International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August, 2019

Digital Signal Processing and Real Time Statistical Analysis in Wireless Sensor Networks Using Xbee and Java

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Abstract: ***Objective of this paper is how Digital Signal Processing can be implemented in Wireless Sensor Network (WSN) using Java. Digital Signal Processing enables the application of digital filters and algorithms. These filters have a great advantage over analog filters. Further, we have performed statistical analysis on the received dataset in real time. Statistical analysis gives us valuable information about the data and how it is distributed. The statistical analysis results will be logged in real time using the Java application.***

Keywords: Wireless sensor networks, Xbee radio, Java, Digital Signal Processing, Statistical Analysis, Data logging.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) play an important role in measuring and monitoring the environmental parameters such as temperature, pressure, humidity etc. WSNs are seen as alternative to their wired counterparts. In measurement of remote location parameters the traditional wired systems fail [1].Industries are gradually adopting the WSNs for process monitoring, control and data processing [2-6].WSNs are collection of miniature autonomous devices on which sensors are embedded known as sensor node [7-8]. Basic components of a typical node are shown in Figure 1. The Xbee radios are scalable, flexible and easy to use. WSN has very wide application in domestic as well as in industrial field, like collection, transmission, processing and monitoring of remote data [9]. Rashmi Singh et al [10] designed a wireless system to monitor and transmit the environmental parameter such as temperature. Boyu Dang et al [11] designed a Wireless Biomedical Sensor Network (WBSN) to collect, transmit and monitor the sensor data in real time onto a Graphic User Interface. A Sumarudin et al [12] developed a system based on microcontroller and Xbee radios in order to monitor the status of soil. Rashmi Priyadarshini et al [13] designed a system based on wireless sensor network for campus monitoring which protects the campus against the intruders who can enter the campus after working hours. Sriram Kagitha et al [14] designed a Wireless Sensor Network for thermal power plants based on Zigbee and GSM modules. Andrey Somov et al [15] developed an Early Gas Detection system consisting of sensor node, actuator and on board sensor. Kothuru Anudeep and S. Srinivas [16] developed a Home Monitoring System based upon Wireless Sensor Network for monitoring the elderly activity. Sung WT et al [17] designed a system based on arduino and Xbee radios to monitor and control the environmental parameters. Eric Ayars and Estella Lai [18] analyzed in their paper that how data can be collected and transmitted to base station using Xbee radios Rashmi Jain et al [19] developed an Irrigation System based on wireless sensor network to monitor various parameters like temperature, moisture etc.

R.K. Dhammi et al [20] demonstrated a very user friendly and effective approach to measure the temperature of remote place by keeping the Xbee radio module with sensor at remote end and collecting the data at receiving end using Xbee radio and Arduino module. Further a wireless real time monitoring and predictive system with cold junction compensation without using any peripheral hardware was developed by R.K. Dhammi et al [21].

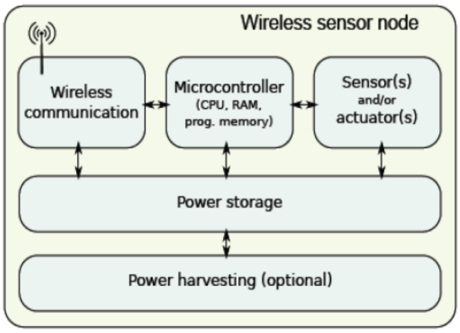

Fig. 1: Hardware components of Wireless Sensor Node

In all above mentioned papers it has been observed that each design is supported by Microcontroller along with wireless radios and also no paper discussed about any filtration process or filtration algorithm to filter out the input noise, no statistical analysis has been done for received data.

Revised Manuscript Received on October 30, 2019.
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In the proposed approach, Xbee radios are used without microcontroller. Capability of Java is used to process the data. The purpose of this paper is to demonstrate the following:

- Application of Digital Signal Processing algorithms to Wireless Sensor Networks using Java.
- The advantage of using digital filters in Wireless Sensor Networks using Java.
- To perform statistical analysis on the data received from a remote node in real time.
- To log the results of the statistical analysis and received data in real time.

