Wind speed monitoring and alert system using sensor and weather forecast

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Abstract. Strong wind allows uproot the trees and causes human victims to be injured or dead. Unfortunately, the strong wind comes suddenly to the trees on the street and many people and traffic are around there. It needs wind speed monitoring and strong wind early warning to avoid the victims due to fallen tree. This paper explains the development of wind monitoring and early warning system using wind speed sensor and weather forecasting. The steps involve investigating the wind speed, designing the system, developing the system, testing, and validating. The result shows that the system can measure the wind speed on the spot in real time and trigger the alert to the people around if the strong wind was occurred. On the other hand, it also informs the forecast of wind speed according to weather web services data few hours before. Applying this system will help the government to prevent the victims of fallen tree due to strong wind.

1. Introduction
Fallen tree caused by strong wind is able to cause human casualties. During 1995 up to 2007 there were 407 death tolls where 44% of victims (180 people) are fallen tree on the street in US [1]. The winds that are caused the deadly fallen tree in US involve thunderstorm, non-convective high winds, tropical cyclones, and tornadoes. In Indonesia, the strong wind occurs in transition time from dry to rainy season while the thunderstorms often occur in January or February. There is no detail information related to human victims due to fallen tree in Indonesia but it was occurred in 28 March 2017 that 12 trees uprooted in Jakarta during two hours' heavy rain. To prevent or decrease the victims of deadly fallen tree, the government should provide early warning system of dangerous strong wind which may cause deadly fallen trees.

Several researchers deal the problem with developing wind speed warning system to inform the wind speed level to the people surroundings the neighborhoods. Wind speed Detection system is developed using agile method, wind sensor, microcontroller and software to calculate the wind speed level and display the warning light or message when it identifies the strong wind [2]. Other cross wind warning system utilizes rotary encoder proximity anemometer, microcontroller, alert Red LED and alarm which are ON if the wind speed is greater than 22 knots [3]. The next approach is using weather data mining collected by sensors of rain fall, temperature, humidity, wind speed and direction. The data are transmitted to the server and used to predict flood disaster early warning system [4]. Based on the approaches mentioned in previous works, it is likely that the wind speed warning system still can be improved adequately by combining both local wind speed sensor and weather data forecasting available
in the weather web services. This weather forecast data can be used to give early warning system before the extreme wind strikes.

This paper explains the investigation of wind speed level that can uproot the trees in Indonesia and development of wind speed early warning system using wind speed local sensor and weather forecast. This work was motivated by the facts that many news reporting the fallen tree death victims related to strong wind on the road. This system hopefully informs the dangerous level of wind speed in real time and warns people to get away from the trees. Weather forecast data was also carefully processed such that it can be used to inform people several hours in advanced, before the strong wind will come to strike the suspected locations. The paper is organized as follows. Section 2 describes the overview of related works followed by section 3 that explains the research method. Section 4 discusses the result and discussion and finally it is concluded in section 5.

2. Related works
Recently natural disaster management and mitigation has been equipped by early warning system to reduce or prevent human victims. The natural hazards overspread in the forms of earth quake, tsunami, flood, landslide, storm, snow, lightning, fallen tree, and etc. Warning system is enhanced with multi sensors, data processing/computing, and informs alerts to authorities and communities. Researches emphasizing to earthquake warning system include earthquake alarm systems (ElarmS) in California [5], earthquake early warning using accelerometer and seismometers applying in Italy [6], and intelligent building damage index alert system due to earthquake in Malaysia [7]. On the other hand, the topics of early warning system regarding to tsunami has been studied by Chatfield and Brajawidagda [8] in Indonesia using social media Twitter to inform whether the earthquake effects the tsunami or not, Kanazawa in the project of Japan Trench earthquake and tsunami monitoring network covers the sea regions involving Hokkaido, Tohoku, and Kanto [9]. Furthermore, Pinto and Cipriano develop Tsunami Early Warning System (TEWS) comprising sensors, communication, processing, dissemination, and decision support system [10]. Other researchers concern to the flood detection and monitoring system including Mousa et al. [11], Putra et al. [4], Rahadiano et al. [12], and Febrianto et. al. [13]. Early warning systems related to lanslides and debris flows are also studied and developed by Baum and Godt [14] that group the warning levels (null, outlook, watch, and warning), Jian et al. [15] that propose 3D WebGIS platform utilizing several sub-systems (wireless sensor network (WSN), analyser, criteria decision, and alert), Kebaili et al. [16] that enhance the prototype using web of thing and MongoDB Big Data database, and Sattele et al. [17] who study the reliability and effectiveness of debris flow warning system.

