Wireless Disturbance Mapping and Path Selection for Placement of Network Control System Components

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Abstract. Wireless transmitters in measurement instruments act for transmitting data or signals using radio frequency or currently better known as WIFI by means of 2.4 GHz. WIFI is a wireless local area network (WLAN) communication network. With the existence of telecommunications, measurement and control in industrial processes are heading to a high level of reliability compared to the conventional wired instruments in reaching hard locations or dangerous and hazardous areas. However, this cannot be done easily especially in maintaining the communication performances. Research is needed on the reliability of the wireless transmitter itself. Several factors such as communication disruptions are new challenges for the industry of wireless technology manufacturers to be able to prevent or to minimize errors that can arise in wireless network control systems. Signal strength mapping is needed in designing wireless network control systems. In this paper, the mapping is performed by measuring the signal strength parameters (Power Level) and the use of channels (Channel Usage) at planned locations. The measurement results are then used as sample points in the mapping. Data show that the signal strength measurement at each channel has a maximum of -60 dBm and a minimum of -105 dBm. Mapping is performed by using two methods, namely Inverse Distance Weight (IDW) and Spline Interpolation (SI) methods. The paper proposes an algorithm to select the appropriate wireless communication paths from the planned locations. The mapping results indicate the appropriate area to place the transmitter and the receiver devices in a wireless data transmission network. With good placement, it is expected that measurements using wireless transmitters have minimum disruptions.

1. Introduction

In 1940s, control system and measurement technology relied on pneumatic technology using 3-15 psig pneumatic signal. The more advanced developments in the field of engineering, scientists and engineers find new innovations in such control technologies such as electrical current using 4-20 mA analog, 4-20 mA smart, and fieldbuses which are widely used in the 2000s, namely multiple fieldbuses in the measurement and distribution of signals or data transfer. Of course, the technologies are increasingly progressing, so that controls and measurements can be made faster with a small potential failure using wired data communications although there occurs time delay in the communication [1][2]
and requires advanced control system strategies such as [3][4][5][6]. In other case, it also needs to consider the utilization of the energy utilization [7].

Newer inventions began to be applied, namely signal distribution or transmission of measurement data using wireless transmitters. Signal distribution using the wireless transmitter has an influence on the performance of the control system induced by the performance of communications [4]. This measurement tool uses wireless technology such as license free frequency bands on 2.4 GHz, to illustrate ISA100. This tool is an instrument with standards made by an international organization namely the International Society of Automation (ISA). ISA100 uses wireless communication technology that is capable of transmitting data without cable (wireless) intermediaries. The technology is developed because of the limited network, the extent of monitoring, and also the difficulty of maintenance when using cables.

With wireless communication, maintenance and coordination between networks will be easier. However, there are weaknesses that arise because the distribution system uses digital signals that are susceptible to interference especially electromagnetic waves. In this technology, a gateway (receiver) is needed in order to connect two different networks. The gateway system is redundant, namely having a duocast system (2 buses) that works actively so that if one fails in the transmission of a data packet, duocast is able to transfer data transmission to another bus. ISA100 uses a frequency band of 2.4 GHz with WPAN technology. At this frequency, there are many interference factors such as noise, user density, interference, and so on. These influences can affect the reliability and the performances of wireless transmitters in transmitting data. For this reason, a signal disturbance mapping is needed so that the placement of the wireless transmitters or receivers in a 2.4 GHz wireless control network can minimize interferences that occur in the deployment of the transmitter in a region having many different disturbances.

The considers interference mapping obtained from the results of the processing of space coordinate data which shows the signal strength criteria at a certain point of 2.4 GHz wireless transmitters. Inverse Distance Weight (IDW) and Spline interpolation (SI) methods [8] are used for signal interference mapping. Signal disturbance maps are then employed as the basis for designing a wireless control system by using an algorithm developed to select an optimal location of transmitters.

2. Networking

A wireless network consists of devices or computers that utilise wireless data linking between network nodes in order to avoid the costly installation process of using cables into a construction or as a connection among many equipment locations [9]. The wireless network operation occurs at the physical level (layer) of the OSI model network structure [10]. Wireless local area networks (WLANs), wireless sensor networks, satellite communication networks, cell phone networks, and terrestrial microwave networks are examples of wireless networks [11].

2.1. A wireless network

Wireless networks are divided into several types such as WPAN (Wireless Personal Area Network), WLAN (Wireless Local Area Network), WMAN (Wireless Metropolitan Area Network), and WWAN (Wireless Wide Area Network). The greater the scope of data transmission entails the greater of the power consumption and the data transmission speed. In [12], it has been figured out various wireless networks conform to IEEE standards as a function of Data Rate vs Power Consumption/Cost/Complexity.