The outline of this paper is as follows: Section II describes about Back Ground, Section III depicts about System Layout which includes experimental set up as well as the Flow Chart. Software and Hardware components are described in Section IV and V respectively. How DSP is implemented using Java is explained in Section VI. Section VII is about 'Statistical Analysis using Java'. Result and Conclusion are discussed in Section VIII and IX respectively. Future Scope is discussed in Section X.

II. BACKGROUND

Wireless Sensor Networks which are spread over a large domain suffer from a number of scalability issues. One of the most common and prominent one is the distance between the remote and controller nodes. The signal strength in wireless sensor networks greatly reduces with distance and obstacles. Wireless data transmission is also prone to interference and noise. The source of this interference can be electromagnetic (EM) waves generating from other electrical devices present nearby. Due to the abundance of wireless devices in modern day workspaces, the chances of In-Channel and Co-Channel interference are greatly increased. This interference can create noise in the received signal. If the received signal is the output voltage of a sensor, there is a high probability that the received signal contains some error. Often analog filters are employed in electric circuits to remove the unwanted components (or noise) in the signal. Analog filters are based on the concept of resonance. Therefore, different combinations of resistors, capacitors and inductors can be used to provide different values of impedance. Impedance is then used to suppress the noise components of a signal. The Java application is used to connect to the coordinator Xbee in the wireless sensor network. The Java application is used to collect data from the wireless sensor network. The digital filters can be applied in the Java application. Digital filters offer a number of advantages over analog filters. Wireless Sensor Networks generate a large amount of data that has to be processed and stored. The stored data may later be used for other purposes. In case of a multi node multi sensor network, the amount of data generated becomes large and complicated. This leads to the need for statistical analysis. Statistical analysis can help to determine the correlation between the two data sets. It can be used to gain the minima, maxima, mean etc. of a given data set. These values hold a large significance for data researchers and for data visualization. Statistical analysis helps present the user with accurate information that can help him in the decision making process.

III. SYSTEM LAYOUT

System layout consists of various software and hardware components which are explained in subsequent sections. Two Xbee radio modules have been used, one as a coordinator and other as a router. The Coordinator and router Xbees work in API and AT modes respectively. The router module makes use of API frame 19 to transmit the data. Temperature data sensed by LM 35, connected at pin no 17 of router Xbee module, is transmitted by router module wirelessly to coordinator Xbee which is connected to PC via USB Xbee Explorer. X-CTU software has been used to configure the Xbee modules as coordinator and router modules. Program has been written in Java using Java Xbee API which makes it possible to communicate easily between Java program and Xbee radios. After fetching the data from received frames the Java program converts it to temperature data, represents the data as a time-temperature graph as well as writes the data to disc [Figure 2.].

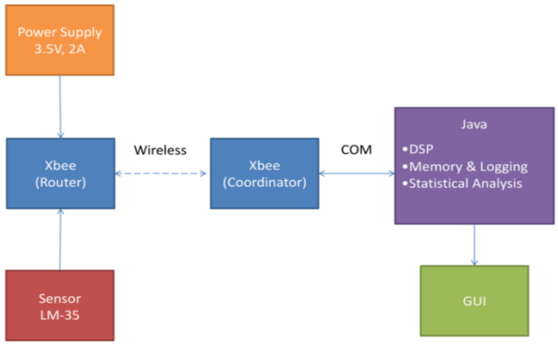

Fig. 2: Block Diagram of Wireless Sensor Network using Xbee & Java.

