2014 IEEE 7th International Conference on Service-Oriented Computing and Applications

Anomaly detection algorithm for localized abnormal weather using low-cost wireless sensor nodes

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***Abstract*—In recent years, we have witnessed an unpresented increase localized heavy weather phenomena such as tornadoes and localized heavy rain which can not be expected by the conventional weather forecast system. However, the number of observation posts is few little for forecasting for tornadoes and heavy rain. It is necessary to increase dramatically the observation points in order to perform ware correct prediction using real data. We have developed a compact and low-cost pressure information acquisition system, to detect the signs of localized abnormal weather. This research proposes an algorithm to predict local weather by detecting anomalous pressure values in the time series of the pressure sensor information, and then to notify users.**

I. Introduction

In recent years, we have witnessed an unpresented increase in localized heavy weather phenomena such as tornadoes and localized heavy rain which can not be expected in the conventional weather forecast system. Current weather forecasting system can not detect such a localized abnormal weather. Thus, in order to detect localized abnormal weather, weather forecasting systems must use local environmental data. However, conventional meteorological observation systems are generally more expensive, and the number of locations is also limited. Therefore, we developed inexpensive environmental sensing nodes for local temperature and atomospheric pressure. This research proposes an algorithm to predict local weather by detecting anomalous pressure values in the time series of the pressure sensor information, and then to notify users. The rest of the paper is organized as follows. Section 2 introduces previous studies and the relative position of our research. Section 3 describes the configuration of our system. Then, describe the algorithm suggested in section 4, in Chapter 5 indicate experimental results. And finally, Chapter 6 in show report summary and future challenges.

II. Related work

A. Weather forecasting system

Weather forecasting is deeply penetrated in our life. Weather forecast information in Japan is offered by Japan meteorological agency. In recent years, weather forecast system is based on computer simulation. Weather forecast probability is calculated by enviromental sensing posts and satellite images, cloud radar. Reliability of weather forecast system in Japan was correct about 85% probability probability of precipitation. That's a high probabillity rate looking at the world. In recent years, the tornado observations based on measurement of environmental information by satellite and radar sites were estabilished all over the country , with millimeter-wave radar[Heinselman 08] and Doppler radar observations[Brown 78] has become mainstream. Doppler LiDAR is using the laser light system, to receive the reflected light from atmospheric dust and fine particles. Further, widely studied weather forecasts using numerical simulation. For example, there are cumulonimbus clouds using cloud-resolving model simulation research[Sato 07] and meteorological modelling simulation, divide to model of cities and States[Kusaka 09]. However, in recent years in the systems to unpredictable localized torrential rain and tornado by localized pressure changes such as often occurs. Especially in Japan past over 10 years ,more than 100 tornadoes have been observed[Niino 97]. In recent years started research to prediction of tornadoes[Suzuki 08]. Because of tornadoes and torrential rains, considering cause a special cumulonimbus clouds called a "supercell"[Browning 64], and occur due to local front cumulonimbus clouds[Wakimoto 89][Wakimoto 00], elucidation of the causes is desired. However, tornado may occur in the narrow range of 100-200 meters width[Mizuno 07]. Therefore, the observed data is not sufficient in the current weather forecasting system for urban units. Because of tornadoes and torrential rains, considering cause a special cumulonimbus clouds called a "supercell"[Browning 64], and occur due to local front cumulonimbus clouds[Wakimoto 89][Wakimoto 00], elucidation of the causes is desired. Therefore, the observed data is not sufficient in the current weather forecasting system for urban units. These prediction for localized abnormal weather need more high density environmental data. For example atmospheric pressure, temperature and humidity data are required. However, for observation equipment represented by environmental sensing post is generally expensive. Therefore increase density and increase number of environmental observation posts is difficult. In particular, the tornado as a representative example of abnormal weather localized, has been studied extensively in the United States, and 1-2 cases of cases that has acquired the pressure change of the tornado just under less. Therefore, by measuring the pressure in small intervals, it is necessary to measure the atmospheric pressure change in the vicinity of the tornado directly under, to elucidate the mechanism of abnormal weather or local tornado. For this reason, we developed inexpensive environmental sensing nodes for local temperature and atomospheric pressure. To this end, we propose an algorithm for localized anomaly weather prediction algorithm that makes usage of a lot a large wireless sensor nodes.

978-1-4799-6833-6/14 $31.00 © 2014 IEEE
DOI 10.1109/SOCA.2014.34

III. Development of environmental information system

A. Localized atmospheric pressure sensing system.

In this research, developed a inexpensive environmental observation nodes for obtains the localized atmospheric pressure value. Observation data is store by cloud server application. Also we implement a server application for reporting to the user at the time of abnormality weather situation. Observation node is measure the temperature and atmospheric pressure by the sensor. Observation nodes send to the server sensing data by GPRS module. Show below the price and structure of the observation node.

