Design of Industrial Wireless Sensor System for Real-Time Data Collection in Steam Turbines

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***Abstract*—Wireless Sensors (WS) are utilized in industries, medical, greenhouses, and other applications to sense and monitor parameters required to control and utilize data. There are many challenges to implement WS networks such as collision, end-to-end delay, dead nodes and power consumption to name a few; however, the main challenge that face the implementation of WS are the sensing and transferring the data between the sensor and the system and the time taken. The time taken of a wired sensor to transfer data is undoubtedly slightly shorter than the time taken in WS. This paper intends to design WS that could reduce the data transfer time and compare the amount of transferred data and the time taken by the wired system. The WS design will be validated first by Bland-Altman method and data will be collected using MATLAB and the PLX-DAQ program. The results show that the amount and time taken to transfer data in WS is comparable to the wired system. The validated results suggested by this work are more than 95% in similarity to Bland-Altman. This led us to conclude that WS can be utilized with a multitude of applications in place of wired sensors.**

***Index Terms*—industrial wireless sensor, real time processing, Bland-Altman plot, wireless speed sensor**

I. Introduction

To date, wireless sensor is frequently utilized in most applications in the manufacturing industry, healthcare system, security services, and greenhouses [1]. Wireless sensors are low cost, flexible, reliable, and easily installed –the reasons that led to consider WS over their wired counterparts [2]. Nevertheless, wireless sensors exhibit drawbacks such as power consumption, real-time transfer, data rate transfer, and validation due to lost packets during transferring data from the source to the destination [3], [4]. An example of the utilization of wireless sensor for industrial application is the speed sensor. Similarly, wireless vibration sensors are used in most applications that collect vibration readings from machines for fault diagnosis or monitoring the vibration by the operators [5]. The objectives of this work are: achieve statistical agreement with the WS design and to compare the real-time processing and the amount of data transferred in the wired and the wireless sensor.

This paper presents the related work in Section 2, followed by the methodology in Section 3. In Section 3, validation of the design and also the experiments done will also be discussed. Section 4 will present the results and discussion. Finally, Section 5 will conclude the paper.

II. Related Work

A new method or design has to be validated first to prove that it is justified or comparable. To date, there are three statistical methods that can be employed to validate the design of the wireless sensor. They are Bland-Altman, Q-Q plot, and Density Function [6], [7]. Specifically and in contrast to the work presented by Zolgharni *et al.* [8], the Bland-Altman method is utilized to validate the results of the new scheme or system. In this method, a check for the agreement between the data of the peak and time integral of the velocity in the context of clinical measurement will be conducted. Rafael *et al.* [9] designed a bio-impedance system to check for heart variations based on feet impedance. The design is validated via Bland-Altman method by comparing the result of the bio-impedance with the ECG of the interval time and heart rates [9]. Chan Yang *et al.* [10] tinkered with low-cost signal systems to capture human physical movements. The throughput of the system agrees with the Bland-Altman results when compared to the standard data of an excited system [10].

On the real-time data transfer, the indicator to the stability operation against the data and also the amount of the processing time utilized, is investigated by researchers [11]. Other work in this regard was mentioned by Neuzil *et al.* [12] who utilized wireless sensors to collect vibrational data from the machine in real-time. The time taken for the 500 samples is 0.065s and it is reported to be the time taken to transfer the data from the wireless sensor to the nearest data bank [12]. Sadik *et al.* [11] designed a wireless sensor to collect data of the speed of the bicycle and the torque with low power consumption. Through Sadik *et al.* design, they collected

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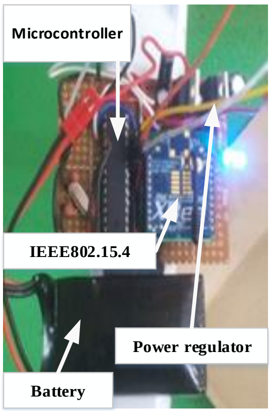
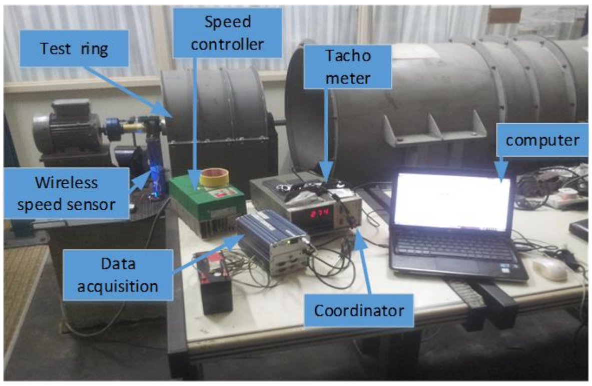
320 samples and transferred them to the computer. The time taken for collection and transferring these samples is 1.3s. [11].