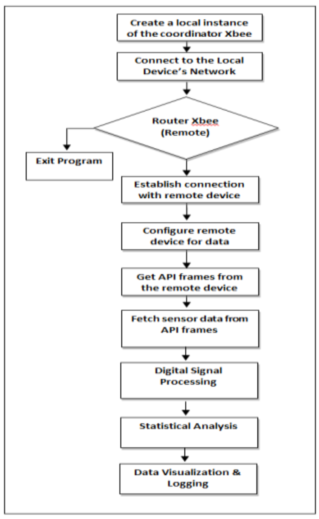

Fig. 3: Flowchart for the Java Program

IV. SOFTWARE COMPONENTS

A. Java SDK

The Java Software Development Kit, or the JAVA SDK 8.2, is a set of tools developed and released for Java programmers and developers by Oracle.

It consists of a number of resources and programming tools to allow for development of Java applications. It also includes the Java Virtual Machine (JVM) and the Java Run-Time Environment (JRE).

B. Eclipse IDE

Eclipse is an Integrated Development Environment (IDE) used for programming Java. Software version 4.6.2 (Neon 2) has been used to program the application.

C. Xbee Java Library

It is a Java API that is used to create Xbee projects developed in Java. It supports for multiple Xbee modules and protocols, supports for Android OS, Easy workflow. It has further following features:

- Ability to configure local and remote Xbee modules of the network.
- Discovery feature finds remote nodes on the same network as the local module.
- Ability to transmit and receive data from any Xbee module on the network.

D. XCTU

XCTU is a multi-platform tool developed by Digi that allows the user to configure and interact with Xbee radios through an easy-to-use GUI (Graphical User Interface).

V. HARDWARE COMPONENTS

A. Xbee S2B Module

Xbee radios are compact, cost-effective and telemetry modules. They can be connected to deploy wireless sensor networks in different topologies. They provide a reliable data link between remote radios. The Xbee S2B operates within the ISM 2.4 GHz radio band.

B. Xbee USB Explorer

The Xbee USB Explorer is a USB-Serial hardware peripheral that allows the user to connect the Xbee radios to PCs through a USB-COM port. It is a USB-Serial convertor, with a hard reset button and a voltage regulator. It acts as a break out board to make it easier to interface with the digital and analog input/output pins on the Xbee radios.

C. LM 35 Temperature Sensor

LM35 is a Precision Centigrade Temperature sensor. Its output (Voltage) varies linearly with temperature (In Centigrade). LM 35 has its temperature range as -55ºC to +150ºC. Variation of input voltage can be between -0.2V to +35V and variation of output voltage can be between -1V to 6V. Current is limited to 10 mA in the output side.

VI. DIGITAL SIGNAL PROCESSING IMPLEMENTED USING JAVA

The need for Digital Signal Processing wireless sensor networks has already been discussed.

The output from sensors can contain noise. The noise often results in errors. Through the use of digital signal processing, we can remove the noise to obtain an accurate output.
The reasons for noise in the sensor output may include:

- RF interference
- LM35 has an accuracy of +/- 2 degrees
- Noise originating in the power source
- Random errors

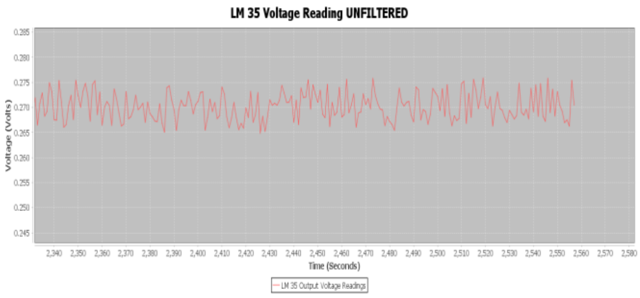

Fig. 4: LM 35 Voltage Reading UNFILTERED

the graph shown in figure 4, the noise in the raw sensor data is quite evident. Kalman filter has been used to perform digital filtering of the raw sensor data in real time. The reasons for selecting the Kalman filter are as follows:

- It is a practically proven filter, with wide spread use in RADARs, robot localization and space applications.
- It is convenient for use in real time filtering / estimating applications.
- It is easy to implement.