- Atmospheric Pressure and temperature sensor：SCP1000 $12
- Arduino UNO $15
- GPRS module $560
- 3.7V 100mAh Li-po battery $10
- Charging unit：Li-Po rider $10
- 1W 80mm*100mm Solar cells $10

The observation node relies on storage batteries that use a photovoltaic device which does not require an external power supply. Moreover, since the device is expected to be used outdoors, it was mounted in a waterproof housing. We shown in Fig. 1. the appearance of the prototyped observation node. Observation node is configured with commercially products,

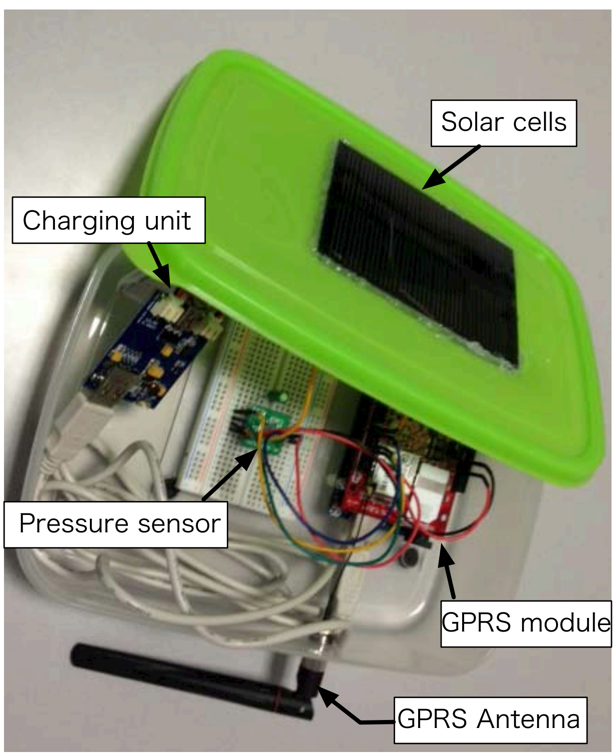

Fig. 1. Prototype of pressure observation node

the configuration of the present node with the GPRS is about $ 600, it is inexpensive compared to existing research. Further, If sharing the GPRS unit in wireless communication such as Zigbee, it can be manufactured in one observable nodes per about$ 100. Therefore, large-scale observations can be realized. Because inexpensive compared to other existing products and research. So far connected temperature and atmospheric pressure sensors. However, can be connect example of wind speed sensor and humidity sensor or various sensors connection is possible. Furthermore, since it incorporates a battery and a solar cells. If installed outdoors is possible to persistent works. In this research, we propose an algorithm of predict tornado by detecting anomalous pressure values in the time series of the atmospheric pressure sensor information, and when detect localized abnormally weather notify to users.

B. Implement of the server application

An overview of the application server shown in Fig. 2. Server applications are based on the web user interface. Users

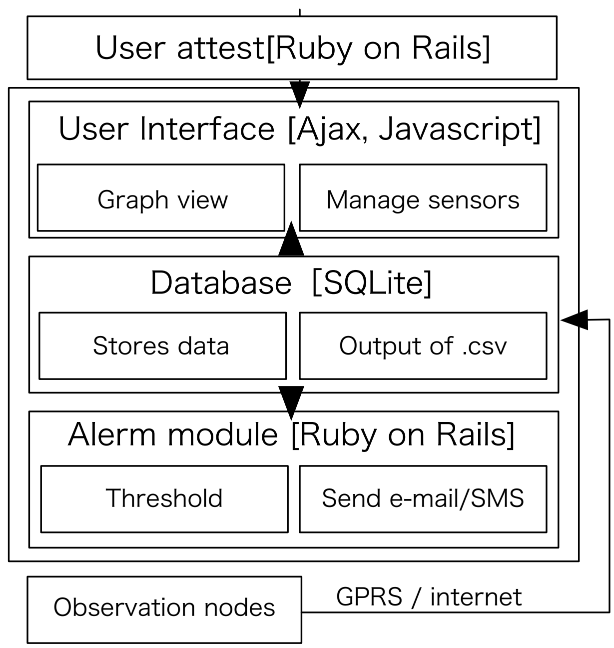

Fig. 2. An overview of the application server

can be report destination e-mail address and SMS destination mobile phone number. Therefore also It is possible to perform inspection of the any sensor information. Furthermore, by registering as a group of individual sensors, possible to carry out and compared to sensor information of the other group. Moreover can be setting of the threshold for each sensor. At present, it is implemented only notification function by a certain threshold. In future, it is possible to implement the abnormal weather detection algorithm proposed in this research. Our research goal is perform the notify quickly to users for localized abnormal weather.

