# Real Time Wireless Sensor Network for Environmental Data Prediction and Monitoring

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**Abstract-** There have been a growing concern over environmental issues like global warming, radiation, energy conservation, efficient energy usage etc. These concern have been given a significant research attention over the years. The advent of Wireless Sensor Networks (WSN) has provide an efficient technique of data collection in a wide variety of application. There are a large number of prior efforts in building low cost WSN for environmental monitoring applications. However, predicting such environmental data for easy decision and preventive measures has not been given a considerable attention. Thus, this paper presents the development of a real time wireless sensor network for any environmental data prediction using naïve prediction model. The developed system was implemented on intranet, Low forecast metric error result obtained shows the accuracy of the naïve model.

**Index Terms—** MAPE, MSE, Naïve Forecast Model, Prediction Model, Real Time, RMSE, Wireless Sensor Network

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## 1 Introduction

There is a growing concern over environmental issues like global warming, energy conservation, efficient energy usage, radiation, etc [1]. These concern have been extensively researched and Wireless Sensor Networks (WSN) has given a viable solution to these issues.

WSN consists of a large number of low-cost, low-power, small size and multifunctional wireless sensor nodes, with sensing, gathering and computation capabilities which can be communicated over a short distance via a wireless medium and collaborate to complete a common task [2]. WSN is generally deployed in unattended and harsh environments. However, some constraints limit their application to some extent. These constraints include limited amount of energy, limited communication range, low bandwidth, limited processing ability and storage in each node [3]. Performance of a sensor node is highly dependent on the effective and efficient usage of these available limited resources that leads to maximum lifetime of the WSN [4]. One primary concern on wireless transmission is the power consumption [5]. As the range of the transmission becomes longer, the module needs more power to transmit the data. Another consideration also is the cost of the system [6] as available sensor platforms in the market are expensive which precludes its use widely [7]. Maximizing network connectivity while maintaining a useful lifetime period without exceeding cost constraints is a challenging design objective for WSN [8]. Adopting a low power consumption and high data rate Radio Frequency (RF) transceivers has become popular in many research works [9] which has made the nRF24 series of 2.4GHz transceivers attractive to developers and makers due to its low-cost, low–power consumption, and its availability as cheap break-out boards [10]. With sensor networks, environmental data can be observed and collected in real-time, and used for forecasting upcoming phenomena and sending prompt warnings if required [11] .The rest of this paper is organized as follows, literature review in section 2,design and implementation

- *Idakwo Monday A. is currently pursuing master degree program in computer engineering in Ahmadu Bello University, Zaria, Nigeria. E-mail: mondabutu@gmail.com* in section 3, experimental set up in section 4 while summary and conclusion in section 5.

## 2 Literature review

Several researches has been done in developing real time environmental monitoring system. In [1] similar to [12] developed an embedded WSN for system monitoring using a simple, cost-effective and low-power method. An Arduino platform paired with a Raspberry Pi was used for data acquisition and data storage respectively. A threshold to monitor any anomaly in weather data by triggering a buzzer was presented in [13]. The research in [14] presented an effective indoor air quality monitoring system to prevent exposure to risk. One great advantage of this system is the notification system that allows users to act in real time in order to significantly improve indoor air quality through the activation of ventilation or deactivation of pollutant equipment. Nevertheless, the system can be improve by forecasting the indoor air quality rather than waiting for the air quality exceeding specific minimum or maximum parameter before sending the notification alert to prevent exposure to risk. More so, [15] presented a comparative study on an application specific forecasting algorithm for extending WSN lifetime. It showed that, naïve model was quite robust compared with both the Autoregressive Integrated Moving Average (ARIMA) and Exponentially Weighted Moving Average (EWMA) models in terms of memory foot-print, computational cost, energy consumption and accuracy. This is the motivation on which this designed was inspired to forecast environmental data prior to event using naïve model. Our developed system is similar to [1] with few changes. We reduced the design complexity by integrating our data coordinator and server together and also we introduced real time data forecasting to the Graphical User Interface (GUI).