The Kalman filter can be called an estimator. It is a recursive filter that allows for real time data processing. The Kalman filter can only be used to remove linear noise. As the current system can be considered a linear system, the Kalman filter can be used.
Noise which is non-linear cannot be removed using the Kalman filter and such scenarios warrant the use of non-linear estimator algorithms.
The Kalman process consists of the following steps. It states that for each time step, (t), it will

- Predict the next state.
- Predict the covariance of the next state.
- Calculate the Kalman Gain.
- Update the current state estimate.
- Update the current covariance estimation.

The following are the system state assumptions:

- The state vector in our case is the data captured from the wireless sensor network.
- It is assumed that the data does not vary quickly with time.
- There is no input control in the system.
- The only observable output of the system is the output of the sensor.

- Process and Observation noise covariance are calculated. The process covariance is assumed to be very low while the observation noise variance is calculated.

The graph of figure 5 shows the output filtered by the Kalman filter in real time. It can be easily seen that the noise has been greatly reduced in the output.

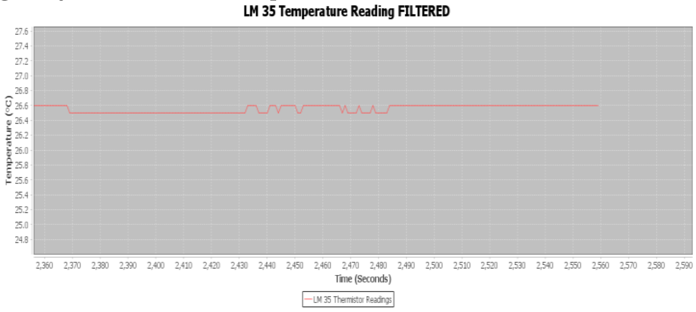

Fig. 5: LM 35 Temperature Reading FILTERED

In existing example, a simple LM-35 thermistor is connected to a single remote node. In other wireless sensor networks, having multiple nodes and multiple sensors, including a mix of digital and analog sensors having different sampling rate, digital signal processing algorithms and filters can play a crucial role in reducing system noise and digital signal conditioning. The two graphs shown in figures 6 and 7 are time / temperature plots of the data received from the wireless sensor network. The graph of figure 7 shows the data set of around 2,500 samples. The Kalman filter is able to remove a large part of the noise from the received signal.

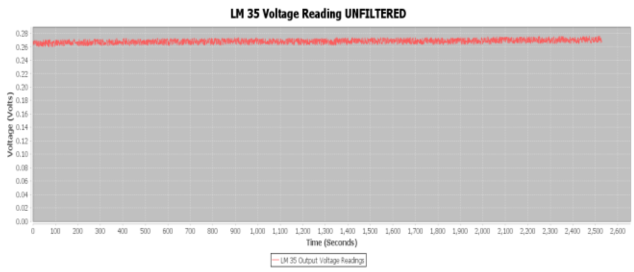

Fig. 6: LM 35 Voltage Reading UNFILTERED

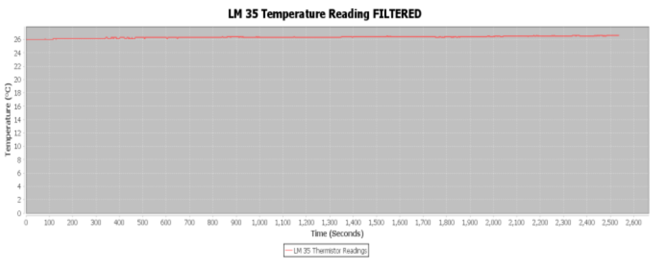

Fig. 7: LM 35 Temperature Reading FILTERED

VII. STATISTICAL ANALYSIS USING JAVA

The Java program is able to perform statistical analysis on the received data in real-time. Some of the functions are described below:

A. Number of Samples

This is the total number of samples in the data set.