IV. Proposal of Abnormal Weather Detection Algorithm

A. The atmospheric pressure variations in the abnormal weather

Our algorithm is focus to atmospheric pressure change for detect early signs of localized abnormal weather situations and notify it. We select the tornado as a typical example of localized abnormal weather events. Those data is actual atmospheric pressure data provided by Japan Meteorological Agency. Shows data collected below.

- Tornado at Fukuoka, Japan Fig. 3.
  Observed at 2011/8/21/ PM12:35
  Observation in : Fukuoka District Meteorological station, Chuo, Fukuoka City
- Tornado at Akita, Japan Fig. 4.
  Observed at 2013/11/7/ AM 6:47
  Observed in : Akita District Meteorological station, Sannou, Akita City
- Tornado at Ibaraki, Japan Fig. 5
  Observation at 2012/5/6/ PM 5:00
  Observed in : Tsukuba Meteorological station, Nagamine, Tsukuba City

Those actual atmospheric pressure data as provided by the Japan Meteorological Agency[Pressure data], those data are in the vicinity of the observation points tornado occurrence point. C. Furthermore, tornado is move. For example, tornado damage of length reached 35km at Ibaraki[Press release]. Therefore, forecast of tornado movement need a lot and wide range observation point of the detailed pressure change. Our system are become obtainable by with increasing observation point and arranged in a grid.

Our objective is to minimize the human casualties by tornadoes, to monitor the atmospheric pressure fluctuations in the time series. Moreover, we propose an anomaly detection algorithms for detecting the early stages of localized abnormal weather.

B. The atmospheric pressure anomaly detection in time-series data

As mentioned in Chapter.IV-A, observing the pressure change in the time series is important for the detection of early stage of the tornado. In addition, knowing whether there is a tornado in the near or far of the current position, is an important information in order to determine the keep indoor waiting and evacuation. Therefore, we observe a variation of localized atmospheric pressure by arranging in a grid of 1000m interval observation nodes. In addition, the user can grasp the distance from the tornado. This information is important of if need decision making to remain indoors or to evacuate. Because forecast the movement path of the tornado by atmospheric pressure data acquired by the individual nodes. From the above, it is possible to detection of the initial stage of the tornados acquire the atmospheric pressure change of the observation. Therefore, we can also detect the distance between the current position and the tornado.

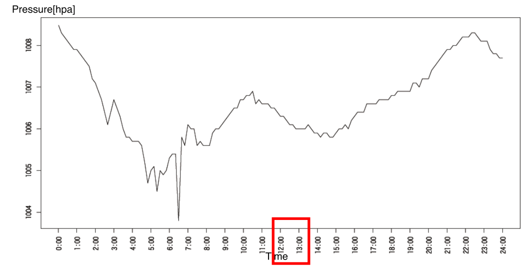

Fig. 3. Pressure observation data of tornado occurrence in Fukuoka City

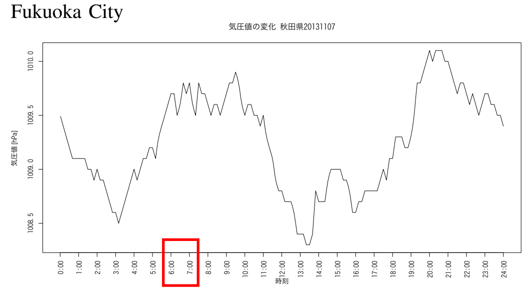

Fig. 4. Pressure observation data of tornado occurrence in Akita City

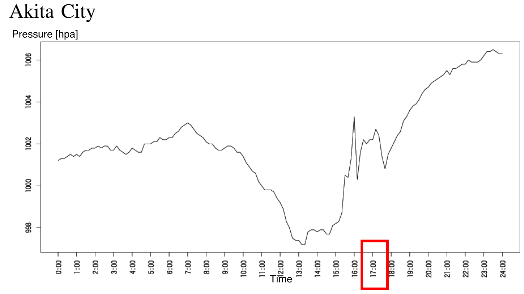

Fig. 5. Pressure observation data of tornado occurrence in Ibaraki City

C. Detection algorithm of abnormal atmospheric pressure data in time series

Then, we describe the detection algorithm of abnormal atmospheric pressure value in time series. Atmospheric pressure data for each observation node show the formula (1). Pressure data at the observation node is represented by X_{node}, data of time that have acquired represent time=t, date=d, year=y.