The contributions of this work are proposing new framework of natural disaster early warning system relating to dangerous wind that is potentially uprooted the trees. The framework involves existing modules of previous works [2-4] and proposed modules. The existing modules include wind sensor/anemometer, microcontroller, display, and alarm. In this research, the framework is enhanced by adding the module of weather forecast harvesting from internet and monitoring module to show the information in computer screen. This module allows the system to inform few hours in advanced, before the arrival of the strong wind.

3. Methods
The method of this research utilizes prototype model including requirement communication, quick plan, modeling quick design, construction of prototype, deployment delivery and feedback. This section emphasizes on discussion of modeling quick design and construction of prototype as part of the methods.

3.1. The proposed framework
The goal of proposed framework was designed to warn the people around the strong wind disaster area in text alert display and alarm notification in real time and few hours before using weather forecast data. The Wewarn framework is illustrated in Figure 1.
Figure 1. Wewarn framework.

The framework consists of hardware unit consisting of anemometer sensor and microprocessor module, software unit involving application unit and weather forecast harvester, notification unit comprising of alarm unit and display unit. This framework also requires weather forecast web services data from openweather.com. Each module is described as follows:

- Anemometer sensor is used to convert wind speed to electric signal to be processed by microprocessor module. This research utilized anemometer sensor HS-FL2 that converts blade revolution to its respective voltage.
- Microcontroller module as processing unit. It converts the analog signal of anemometer sensor to serial data format. The wind speed data can be read via USB port by application unit. Microprocessor was used in this research is Arduino Uno. Small script of C Arduino was embedded to convert analog data to wind speed value in m/s and then transfer to USB port.
- Weather forecast harvester is small client program using API weather forecast harvester from openweathermap.com. The data is presented in XML format and provided every 3 hours. The weather data used in this research involve in wind speed, temperature, and date-time in specific location (Semarang Indonesia).
- Application unit is a software developed in VB.Net that converts wind speed value from m/s to km/h and determines the warning thresholds in tree conditions such as safe (< 18 km/h), beware (18 - <=60 km/h), danger (>60km/h). The alert of tree conditions refers to wind speed Beaufort scale.
- Alarm unit is a sound media to warn the people around the sensor that actives if the wind speed was categorized in beware and danger level.
- Display unit shows the wind speed on location, level of warning, and weather forecast data in next three hours. Display unit is a LCD monitor. It also displays the early warning notification in text format few hours before based on wind speed data from weather forecast web services.

3.2. Wind speed measurement circuit design

To measure the wind speed, this system needs anemometer sensor, microprocessor, and embedded program developed in C Arduino. This design utilizes analogue anemometer sensor HS-FL2. The measurement range is from 3.6 km/h up to 108 km/h represented in voltage output of 0.17 - 5 volts with tolerance error ± 0.3%. The wind sensor HS-FL2 is depicted in Figure 2.
The circuit of wind sensor and microprocessor (Arduino Uno) is illustrated in Figure 3.

The sensor should be connected to DC power supply 6-24V for output voltage 0-5 V. Signal output of wind sensor is connected to analog input of Arduino A0. Small program written in C Arduino is used to convert analog signal to wind speed value in km per hour. The pseudocode of such program is described as follows:

```c
void loop
sensorValue ← read analog voltage A0 outvoltage ← sensorValue * 5.0/1023
Windspeed ← 6 * outVoltage * 3600/1000 Serial.println ← Windspeed
```

The program reads analog voltage of wind sensor via port A0 and it is assigned to variable sensorValue. Furthermore, the value of sensorValue is calculated by multiplying 5.0 and dividing 1023 due to decimal data of A0 is integer ranging from 0 to 1023 and the output voltage of wind sensor is 0 to 5 V. To convert outvoltage to wind speed in km/h the value is computed by the equation 6 * outVoltage * 3600/1000. Last step is transferring Windspeed data to serial port (USB).