B. Minima

Minima is the value with the smallest value in the data set.

C. Maxima

Maxima is the value with the highest value in the data set.

D. Mean

Mean is the average of all the samples in the data set. Mathematically, it is defined as:

Sample mean:

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i .$$

x (bar) is the mean, n is the number of samples and x_i is the i^{th} sample.

E. Mean deviation

Mean deviation is the difference between the current sample and the mean of the data set.

F. Median

Median is the middle value of an ordered data set. In case the total number of samples is odd, the middle value is called the median. If the total number of samples is even, then the average of the middle two values is considered the median.

G. Standard Deviation

Standard deviation of a sample is the measure of the amount of variability. It can be called the average distance from the mean. Mathematically, it is the square root of the variance.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{x})^2}.$$

H. Variance

Variance is a measure of variability of the sample. Mathematically, variance is the average of the squared differences from the Mean.

Sample variance:

$$s_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2 = \frac{1}{n-1}\left(\sum_{i=1}^{n} x_i^2 - n\overline{x}^2\right).$$

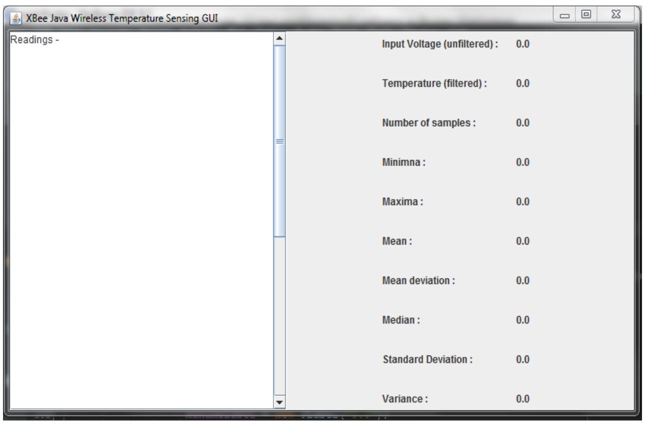

Fig. 8: Sample GUI

International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-6, August, 2019

XIII. RESULT

Following are the results of this paper:

A. Implementing Digital Signal Processing and Digital Filters in Java

Through this paper, it has been demonstrated that how digital signal processing algorithms and filters can be implemented in wireless sensor networks using Java. The GUI consists of two graphs as shown in figure 9, comprising of raw unfiltered data and data filtered using DSP filters. In this case, Kalman filter has been used. The graphs are updated every second.

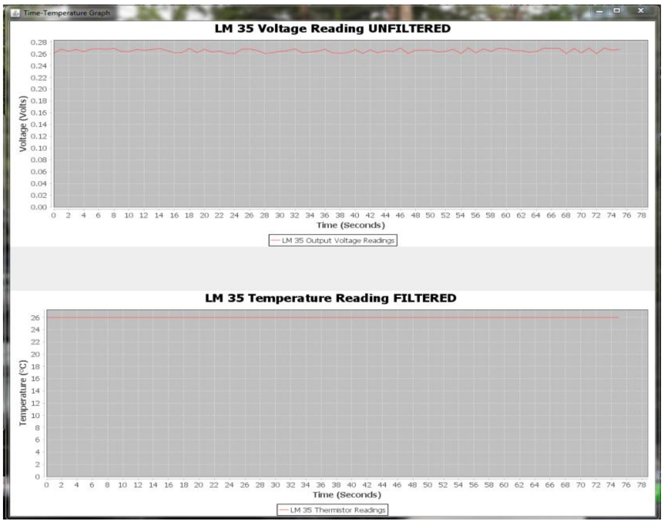

Fig. 9: Graph GUI

B. Performing Real Time Statistical Analysis

The program is able to use the filtered data and perform a number of statistical operations in real time. The mean, median, mean deviation, minima, maxima, variance, standard deviation and the number of samples in the data set are calculated. This data gives us an insight about the type of data being generated by the wireless sensor network. The GUI shows the complete data set as shown in figure 10, along with the time at which the sample was registered by the Java program.

