, temperature sensor, ultrasonic sensors – for water measurement and etc. Which type of sensors to be chosen is based on the targeted types of disasters.

IV. WSN FOR DISASTER MANAGEMENT PROJECTS

There are a number of projects conducted for enhancing disaster management operations including search and rescue operation with the help of WSN. WSN is commonly used for monitoring and detection in disaster prone areas. Data collected provide authorities with the abilities to make predictions which help them with the decisions such as evacuation, issuing warnings, etc. In search and rescue operations, generally, the WSN is used to locate victims and help the rescuers to assess the situation from a safe distance thus allowing them to come out with an effective rescue plan. In this section we will review some of these projects.

A) Early Warning Flood Detection Systems in Honduras

This project is conducted on the Aguán River in north-eastern Honduras to provide early warning to the communities of incoming flood [3]. The aim of the project is to predict the incoming flood hours before it happens so that the communities have enough time for evacuation.

The system proposed, measures the river level, rainfall, soil conditions and air temperature for the prediction. The readings will be compared with data in look up table to determine whether the threat exists. The nodes used in this project are solar powered and the system communicates in two modes; mini-network for short range communication - within 8km, and long-range links for communication of approximately 25km. The prediction is to be informed to selected city members whom are responsible for alerting their communities of potential danger.

B) Low Cost WSN Based Flood and Landslide Monitoring System in Indonesia

In [34] a WSN for floods and landslide monitoring system is proposed. The system used ultrasonic sensors to measure water level, luminance sensors, temperature sensors and wireless IP camera for visual monitoring. The nodes communicate using single hop or multihop. The reading of a sensor is send to its aggregator node which aggregates all the readings from its neighbouring sensors before transmitting the aggregated readings to the base station. Each of the nodes is uniquely identified using the individual IP address.

The authors believe that this system could be adopted as tsunami early warning system too.

C) WSN for Debris Flow Observation

A WSN for monitoring debris flow in mountainous area in Taiwan is proposed in [7]. The WSN is adopted to provide a better monitoring system compared to the traditional method. The wireless communication solves issues faced by traditional method such as broken telephone line during severe weather conditions.

This project also proposed mobile sensor known as Mass Flow Sensor which will move with the debris so that more accurate and detailed readings can be retrieved. The Mass Flow Sensor is packed within a weather proof, pyramid shaped capsule. Each of the capsules is equipped with an accelerometer, radio transceiver, circuit board, a GPS and rechargeable battery. The Mass Flow Sensor will move with the flowing debris and its reading gives the momentum of the flow. This information could be used to signal for possible disaster threat.

D) WAPMS: WSN Air Pollution Monitoring System

WAPMS is a WSN for monitoring air quality project [16]. Among the pollutants monitored by the sensor nodes are; ozone, fine particles, nitrogen dioxide, carbon monoxide, sulphur dioxide and total reduced sulphur compound. The sensor nodes deployed in the region of interest are divided into clusters which are decided based on their location. A cluster head is in charge of collecting data from its cluster members, aggregates the data and transmit it to the sink. The system used multiple sinks with each sink is in charge of a group of cluster heads. The sinks are connected to a gateway which relays the readings to database.

A new data aggregation algorithm; Recursive Converging Quartiles (RCG), was proposed for WAPMS. The PCQ algorithm is divided into two parts; duplicate elimination and data fusion. In the first part, the algorithm checks for any duplicated data using packets id. The second part of the algorithm is to summarize the data.

The system was tested over the capital of Mauritius; Port Louis. Promising results were recorded. The authors planned to implement the system over the entire island of Mauritius to monitor its air quality.

E) WSN for Volcanic Eruption Monitoring

Among the earliest application of WSN for volcanoes monitoring is reported in [32]. Infrasonic microphones are used as low-frequency acoustic sensors to sense infrasonic signals from erupting volcano. These acoustic sensors are connected to aggregator. The aggregator sends its collected data to the base station over a long range wireless link.

A short test conducted over the Volcán Tungurahua, Ecuador's active volcano, shows that this system has a great potential for volcanoes monitoring.

F) WSN for Flash-Flood Alerting in Andean region Venezuela

The architecture of flash-flood alerting system for the Andean region, Venezuela is presented in [6]. The system is designed to predict, detect and generate alarm. There are six categories; i) no sign of flash flood – data from the sensor nodes shows stable readings, ii) rain formation – dropped in air pressure, iii) rain, iv) landslides, v) dam forming – caused by landslide, and vi) flash flood.

The sensor nodes used could be grouped into three categories:

- Hydrological nodes – to monitor water level and its flow along the river bank
- Meteorological nodes – monitoring light, temperature, humidity, barometric pressure, wind direction and speed of the surrounding.
- Landslide nodes – geophone, soil moisture sensor and creep sensor.

Among the major challenges for developing flood alerting system is false alarm, this project focused on the tradeoffs between sensitivity of the system and reducing false alarm.

G) Search Balls: Special Project for Earthquake Disaster Mitigation in Urban Areas

In the search balls project, small search balls each equipped with wireless camera, infrared LEDs, radio receiver, batteries and electronic circuit are used for searching victims inside collapsed buildings [13]. There are two type of search balls; balls with three fixed wireless cameras and balls with two rotating cameras. The two rotating cameras provide a wider view. All of these equipments are packed in impact resistance ball.

The search balls are thrown inside the rubble of a collapse building to search for survivors. No controlled mobility is provided to the balls, however due to its structure, the balls will roll and bounce within the rubble and get scattered around the search area. To compensate for lack of mobility, large number of balls is deployed. The search balls transmit their information to monitoring station stationed at the perimeter of the rubble. Based on the signal from the balls rescuers are directed towards the victims' location thus the rescue mission can be conducted efficiently. As the rescuers reach the victims the balls are collected by them to be reused.

H) RESRS: Robot Emergency Search and Rescue System

RESRS is a project that integrates WSN with the robotic field [31]. The RESRS system monitors for leakage of hazardous chemicals and conduct search and rescue operation during emergency events. The system consists of three parts: WSN of fixed sensor nodes, mobile robots and a monitoring centre. The mobile robots of RESRS are also equipped with sensors therefore these robots can also be viewed as WSN of mobile sensor nodes.

The system operates in two modes; normal mode and rescue mode. In normal mode the fixed WSN monitors the area and record the reading of the environment. When a leakage is detected the system switch to rescue mode and the mobile sensor nodes are deployed. The mobile sensor nodes receive instruction from monitoring centre which makes decision based on information from the fixed WSN. These mobile sensors are able to provide more active search and rescue operation. The information from mobile sensors can be used to provide route information to rescuers on how to reach the victims and also to lead the rescuers and victims out to a safe site.

V. Conclusion

Disaster management need efficient techniques with high level of precision and timeliness. WSN is a good candidate for such applications. In this paper the need for efficient disaster management application is discussed. The design issues of WSN are also reviewed. Existing projects such as; WSN for floods monitoring, WSN for landslides monitoring, WSN for air pollution monitoring, WSN for volcanoes monitoring, search balls, and RESRS are also presented. These projects prove that WSN is an effective technological solution for a better disaster management, therefore more research works should be conducted in this area.

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