Prediction of wind disaster using kriging spatial interpolation and internet of things

Frans Richard Kodong\textsuperscript{1} and Juwairiah Fajar\textsuperscript{2}

\textsuperscript{1}Universiti Teknikal Melaka, Malaysia (UTeM)  
\textsuperscript{2}UPN Veteran Yogyakarta, Indonesia

E-mail: frkodong@gmail.com

\textbf{Abstract.} The Indonesian Disaster Management Agency (BNPB, Badan Penanggulangan Bencana) estimates that wind disaster are increasing in some parts of Indonesia. The occurrence of wind disaster can not be predicted, when and where they occur, because the cause of natural factors, namely differences in pressure. Disasters that occur in Indonesia is caused by human factors, namely changes in land use and a way of life that does not pay attention to environmental conservation. Public preparedness in the face of the possibility of disaster increases, when disaster occurs they immediately evacuate themselves to a safer place. Therefore it is necessary socialization and understanding to the community against the possibility of disaster, another thing to think about is preparing early warning facilities and infrastructure. Yogyakarta is one of the areas that must be wary of the threat of a tornado, especially when there will be seasonal changes. The damage caused by the wind disaster is increasing, indicating that wind speed plays an important role in relation to the impact of damage caused. In this research methodology of system development that will be used is System Development Life Cycle (SDLC). For estimation of direction and wind speed will be used Kriging Spatial Interpolation Method. The IoT technology used consists of an anemometer and a microcontroller device and GSM (Global System for Mobile Communications) to obtain or capture real-time data of wind speed and direction sent over the internet to the server.

1. Introduction
Wind is air that moves from areas with high air pressure (maximum) to areas with low air pressure (minimum). Differences in air pressure result from differences in air temperature. If the air temperature is high, the air pressure is minimum, whereas if the air temperature is low, the air pressure is maximum (Figure 1). The tool for measuring wind direction and speed is an anemometer.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Causes of wind flow, Coriolis force}
\end{figure}
Wind flows from the air in the atmosphere caused by warming the earth that is uneven by sunlight. The wind cannot be seen or caught but we can feel its strength, so it is usually described with its direction and speed. This is a very good counterweight to the atmosphere, transporting heat, moisture, pollutants and dust. The difference in atmospheric pressure produces wind. Generally, wind flow from high pressure areas to low pressure areas. When traveling wind on speed, altitude and water or different land, it can cause various types of patterns. There are various types of winds such as breezes, crosswind, wind gusts, monsoons, tornadoes, hurricanes, typhoons, whirlwinds and hurricanes. (http://myhabitxxm.blogspot.co.id).

Wind speed is a measure of the movement of air over the surface of the earth including distance units per one unit of time. Wind speed is usually measured in kilometers per hour. Anemometer is a device used to measure wind speed. The amount of force produced by the wind is measured according to the Beaufort scale. This scale is named for Sir Francis Beaufort, who founded the system to describe wind power in 1805 for the British Royal Navy. (Von, 2015).

The strength of the wind is determined by its speed, the faster the wind blows, the greater the strength. The scale of wind strength can be seen in Table-1.