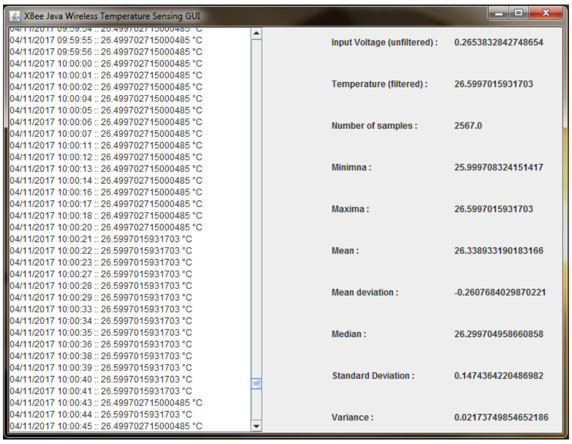

Fig. 10: Statistical Analysis GUI

C. Logging of Wireless Sensor data and results of Statistical Analysis in Real Time

Using Java program it is possible to log the data from the wireless sensor network to the hard disk in the form of 2 .txt files. One file contains the filtered sensor data received from the wireless sensor network as shown in figure 11. The second .txt file contains the output of the statistical data in CSV format as shown in figure 12.

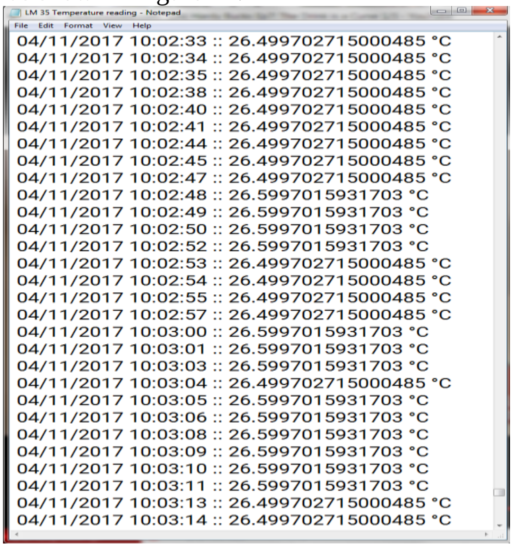

Fig.11: Filtered Wireless Sensor Network Data

Fig.12: Statistical Data (CSV Format)

IX. CONCLUSION

In this paper, following has been successfully demonstrated:

- Applying DSP algorithms in Wireless Sensor Networks using Java
- Applying programmable digital filters in Wireless Sensor Networks
- Performing statistical analysis in real time
- Logging of received sensor data and the result of statistical analysis in real time

The advantages of using digital signal processing and digital filters make them the obvious choice over analog filters. Digital filters do not require additional hardware. They are easily customizable and programmable. This means no additional capital investment is required to implement them. Digital filters do not suffer from drift and changes in performance due to heating. Statistical analysis helps us better understand the data being received in the wireless sensor network.

Real-time data logging helps us save the data for future use and research. Certain drawbacks do exist. Designing and implementing DSP is a complicated process. DSP becomes expensive when large bandwidth signals are involved. This might be seen in large wireless sensor networks. Further, additional hardware would be required when performing DAC (Digital to Analog Conversion) in a wireless sensor network. The same can be said for ADC (Analog to Digital convertors).

X. FUTURE SCOPE

This paper was a proof of concept, to prove that DSP and Digital filters could be implemented in Xbee Wireless Sensor Networks using a program written in Java. Future work can include implementation of more complicated digital filters. The program is highly customizable and modular. It can be easily modified for deployment in different workspaces and environments. The statistical analysis is of great importance to data miners and data visualization scientists. The Java program can be easily customized to perform data visualization in real-time.

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