III. Methodology

The wireless sensor consists of three main blocks: the physical sensor [13], the Microcontroller (MC) ATmega328p [14], and the radio part which uses ZigBee (based on IEEE802.15.4 properties). The baud rate of the computer and sensors is 19200 bits per second. Fig. 1(a) shows the design of the wireless sensor. The WS was configured using C++ to sense and collect the data and then transferred to the main computer via MATLAB-coding. The collected data within the wireless sensor was processed based on the X-CTU (expand this abbreviation) program. On the other hand, the Integrated Measurement and Control (IMC) device shown as Data Acquisition were used to validate the design of the Wireless Speed Sensor (WSS). Fig. 1(b) shows the industrial wireless sensor system.



(a)



(b)

Figure 1. (a) Wireless sensor designed, (b) data collected from test rig

A. *Validation Process*

The Bland-Altman method is utilized to achieve statistical agreement on the industrial WS system designed. The data is collected via algorithms or developed devices based on the comparison with data gathering from the validated system or devices [15]. This method is based on the mean difference between the validated systems and the developed system or instrument. The mean difference value will limit the accepted area of the data that it is created via the addition or subtraction of the standard deviation (SD) [9]. The formula of Mean and SD used are as written in (1) and (2),

$$\mu = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{1}$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \mu)^2 \tag{2}$$

where X is the difference between the two situations of the measurement, n is the number of the samples, σ represent the standard deviation, and μ is the mean differentiate data [16].

B. *Experimental Work*

The experimental setting of the test rig, which is the turbine model, consists of a part that is rotated via a three-phase motor and controlled by the speed controller. A magnetized part is fixed on the shaft of the system while the magnetic field sensor was installed in front of the shaft to calculate the Revolutions per Minute (RPM). The tachometer is fixed in front of the shaft to measure the RPM of the test rig. That data will then be collected and saved simultaneously by both the wireless sensor and data acquisition IMC to be further used for validation of the WSS algorithm.

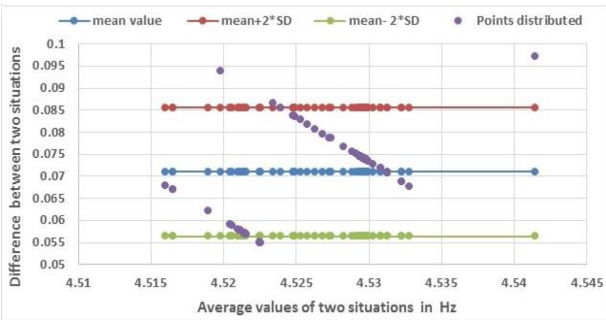
IV. Results

The results are classified into two parts: validating the design based on the Bland-Altman and a comparison of real time between wired and WS.

A. *Validation of the WS Design*

In order to validate the WS design, data was selected from the test rig based on the three cases: 300, 600, and 900rpm. The Bland-Altman plot was utilized to quantify the properties of the WS design [17]. The acceptable zone is limited by the mean ± 2*SD (95% approval area) where the mean value will be the center of the agreement zone and, as such, the error or the data outside the agreement zone should be less than 5% [18].

The data was collected simultaneously via the WS and the IMC data acquisition device. Fig. 2(a), Fig. 2(b), and Fig. 2(c) show the distribution measured zone via standard deviation error with speed condition of 300, 600, and 900 rpm, respectively. The results clearly show that the most of the measured data is located in the acceptable zone. The results are in good agreement with Bland-Altman expectation. The results in this work are 98.04%, 97.6% and 97.25% for speed condition of 300, 600, and 900rpm, respectively.



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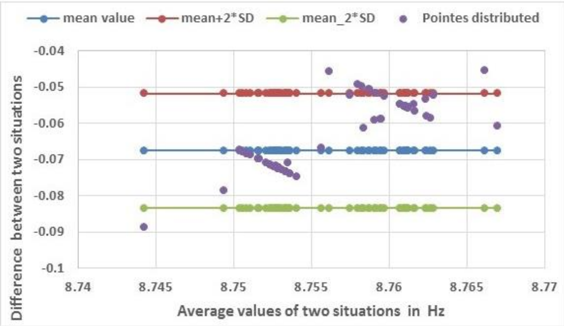

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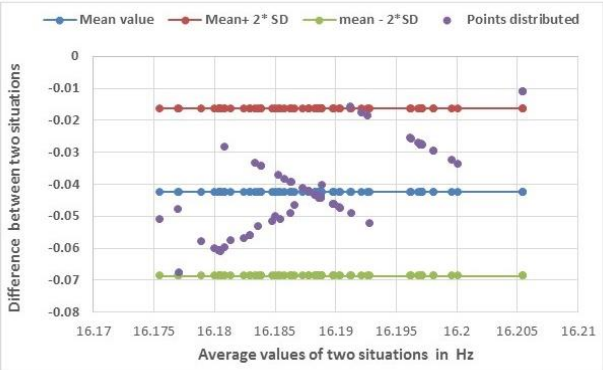