$$\boxed{X_{node}(t,d,y)} \tag{1}$$

Then, we scoring by the formula (2) the pressure variation in the time series. Calculate the average square error of past data to be specified in the min scores at each time of each observation nodes, and outputs the score variation of the pressure data in time series. Currently, it is set to $min = 5$, and compared with the pressure measurement data of the last 5 minutes, thereby calculating the score.

$$val_{node}(t,d,y) = \sum_{i=1}^{min} \{x_{node}(t,d,y) - x_{node}(t-i,d,y)\}^2 \tag{2}$$

In addition, we make sure that the anomalies in the time series are scored based on the proposed algorithm. The confirmation of the algorithm, using the pressure of the tornado occurrence of actual mentioned in chapter IV-A, and scored by the formula (2). The score, it approaches 0 if there is no change of atmospheric pressure. The value increases as in the last 5 minutes, pressure fluctuations. Next, we show the scoring results of the test data. Fig. 6. scoring result of tornado occurrence in Fukuoka City, are shown in Fig. 7. scoring result of tornado occurrence in Akita City, and shown in Fig. 8. for scoring results of tornado occurrence in Ibaraki City. According to the scoring results, it can be seen score

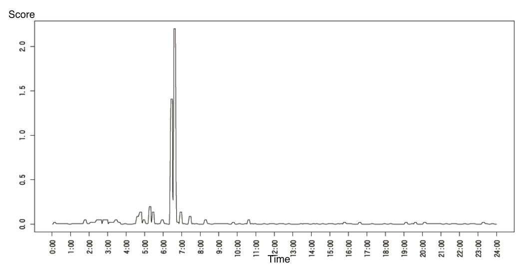

Fig. 6. Scoring results of tornado occurrence in in Fukuoka City

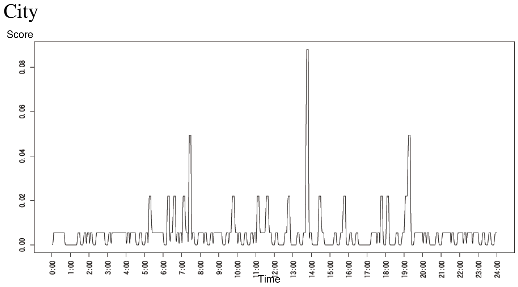

Fig. 7. Scoring results of tornado occurrence in in Akita City

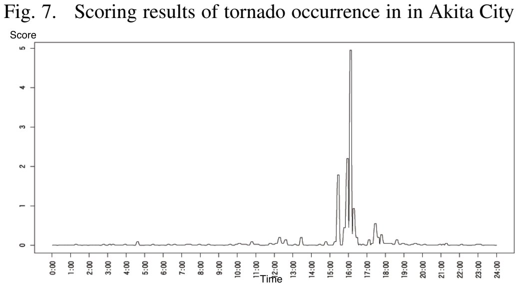

Fig. 8. Scoring results of tornado occurrence in Ibaraki City

value's increases with atmospheric pressure change. In addition, significant changes in score values can be observed in the previous minimum of atmospheric pressure when approaching tornado. It is shown that by this result, can be detected when early stages of tornadoes using atmospheric pressure variations in the time series.

V. Experimental Evaluation

A. Experimental setting

In this section, we describe the experimental setup that was used for the evaluation experiment. In this experiment, we scored atmospheric pressure change of nearest tornado node and adjacent to the atmospheric pressure change nodes. We assume total 3 observation nodes. Observation node A is nearest the tornado, observation node B and node C is adjacent to the observation node A. We use to generate a pressure

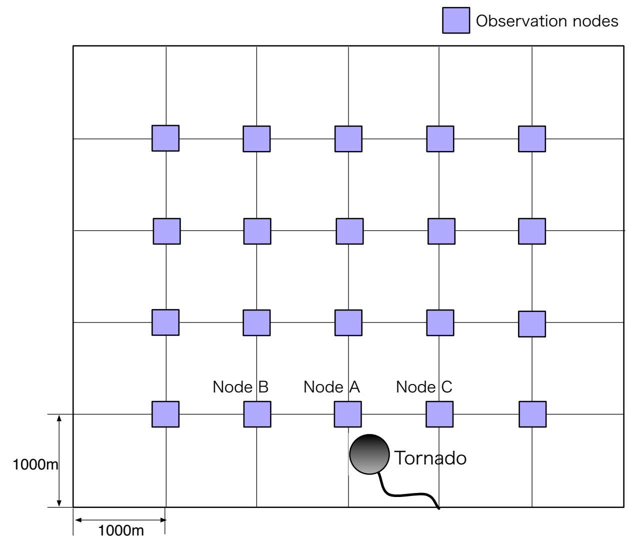

Fig. 9. Location of observation nodes and tornado

of dummy data in each node. Dummy data was refer to the meteorological agency tornado occurrence data. Following the characteristics of the data.