2.2. Industrial Wireless ISA100

Currently, for the industrial wireless implementation, ISA100 capabilities are at the WPAN network level (802.15.4). ISA100 is an integration of several instruments and networks that use ISA100.11a standards-based technology. Therefore, ISA100 is a combination of wireless transmitters, wireless networks, and communication protocols. The technology uses radio frequency or WIFI with a frequency of 2.4 GHz. Some of the standards applied to ISA100 are 802.11 and 802.15.4. An
architecture in wireless communication systems based on ISA100.11a standards is described in [13] which includes gateways. Gateway function is to unite two or more networks that have different protocols. Each data packet will be sent through the gateway and be sorted out which data are suitable and may be sent to a master or a client. A gateway acts as an interface between wireless networks and applications for further applications in control systems such as in distributed control systems (DCS) [14]. Backbone routers have a function to connect between wireless devices in the field and gateway. System managers and security managers have roles to control and to manage the behavior and the security of wireless networks.

2.3. Power Level
Power Level (dBm) is a logarithmic (decibel) unit size that shows the ratio of power in multiples of one milliwatt. The ratio can be in the form of power, sound pressure, voltage, and intensity, etc. In a wireless network, dBm describes the strength of the signal emitted by the source if the source has power in milliwatts. For example, 0 dbm is equal to 1 milliwatt. A 3 dB increase will cause the power level 2-fold to 2 milliwatts. Conversely, a 3 dB decrease will reduce half of the power level of 0.5 milliwatts. The dBm mathematical equation is given as follows:

\[ x = \frac{10 \log_{10}(P)}{10} + 30 \]  

where \( x \) is the power ratio (signal strength) in dBm and \( P \) is the power in Watts.

2.4. Channel usage
In the 2.4 GHz frequency, channel usages in both protocols can influence each other. One example is signal interference and data overlapping. To determine the use of a channel, in general, the factor that must be considered is the range of the signal transmission frequency. The frequency range allowed is not overlapping by 20 MHz so that channel settings are divided into 3 large segments in the range 2400 - 2484 MHz. The communication protocol channel slice is illustrated in Fig. 1 as follows:

3. Experiment Design
3.1. Space design
Mapping is carried out in rooms located on the second floor of a building as shown in Fig. 2. On that floor, 20 measurement sample points are taken with a certain distance. Data taken at each point are signal strength and percentage of channel usage. In this paper, two devices are used, namely USB Spectrum Analyzer that functions as a sensor for capturing signal criteria and ArcGIS Simulator as a
software that functions to map signal strength data and the percentage of channel usage. The measurement results are then used for interpolating surfaces in ArcGIS spatial analyst [8].

Figure 2. Space layout and measurement points.

3.2. Interpolation methods
The methods used in signal interference mapping are the Inverse Distance Weight (IDW) [16][17] and the Spline interpolation (SI) by using regularization including tension [18][19][20]. The IDW method is an interpolator by assuming known sample points have a local influence on the point to be searched for. The influence of a point close to the point searched will be greater than the point far away. The influence will decrease with increasing distance between the sample point and the search point. However, all sample points within a certain distance can be used to determine the output value from the search point. Mathematically, the IDW function [16][17] can be written as follows:

$$z = \frac{\sum_{i=1}^{N} z_i (\frac{1}{D_i^2})}{\sum_{i=1}^{N} (\frac{1}{D_i^2})}$$

where:
- $z$: Output point value of the search point at a certain distance
- $z_i$: Value at point $i$
- $D_i$: The distance of the search point to the point $i$
- $N$: Number of points (1,2,3,..., $N$).

While the Spline interpolation (SI) method [18][19][20] is used to interpolate the surface so that the curve or the fracture can be minimized. The SI method is suitable for mathematical functions that have a value close to the sample point. If the value of the output between points has a high level, then the interpolation value can produce a value that is far from the estimate. In this paper, the method of approach with a regular system (regularized) is used. This approach sets the parameter weight to
define the weights of the third derivative of a surface function. The weight determines the minimization of the fault of an output value on the surface. The mathematical function of the spline method with the regularized approach is written in the equation below:

\[ S_{(x,y)} = T_{(x,y)} + \sum_{j=1}^{N} \lambda_j R_{(j)} \]  