(c)

Figure 2. (a) Data validated of the 300 RPM, (b) data validated of the 600 RPM, (c) data validated of the 900 RPM

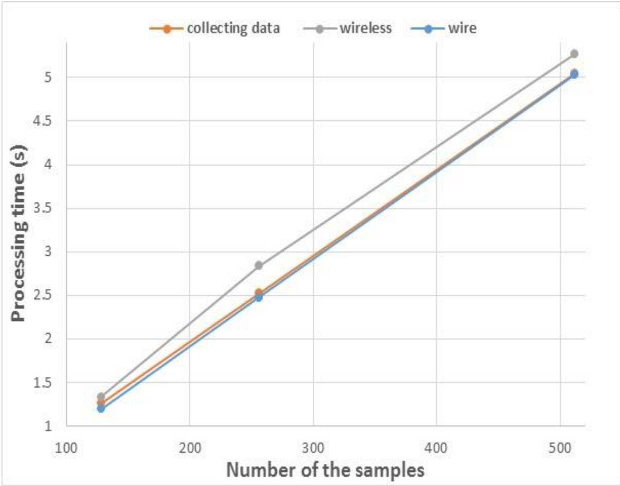
B. *Real Time Result*

In this work, data were collected at different rpm as follows: 128, 256, 512rpm and three coordinates denoted by x, y, and z as shown in Table I. In this scenario, ie in the first trial, each reading is counted as a sample in which for 128rpm and x, y, and z transmitted, altogether 4 samples are collected at one go. In the second trial, the three samples were collected as follows: y and rpm as shown in Table I. Two methods were used to send the collected data from WS to the computer which are through wireless transmission and wired media. The collected data in Table I are plotted with two schemes (wired and wireless) to show the behavior of sensor based on the amount of the data transferred and the time taken

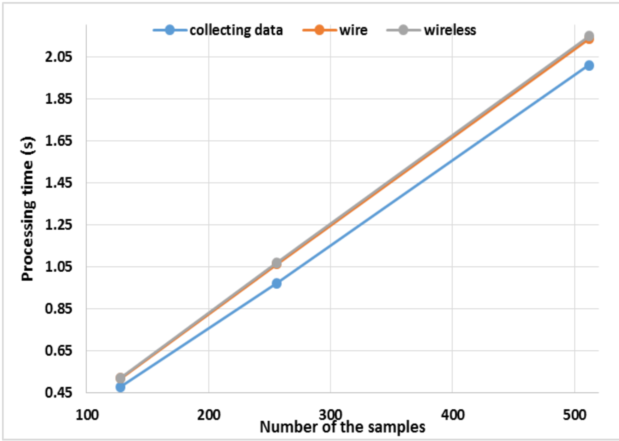
TABLE I. RESULTS OF TIME TAKEN TO COLLECT AND SEND DATA

No	Sample number and prototype read and send	Time needed to collect data by the sensor(s)	Time needed to collect and send data through **wire(s)**	Time needed to collect and send data through **wireless**(s)
1	128 [x y z rpm]	1.1948	1.258	1.3325
2	256 [x y z rpm]	2.4718	2.5212	2.8342
3	512 [x y z rpm]	5.0342	5.0465	5.2707
4	128 [y rpm]	0.481	0.521	0.5232
5	256 [y rpm]	0.9734	1.065	1.0708
6	512 [y rpm]	2.0105	2.1351	2.1477

Fig. 3 illustrates the comparison between real time collect and transfer data from the sensor to the computer via wired and wireless method. The data for 4 samples are shown in Fig. 3(a) while the data for 2 samples are shown in Fig. 3(b). In both cases, the time difference between the two methods of sending the data to the computer is minimal when the number of sample is taken at 128 rpm. Notice also that the trend of the two methods show linear relationship regardless of the number of samples taken.



(a)



(b)

Figure 3. (a) Related to collected data in the direction of x, y, z and rpm (b) data has collected the direction of Y and rpm.

V. CONCLUSION

The design of an industrial WS was developed and then used to sense and transfer data to the computer was presented in this paper. The design was validated using Bland-Altman statistical method. The number of samples taken into consideration is 128, 256, and 512 while the angular speed of the test rig was taken at 300, 600, and 900rpm. The data is collected by the sensor and then sent to computer via two methods: wired and wireless. The results show that for both methods the time difference is minimal when the number of the sample is 128. The time difference increases linearly as the number of sample increases to 256 and 512 samples. The results suggested that the number of sample plays an instrumental role in the monitoring system if time is the main concern. The data is more stable when data are sensed and transferred at 128rpm.

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