3.3. Software design
The software running in a computer involves application unit and weather forecast harvester. Both of software are developed using VB.Net. Application unit reads serial data on USB port connected to Arduino board. Wind speed data in km/h are categorized into tree levels namely safe, beware, and danger. If the status is beware and danger, the application will trigger the alarm unit and send notification to display unit (screen). Thus the people around the location will be warned to go away from the trees.

On the other hand, weather forecast harvester requests weather forecast data according to specific location (Semarang) to openweathermap.org. The response contains several weather data including date, time, temperature, wind speed, air pressure, precipitation, and weather condition.

In this design, data of wind speed, temperature, and time are used and displayed on the screen. If the next hour wind speed forecast data status is beware or danger the notification will be displayed to the screen as the early warning information. The steps of program are illustrated in a flowchart in Figure 4.
Figure 4 describes the flowchart of Wewarn system. It obtains data from two sources including anemometer data and forecast data of weather web services. Actual wind speed of anemometer is assigned to windact variable whereas the forecast data (date time, wind speed, and temperature) are assigned to timefore, windfore, and tempfore variable. Each value of windact and windfore is checked.
whether the value is less than or equal 18 Km/h or not. If the result is yes, then the notifact variable is set to “safe” and notifore variable is assigned to the value timefore and “safe”. Otherwise both value of windact and winfore are examined if the values are greater than 18 km/h and less than 60 km/h. If the result is yes then the message “beware” is set to windact and windfore variable, else the massage “danger” is assigned. At the end, all of the data are displayed to monitor including windact, notifact, timefore, windfore, and notifore value.

3.4. Wind speed threshold design
Threshold of wind speed warning refer to beaufort wind scale described in Table I. Safe category is set ranging from scale 0 to 3 (gentle breeze) that represents wind speed 10 knots or 18 km/h. This speed will cause leaves and small twigs constantly moving and light flight extended. The second category is beware which refers to scale 4 to 7 having the speed between 11 to 33 knots or 19.8 to 59.4 (rounded off to 60) km/h. The last category is danger which refers to scale 8 to 12. This category will cause from twigs breaking off trees until trees broken or uprooted and structural damage.

Table 1. Beaufort scale.

| Scale | Wind speed | Desc      |
|-------|------------|-----------|
|       | Knots      | Km/h      |
| 0     | < 1        | <1        | Calm      |
| 1     | 1-3        | 1.8-5.4   | Slight air|
| 2     | 4-6        | 7.2-10.8  | Slight breeze|
| 3     | 7-10       | 12.6-18   | Gentle breeze|
| 4     | 11-16      | 19.8-28.8 | Moderately breeze|
| 5     | 17-21      | 30.6-37.8 | Fresh breeze|
| 6     | 22-27      | 39.6-48.6 | Strong breeze|
| 7     | 28-33      | 50.4-59.4 | Near gale|
| 8     | 34-40      | 61.2-72   | Gale      |
| 9     | 41-47      | 73.8-84.6 | Strong gale|
| 10    | 48-55      | 86.4-99   | Storm     |
| 11    | 56-63      | 100.8-113.4| Violent storm|
| 12    | >63        | >113.4    | Hurricane |

3.5. Prototype development
Wewarn system has three components involving anemometer sensor, microprocessor, and desktop application. Two software are developed and installed to Arduino microprocessor and desktop computer. Figure 5 illustrate the prototype design.

Figure 5. Prototype design.
Threshold of wind speed warning refer to Beaufort wind scale described in Table I. Safe category is set ranging from scale 0 to 3 (gentle breeze) that has wind speed 10 knots or 18 km/h. Beware category is set from greater than 18 Km/h to 60 Km/h (4-7 scale). The over 60 Km/h wind speed is a danger level.