The contribution of this paper are highlighted as follows:

(i) The paper developed and efficient model for environmental data prediction using naïve model.

(ii) The developed system has a friendly GUI that display real time data every minutes, Predicted data, and computes both the forecast error metrics and graph every five minutes.

### 2.1 Prediction Model

The concept of in-networking information processing by using prediction models like ARIMA [16], Generalized Autoregressive Conditionally Heteroskedastic (GARCH) [17], EWMA [18], Naïve Models [15], etc. has been widely studied in literature [19]. Data collected by sensors can be considered discrete temporal series, where the time corresponds to the instant when a given value was collected. Sensed data represent the values, and the time range is determined by the duration time of the query. To predict future values of sensed data it is necessary to find a trend in the temporal series. From the standpoint of data accuracy, the best case is to have the exact change pattern of sensed data in a given WSN [20]. Detecting this pattern is non-trivial especially when there is no underlying statistic or data that explains the monitored phenomenon. Naive model are known to be optimal for efficient stock market and it could be very difficult to outperform it hence it is normally used in other domains as a benchmark for the

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more complex models such as ARIMA, GARCH, EWMA, etc [21]. When dealing with WSN it is necessary to take into consideration the limited battery supplies especially when the goal is to have a monitoring system that can last for years. The complex models normally requires some historical data to train a predictor exposing the network to large consumption of energy resources during computation. This gives Naive model additional advantage over the more complex models, because it is very simple to implement even on large scale networks, and requires low memory footprint. However, one of the drawback of Naïve model is that the performance reduces when the variance of the signal is high [15].

### 2.2 Naïve Forecast Model

A naive forecast model**,** uses a single previous value of a time series as the basis of a forecast. The naive approach can be used with a stable series (variations around an average), with seasonal variations, or with trend.

(i) Stable time series data: Forecast is the same as the last actual observation [15]

$$y_t = \tilde{y}_{t-1} \quad (1)$$

Where $y_t$ is the observation, $\tilde{y}_{t-1}$ is the forecast

(ii) Seasonal variations: Forecast is the same as the last actual observation when in the same point in the cycle, where a cycle lasts $n$ periods. For example, the forecast for highway traffic volume this Friday is equal to the highway traffic volume last Friday**.**

$$y_t = \tilde{y}_{t-n} \quad (2)$$

(iii) Data with trends: There is constant trend, the change from $(t-2)$ to $(t-1)$ will be exactly as the change from $(t-1)$ to $(t)$

$$y_t = \tilde{y}_{t-1} + (\tilde{y}_{t-1} - \tilde{y}_{t-2}) \quad (3)$$

### 2.3 Mean Square Error (MSE)

This is a quantitative performance metric used in forecasting to evaluate forecast accuracy [22]. The MSE measure the variability in forecast errors and is a direct estimator of the variance one-step-ahead forecast errors. Therefore, the mean square error can be mathematically expressed as follows:

$$MSE = \frac{1}{n}\sum_{t=1}^{n} |y_t - \hat{y}_{(t-1)}|^2 \quad (4)$$

Where $y_t$ is the observation, $\hat{y}_{(t-1)}$ is the forecast that was made, $n$ is the number of observations and $t$ is the time of observation.

The lesser the value of MSE, the more accurate the prediction [23].

### 2.4 Root Mean Squared Error (RMSE)

The RMSE has been used as a standard statistical metric to measure model performance in meteorology, air quality, and climate research studies [24]. It result quantify the average difference between predicted to measured value.

$$RMSE = \sqrt{\frac{1}{n}\sum_{t=1}^{n} (y_t - \hat{y}_{(t-1)})^2} \quad (5)$$

### 2.5 Mean Absolute Percentage Error (MAPE)

This is like Mean Average Difference (MAD), but penalizes error on the basis of what proportion of the actual value it is rather than its raw numeric amount [22].