- Node A：Assumes atmospheric pressure data of the tornado directly under (The generated based on near by tornado actual data)
- Node B：Assumes atmospheric pressure data of a tornado near（Generate delayed by 30 minutes half of the amount of change in node A）
- Node C：Assumes atmospheric pressure data at a position slightly away from a tornado

We scoring using those dummy atmospheric pressure data. As a result, detection and early stage of the tornado, and to verify the relationship between adjacent nodes.

B. Experimental result

We are calculated using the experimental environment set in section V-A scored for each observation nodes. Shows the generated atmospheric pressure values in Fig. 10. shows the scoring result in Fig. 11. As with the validation result of the sectionIV-C, high score has been detected in the early stage of a tornado, according to the score calculation result. Therefore, We found that abnormalities in the early stages of a tornado can be detected. Moreover, when the observation particular node has detected an abnormal value, it is considered to be a problem with the atmospheric pressure sensor. However, as the nodes of the current observation data can be seen that the abnormal value of the atmospheric pressure is observed when the same trend is truth observation data. As described above,

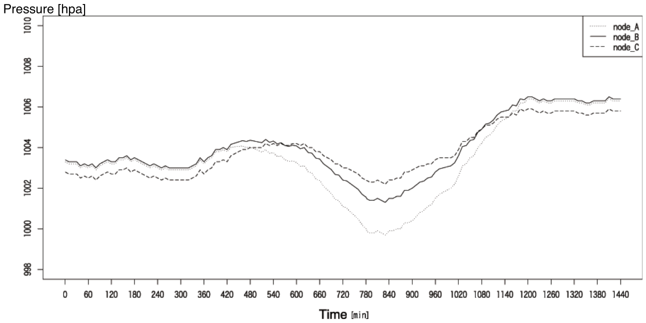

Fig. 10. The value of the dummy pressure

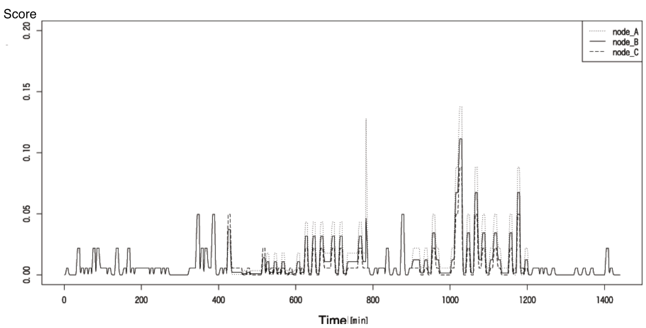

Fig. 11. The result of score

by using the algorithm proposed in this paper, the detection of localized abnormal weather are possible. Moreover, it was also shown that by comparing the values of the observation nodes, it can be determined observations is localized abnormal weather or atmospheric sensor fails. In the future, with the aim to improve the accuracy by accumulating past data provided by the Japan Meteorological Agency, and compared with the measured value. In addition, a miniaturization Environmental Information observation node and implement certain low-cost nodes with Zigbee communication.

VI. Summary

In this research, we implemented a low-cost environmental information collection system for the purpose of predicting localized abnormal weather. By using the actual atmospheric pressure change of the tornado occurrence , it is possible to determine the sudden change in atmospheric pressure of the observation points. It is also demonstrated is possible to detect abnormality in the initial stage of tornadoes. From the above, changes in the atmospheric pressure value of each observation node, it is possible to acquire the pressure change of the observation node and a separate detection of the initial stage of the tornado. Therefore, we can also know the distance between the current position and the tornado. Consequently, it also helps to reduce human losses. Moreover, it was also shown that by comparing the values of the observation nodes of sensor fail or localized abnormal whether. In the future, that it performs a data collection set up observation node actually, wind speed and temperature and humidity sensors, and to determine the comprehensive data, such as the accumulation of past data of the Japan Meteorological Agency. It will continue to implement the prediction system and abnormality detection with high accuracy. Furthermore, we will study a method of fault detection by performing long-term experiments with increasing observation points.

Acknowledgment

This work is partially supported by the Hori Science and Art Foundation.

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