**Table 1. Beaufort Scale**

| Beaufort Number | Name     | Knots | MPH   | Effects Observed Far From Land | Effects Observed On Land |
|-----------------|----------|-------|-------|-------------------------------|--------------------------|
| 0               | Calm     | Under 1 | Under 1 | Calm; smoke mass vertically. |                          |
| 1               | Light Air| 1-3   | 1-3   | Rippled with appearances of scales; no leaf creeds. |                               |
| 2               | Light Breeze| 4-6 | 4-7   | Small waves; crests of glossy appearance, not breaking. | Wind fills air, leaves small dust.                                |
| 3               | Gentle Breeze| 7-10 | 8-12  | Large waves; crests begin to break; scattered whirlwinds. | Leaves and small things in constant motion; wind screenweight flag. |
| 4               | Moderate Breeze| 11-16 | 13-18 | Small waves, becoming longer; numerous whirlwinds. | Rasso dust and loose paper; small branches are aworn. |
| 5               | Fresh Breeze| 17-21 | 19-24 | Moderate waves; taking longer form; many whirlwinds on increased waters. | Strong waves; rain begins easy; creased wavelets form on increased waters. |
| 6               | Strong Breeze| 22-27 | 25-31 | Larger waves forming; whirlwinds everywhere; more spray. | Large beaches in motion; whistling sound in eaves, hair, and hair worn with wind. |
| 7               | Near Gale| 28-33 | 32-38 | Deep lumps up; white foam from breaking waves begins to be blown in streams. | Weather trees in motion; inclement weather; in walking against the wind. |
| 8               | Gale     | 34-40 | 39-46 | Moderately high waves of greater height; crests begin to break into splashes form is blown to windward. | Breaks large off trees; generally destroys progress. |
| 9               | Strong Gale| 41-47 | 47-54 | High waves, washing in; nest; dense branches of foam; spray may reduce visibility. | Right structural damage occurs (primary ones and some minor). |
| 10              | Storm    | 48-55 | 55-63 | Very high waves with overhanging crests; sea taken white; appearance form is blown on very dense streams; rolling big heavy and visibility reduced. | Extreme structural damage; trees uprooted; considerable architectural damage occurs. |
| 11              | Violent Storm| 56-63 | 64-72 | Exceptionally high waves; sea covered with white foam patches; visibility still very reduced. | Very rare experienced; accompanied by widespread damage. |
| 12              | Hurricane| 64 and over | 73 and over | Air filled with foam; sea completely abled with driving spray; visibility reduced. |                          |

Wind damage is a natural disaster caused by strong winds. Wind hazards are a threat to many places around the world, can cause human casualties, damage to homes, property losses and other business disruptions. In Indonesia, the danger of winds such as pickaxe or small-scale tornadoes often occurs both in urban and rural areas (Figure 2).
Figure 2. The impact of the wind disaster, Yogyakarta, Indonesia 2018.

1.1. Spatial Data
Spatial data is obtained from measurement results that contain information about locations and measurements. This data is presented in the form of the geographical position of the object, location, relationship with other objects, using coordinates and area. Spatial data can be in the form of discrete or continuous data. Spatial data has regular (irregular) and irregular spatial locations. Spatial data is one of the dependent (non-free) data models, because spatial data is collected from different locations indicating the dependence between data measurement and location. Spatial data has two important parts that make it different from other data, namely location (spatial) information and descriptive information (attributes). Spatial data is divided into three types according to the type of data, namely: geostatistical data, data area (lattice data), and point pattern. Geostatistics is a statistical science that is applied to geology and some other earth sciences. Geostatistical data leads to a sample in the form of a point from a continuous spatial data, both regular and irregular. Area data is a discrete data collection which is the result of calculation or addition of polygons zones in certain regions. In general, area data is used in epidemiological studies. A dot pattern will appear if the thing to be analyzed is the location of an event. The most important thing about point patterns is knowing the relationship between points.

1.2. Kriging
Kriging is a method of analyzing geostatistical data that is used to estimate the magnitude of a value that represents a point that is not sampled based on the sampled point surrounding it by using a semivariogram structural model. Kriging is also a method used to accentuate a special method that minimizes variance from estimation results. When viewed in general, the Kriging method is a geostatistical analysis method to interpolate a content value as an example of mineral content, based on sample data taken in irregular places.

In general, kriging is a method for analyzing geostatistical data to interpolate a mineral content value based on data sample. Sample data on geology is usually taken in irregular places. In other words, this method is used to estimate the value of the characteristics. At the non-sampled point, it is based on information from the characteristics of the sampled points surrounding it by considering the spatial correlation that exists in the data.

Kriging is a method of analyzing geostatistical data used to estimate the value of a value that represents a point that is not sampled based on the sample points surrounding it by using a semivariogram structural model. Kriging is also a method used to highlight special methods that minimize variance from estimation results. When viewed in general, the Kriging method is a geostatistical analysis method to interpolate the value of content as an example of mineral content, based on sample data taken in an irregular place. In general, kriging is a method for analyzing geostatistical data to interpolate the value of mineral content based on data, tasting. Sample data on geology is usually taken in an irregular place. In other words, this method is used to estimate characteristic values.