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} |(\frac{y_t - \hat{y}_{(t-1)}}{y_t})100 \quad (6)$$

## 3 Design and Implementation

The system developed includes a base station and a number of distributed wireless sensor nodes as shown in Fig 1.

### 3.1 Design of Sensor Node

In this research, we developed networked sensor nodes using Arduino and nRF24L01 transceivers. Arduino is a widely used open sources single-board microcontroller devel-

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opment platform with flexible, easy-to use hardware and software components. Arduino Uno R3 is based on Atmel Atmega328 micro-controller and has a clock speed of 16 MHz. It has 6 analog inputs and 14 digital I/O pins, so it is possible to connect a number of sensors to a single Arduino board. The nRF24L01 is a 2.4GHz transceiver for low power wireless application, draw very little power (0.14mA in sleep mode, 13.6mA in transmit mode) and with a data rate up to 2Mbps. Also, the nRF24L01 divide their transmit/receive hardware into several pipes which enable them to transmit data on one pipe and synchronously listen to another 5 pipes, this allows for star and mesh network topologies. To keep the design simple temperature sensors only were used. The nRF24L01 uses Serial Peripheral Interface (SPI) in communicating with the arduino ATmega328P microcontroller.

### 3.2 Base Station Design

For the base station, we used nRF24L01 and the low power credit-card-sized single-board computer Raspberry Pi Model B. The CPU on the board is an ARM processor with 700 MHz clock speed. It has a variety of interfacing peripherals, including USB port, HDMI port, 512MB RAM, SD Card storage and interestingly 8 GPIO port for expansion. It supports a number of operating systems including a Debian-based Linux distro, Raspbian, which is used in our design. The Raspberry pi was connected to nRF24L01 transceiver which was configured as the Personal Area Network (PAN) Coordinator and provide DHCP services to the sensor nodes.

A Web server application was built with Apache HTTP web server on the Raspberry pi. The client side web interface was implemented with HTML, CSS, JavaScript, Ajax, jQuery, and Flot. HTML and CSS in combination were used in styling the web page. JavaScript was used for client-side scripting to enable dynamic display and interactive user interface. Flot was used to visualize sensor data in dynamic real-time graphical displays. In the real-time display mode, instead of refreshing and re-drawing entire web page, Flot provides the capability to only update the chart with new data that are fetched periodically from the server. Ajax and jQuery were used to feed the Flot charting functions with continuous flow of data from the MySQL database on the server via the web services written in PHP. The data is serialized into the JSON (JavaScript Object Notation) format to be communicated between server and client.

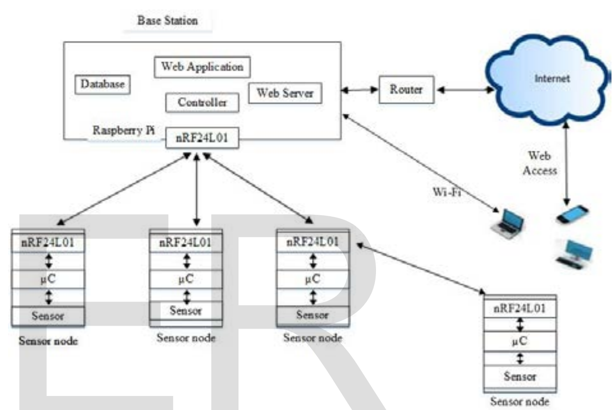


Fig.1: System Architecture of the Developed System

The naïve model was integrated on the developed system GUI using JavaScript and the flow chart is as shown in Fig.2.