4. Results and discussion
The testing of Wewarn prototype is performed in Laboratory of Electrical Engineering Department including wind speed measurement, alert system, weather data harvesting, and display. The results are compared to previous researches in comparative analysis views.

4.1. Wind speed measurement standard error
The measurement data of wind speed are compared to the other digital anemometer measurement data. Wind source is got from fan having three speeds. The sensor measures the wind speed ranging from the distance 0.5m, 1m, 1.5m, 2m, and 2.5. These data are analyzed using standard error equation. Based on the data of Table II, Standard Error (SE) is obtained 4.4%. It means that the measurement is acceptable and applicable.

Table 2. Measurement data.

| Speed Distance (m) | Measurements (Km/h) | Other digital anemometer | This device |
|-------------------|--------------------|--------------------------|-------------|
| 1                 | 0.5                | 7.92                     | 8.1         |
| 1                 | 1                  | 6.89                     | 6.8         |
| 1                 | 1.5                | 5.38                     | 5.4         |
| 1                 | 2                  | 0.00                     | 0.1         |
| 1                 | 2.5                | 0.00                     | 0.5         |
| 2                 | 0.5                | 8.34                     | 8.6         |
| 2                 | 1                  | 7.79                     | 7.3         |
| 2                 | 1.5                | 6.33                     | 6.3         |
| 2                 | 2                  | 2.68                     | 2.9         |
| 2                 | 2.5                | 0.00                     | 0.5         |
| 3                 | 0.5                | 10.3                     | 10.4        |
| 3                 | 1                  | 8.02                     | 8.0         |
| 3                 | 1.5                | 6.64                     | 6.5         |
| 3                 | 2                  | 3.91                     | 3.8         |
| 3                 | 2.5                | 0.34                     | 0.5         |

\[
\text{Standard Deviation} = \sqrt{\frac{\sum(x_i-x)^2}{n-1}}
\]

\[
= \sqrt{\frac{0.41}{14}}
\]

\[
= 0.17
\]

\[
\text{Standard Error (\%)} = \frac{\text{Standard Deviation}}{\sqrt{N}} \times 100\%
\]

\[
= \frac{0.17}{\sqrt{15}} \times 100\%
\]

\[
= 4.4 \%
\]

4.2. Wind speed monitoring and alert
Information of wind speed measurement and weather forecast data are shown in LCD monitor. Application built in VB processes the input data of anemometer sensor and weather forecast of...
openweather.org. It also notifies the alert in text warning and alarm if the wind speed data are in beware and danger level. The result of wind speed monitoring and alert is illustrated in Fig 6.

![Wind speed monitoring and alert](image)

**Figure 6.** Wind speed monitoring and alert.

Figure 6 shows the information of wind speed measurement, weather forecast data, and alert. The notation 1 describes the current actual wind speed of 3 Km/h whereas the notation 2 explains the alert of wind speed level in safe category. Number 3 illustrates the weather forecast every three hours later including time, temperature, and wind speed.

This research has successfully developed the monitoring and alert system of wind speed. It can be implemented in public area to notify the warning if the level of wind speed is not safe. The system also informs early warning to public if weather forecast data is in level of beware and danger. Related to wind speed monitoring research, this work has similar topics with [2] and [3]. Both of previous researches measure the actual wind speed measurement and group in several levels that this work is similar with this research. This research has innovation feature by combining the actual measurement and weather forecast data for notifying community around the system about the level of wind speed in advanced. Regarding to natural disaster warning, this research has similar topic with early warning of tsunami [8-10], earthquake [5-7,9], flood [4,11-13,18], land sliding [16], and wind [2,3].

5. Conclusion
This paper describes the development of wind speed monitoring and early warning system using wind sensor and weather forecast data. All of the functionalities including wind speed measurement, weather data harvesting, and warning system have successfully worked based on the testing result. The measurement data is analyzed using standard error equation with other digital anemometer and it is obtained the SE of 4.4%. This work can be enhanced by displaying of actual and weather forecast data in running text display as an outdoor device and informing the warning to social media.

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