(4)

where

\[ \lambda_j : \text{Coefficients obtained from a system of linear equations} \]

\[ r_j : \text{Distance from point } (x,y) \text{ to } j \]

\[ N : \text{Number of points } (1,2,3,\ldots,N). \]

In which, \( T_{(x,y)} \) and \( R_{(j)} \) are separately defined so that the equations are written as follow:

\[ T_{(x,y)} = a_0 + a_x x + a_y y \]  

(5)

\[ R_{(j)} = \frac{1}{2\pi} \left[ \frac{r^2}{4} \left[ \ln \left( \frac{r}{2\tau} \right) + c - 1 \right] + r^2 \left[ K_0 \left( \frac{r}{\tau} \right) + c + \ln \left( \frac{r}{2\pi} \right) \right] \right] \]  

(6)

where

\[ \tau : \text{Parameter specified in the command box} \]

\[ r : \text{Distance from the sample point to the search point} \]

\[ K_0 : \text{Modified Bessel function} \]

\[ c : \text{A value constant } 0.577215 \]

\[ a_i : \text{Coefficients obtained from system solutions of linear equations.} \]

Modeling validation is done by taking random points in the mapping area. These points are taken in the same way as the initial data collection. Validation data has a specific point or location. At that point, the output value taken is directly compared to the value generated in the mapping. Then the matching results are yellow and those that do not match are white. Validation is done by dividing OK results with NO results.

4. Data processing and analysis

Mapping is obtained from the results of the processing of space coordinate data which show the signal strength criteria at a certain point. The signal disturbance maps will be used as the basis for designing a wireless network of transmitters. The IDW method has the basic principle of calculating interpolation with distance parameters as the main parameter. In accordance with the equation (3), the distance between the sample point and the search point greatly affects the output of the interpolation method. The greater the distance, the smaller the effect caused by the collection of sample points. The SI method uses the equations (4), (5) and (6).

The results below show a mapping of channel 3 signal interference on the 2nd floor as shown in Fig. 3 and Fig. 4. Green areas indicate areas with the highest signal interference in the range 96 - 102. Whereas the white area is the area that has the lowest signal interference. After going through a 5-point validation test, this method has a validation of 57%. When compared with the IDW method, the results of this mapping have similarities in signal interference areas within a radius of no more than 5 m. However, the validation of these two methods has a significant difference. After passing the validation test with 5 points used in the IDW method validation test, the SI method has a validation of signal disturbance mapping of 73%. Because the SI method shows more similarities to real conditions,
the mapping used as the basis for analysis of signal interference mapping is mapping with the spline approach method.

**Figure 3.** Channel 3 signal interference map on the 2nd floor with IDW method.

**Figure 4.** Channel 3 signal interference map on the 2nd floor with the SI method.

### 4.1 Correlation Between Signal Strength and Channel Use

Based on measurements carried out on the 2nd floor, the data shows that signal strength or signal interference in the design of wireless control network is in the range of minus 60 - 105 dBm. It can be concluded that the power received by the recipient at the measurement location is in the range 0.003 - 1 pW. The maximum value is in channel 2 and channel 5 which is equal to - 81.7 dBm. When viewed as a whole, channels 1 to channel 6 have signal strength and a higher percentage of channel usage than channel 7 to channel 14.

### 4.2 Transmitter Placement Optimization

A regional selection technique is performed, namely by dividing the mapping layer into 6 parts, such as area A, area B, area C, area D, area E, and area F. In Fig. 5, the color areas that cannot be crossed by the two devices are the areas above orange with negative signal strength 96.5 - 97.4 dBm. If between locations/points of both devices are drawn in a straight line, then the line may not pass through the color area in questions. Through the validation test, the IDW and the SI methods have validation of 57% and 73% respectively.

To determine the most optimal area, it is proposed an algorithm in selecting the wireless transmitter placement coordinates in flowchart form as shown Figure. 6. The algorithm is based on the estimation results of mapping that has been done on 14 channels. In this paper, the results are only shown for channel 3.
Figure 5. Description of determination of areas.
5. Conclusion
The paper proposed an algorithm to select the optimal paths for placement of transmitters of wireless network control system after measurement of the signal strength or the signal interference in the planned locations. The mapping of the signal disturbances were completed by means of the Inverse Distance Weight (IDW) and the Spline Interpolation (SI) methods. The mapping provided the estimation values of the signal interference indicated the level of disturbances to the wireless network control system. The proposed algorithm selected the optimal paths resulted in the minimum signal interference. Distances and obstacles such as attenuation were the main parameters in decaying signal strength of the transmitters.
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