At the non-sampled point, it is based on information from the characteristics of the sampled dots that surround it by considering the spatial correlation that exists in the data. The kriging estimator can be written as follows (Bohling, 2005):
\[ \hat{Z}(u) - m(u) = \sum_{\alpha=1}^{n} \lambda_\alpha [Z(u_\alpha) - m(u_\alpha)] \]  

Information:
u, u_\alpha: the location vector for the estimation and one of the adjacent data, is declared \( \alpha \).
m (u): expectation value of \( Z(u) \)
m (u_\alpha): the expected value of \( Z(u_\alpha) \)
\( \lambda_\alpha (u) \): \( Z(u_\alpha) \) value for location estimation \( u \).
The same \( Z(u_\alpha) \) value will have different values for estimates at different locations.
n: the number of sample data used for estimation.
\( Z(u) \) is treated as a random field with a trend component, \( m(u) \), and the remaining component or error, \( e(u) = Z(u) - m(u) \).
Remaining kriging estimates for \( u \) as a summation of the remainder in the surrounding data. The \( \lambda_\alpha \) value is obtained from the covariance or semivariogram, with the remaining characteristic components required.
The purpose of kriging is to determine the value, \( \lambda_\alpha \) which minimizes the variance in the estimator, can be stated as follows:

\[ \hat{\sigma}_e^2 = \text{var} \{ \hat{Z}(u) - Z(u) \} \]

Many methods can be used in the kriging method, but based on whether or not the mean is known, Kriging can be divided into three, namely Simple Kriging, Ordinary Kriging, and Universal Kriging.

Simple Kriging
Simple Kriging is a kriging method with the assumption that the average (mean) of the population is known and has constant value. The processing of the Simple kriging method is by means of the spatial data that is supposed to be partitioned into several parts.

Ordinary Kriging
Ordinary kriging is a method that is assumed that the average (mean) of the population is unknown, and that spatial data does not contain trends. Besides not containing trends, the data used also does not contain outliers.

Universal Kriging
Universal kriging is a kriging method that can be applied to spatial data containing trends or non-stationary data.

1.3 Kriging Spatial Interpolation
Spatial interpolation is the prediction of a variable at an unmeasured location based on a sample in a known location. Spatial interpolation method using GIS can be used when estimating wind speed for a location. There are various spatial interpolation methods such as IDW, Kriging, Natural neighbors, Spline, Topo to Raster, and Trend. Weather data is generally recorded at point locations, so some form of spatial interpolation is needed to estimate data values in other locations. Various deterministic and geostatistical interpolation methods are available to estimate unmeasured locations but, depending on the spatial attributes of the data, accuracy varies greatly between methods. The final use of the surface of the interpolation variable must also be taken into account because different methods produce different results (Willmott et al. 1985). Spatial interpolation is more useful if adequate weather station densities are available throughout the study area. Wind speed, for example, is more varied in distance shorter than temperature or relative humidity, and is therefore expected to require a denser network of monitoring sites to achieve accurate and precise interpolation surfaces (Luo et al. 2008).
Spatial data play an important role in planning, risk assessment and decision making, especially in wind disaster management. However, it is usually not always available and is often expensive and difficult to obtain. Spatial data collected in the field usually comes from a coordinate point source, the processing requires continuity of spatial data of an area / region under study so that the interpretation obtained is accurate (Chinta, Agarwal, and Rao 2014).

2. Approach
For estimation of direction and wind speed will be used Kriging Interpolation Method. The IoT technology used consists of an anemometer and a microcontroller device and GSM (Global System for Mobile Communications) to obtain or capture real-time data of wind speed and direction sent over the internet to the server and users (Figure 3).