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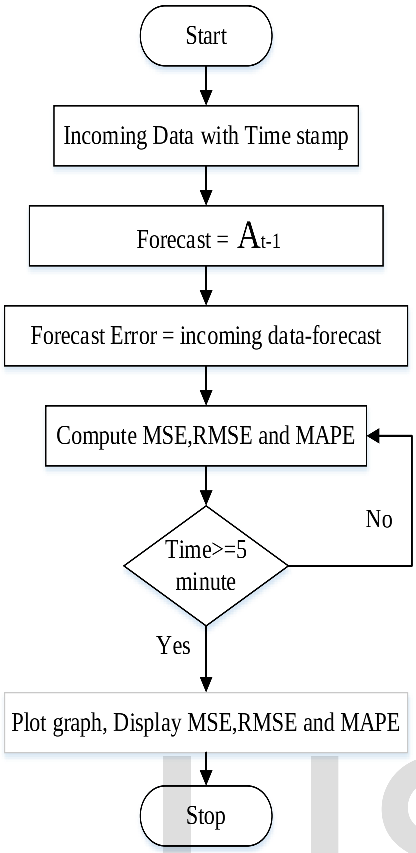


Fig.2: Naïve Forecast model flow chart

## 4 Experimental Setup and Results

The experimental setup was carried out in Ahmadu Bello University Zaria Electrical and Computer engineering faculty using the setup shown in Fig.3 and Fig.4. The base station was connected to the school network through a router and the result was captured remotely. For simplicity, the naïve forecast model was implemented on temperature data only. This data was captured from 12th December 2016 to January 12th 2017. The GUI captures real time data every minutes, computes the forecast error metrics and plot the chart every 5 minutes. The developed naïve model was used in forecasting one day and one week temperature data as shown in Fig.5 and Fig.6 respectively.