![Figure 3. IoT to Capture speed and wind direction](image)

Kriging is a method for analyzing geostatistical data to interpolate a mineral content value based on data sample. Sample data on earth science is usually taken in irregular places. In other words, this method is used to estimate the value of characteristics. At an unpaved point based on information from the characteristics of the dotted points that surround it taking into account the spatial correlations present in the data. The kriging estimate can be written as follows [1]. Kriging can be divided into three, namely Simple Kriging, Ordinary Kriging, and Universal Kriging.

Spatial interpolation is a prediction of variables in an unmeasured location based on a sample at a known location. Spatial interpolation methods using GIS can be used when estimating wind speed for a location. There are various spatial interpolation methods such as IDW, Kriging, Natural Neighbors, Spline, Topo to Raster, and Trend. Weather data is generally recorded at point locations, so some form of spatial interpolation is required to estimate the value of data in other locations. Various deterministic and geostatistical interpolation methods are available to estimate the location that is not measurable but, depending on the spatial attributes of the data, the accuracy varies greatly between methods.

The final use of interpolated variable surfaces should also be taken into account because different methods produce different results [7]. Spatial interpolation is more useful if adequate weather station densities are available throughout the study area. Wind speeds, for example, vary significantly shorter than relative temperatures or humidity, and therefore are expected to require a denser network of monitoring sites to achieve accurate and precise interpolation surfaces [3]. Spatial data plays an important role in planning, risk assessment, and decision-making, particularly in the prevention of wind disasters. However, it is usually not always available and often expensive and difficult to obtain. Spatial data collected in the field usually comes from a source of coordinate points, processing requires continuity of spatial data of a region / region under study so that the interpretation obtained is accurate [2].

3. Simulator Design and Implementation
System design architecture can be seen in Figure 4. Explanation of Figure 4 is as follows; Anemometer equipment, which acts as an IoT to measure wind speed and direction, is installed in several places in one area, for the simulation used the special area of Yogyakarta, in Indonesia. The
anemometer is then connected to a mobile phone (GSM) device that can transmit data to the central server via internet or SMS. Wind speed and direction data from various points will be mapped and interpolated to obtain a map of the distribution of wind speed and direction, this deployment map will provide an overview of wind conditions, so that it can be used to monitor and predict the disaster caused by the wind.

The implementation of this system uses the Matlab Kriging Toolbox, part of the simulation program can be seen in Figure 5. The inputs are anemometer coordinates, wind speed and direction data from various points. Geostatistics data processing using Matlab will result in interpolation from the wind data, the results of the simulation can be seen in Figure 6 and Figure 7.
4. Contributions
This research developed a system that can predict wind direction and speed using Kriging spatial interpolation method. Interpolation results in the form of a map of the distribution of wind conditions in a region. Map maps and wind speed maps can be used by disaster management agencies and communities to monitor and anticipate disasters caused by tornado winds, thereby minimizing the impacts of victims, damage and loss of property caused by wind disaster. In addition to applications for the community, this study will also contribute knowledge on how to utilize the spatial interpolation methods of kriging and IoT technology in the field of disaster management.

References
[1] Bohling G 2005 Kriging http://people.ku.edu/~gbohling/cpe940
[2] Chinta, Sandeep, Arun Agarwal and C R Rao 2014 Wind Speed Model for Anantapur District Western 1(8): 177–83
[3] Junaidi Apri 2015 Internet of Things, Sejarah, Teknologi dan Penerapannya: Review 1(3): 62-66
[4] Luo Wei, et al 2008 Chemosphere Distribution and Availability of Arsenic in Soils from the Industrialized Urban Area of Beijing, China 72: 797–802.
[5] Presman R S 2010 Software Engineering, a Practitioner’s Approach Seventh Edition Mc. Graw Hill International Edition
[6] Robini, Shete and Sushma Agrawal 2016 IoT Based Urban Climate Monitoring Using 2008–12
[7] Von 2015 Estimation And Validation of Wind Speed
[8] Willmott CJ, et al 1985 Statistics for the Evaluation and Comparison of Models 90(5): 8995-9005.
[9] Pengertian, Kecepatan dan pergerakan Angin http://myhabitxxm.blogspot.co.id)/2017/03/angin pengertian-kecepatan-pergerakan.html