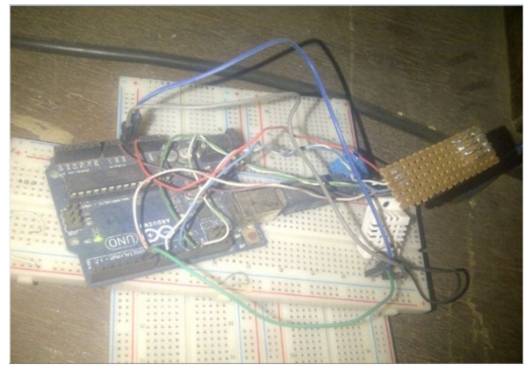

Fig.3 Temperature Sensor Node

Fig.4: Base Station

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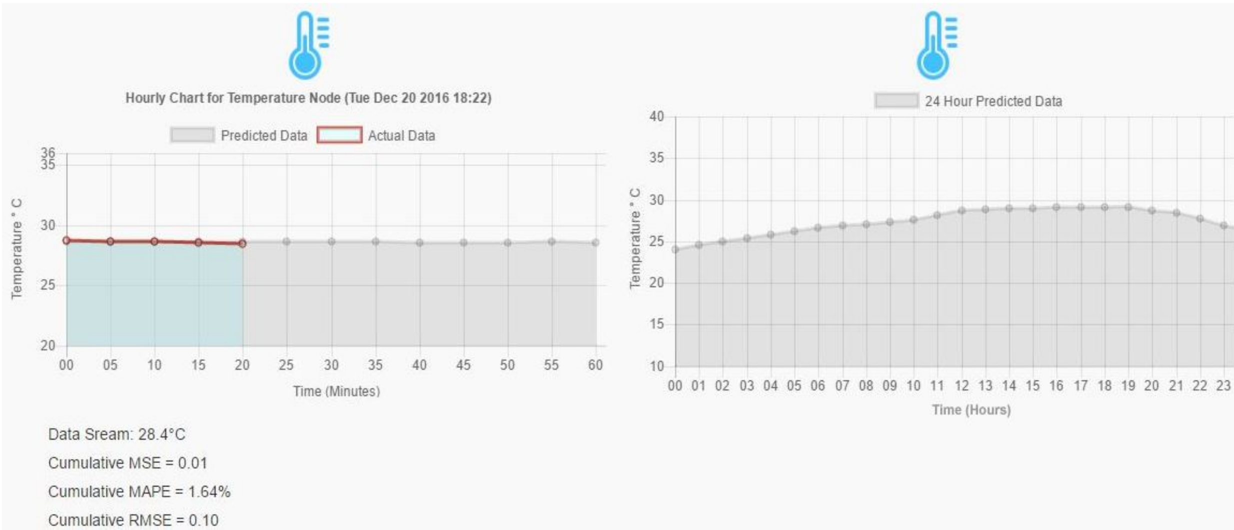
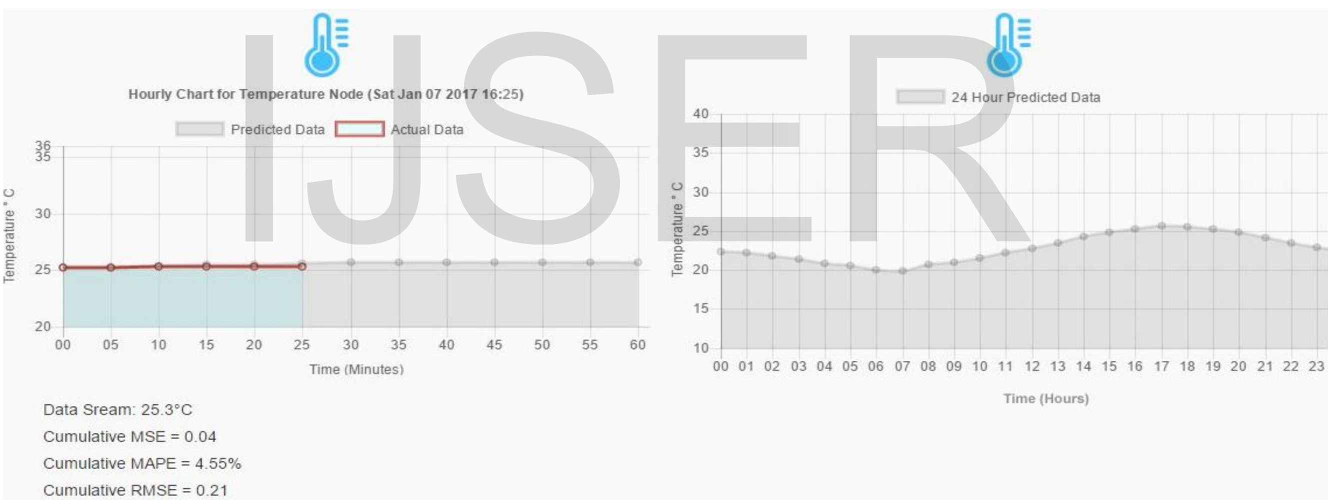



(a) Forecasted and actual temperature data (b) Predicted full day temperature

Fig.5: One day forecast






(a) Forecasted and actual temperature data (b) Predicted full day temperature

Fig.6: One week Forecast

Fig.5 shows the snap shot of one day forecast. We predicted Tuesday December 20 2016 from the temperature data captured on Monday December 19$^{th}$ 2016. Fig.5 (a) shows a chart of an hourly real time captured data and the predicted data. The low MSE (0.01), RMSE (0.10) and MAPE (1.64%) shows the accuracy of the naïve model in our forecast. While Fig.5(b) shows the full day predicted graph. We extended the temperature forecast to a week by forecasting Saturday 7$^{th}$ January temperature from Saturday 31$^{st}$ December 2016 temperature data and the snapshot in Fig.6 shows our result. Fig.6(a) shows that the naïve model can forecast a short term environment data as we obtained a low MSE (0.04), RMSE (0.21) and MAPE (4.55%).While Fig.6(b) shows the predicted Saturday 31st December 2016 full day temperature graph.

## 5 Summary and Conclusion

In this paper, we have presented a wireless sensor network system designed with Arduino, Raspberry Pi, nRF24L01, and a number of open-source software packages for predicting environmental data. The system has a number of attractive features, including low-cost, compact, scalable, easy to customize, easy to deploy, and easy to maintain. One major advantage of the design lies in the integration of the naïve forecast model into the GUI for live data prediction. Since naïve model doesn't require complex historical data to train a predictor, the network was not exposed to large consumption of energy during computation. Which makes it possible to plot chart, display forecast error metrics result and still stream live data concurrently. The low forecast error metrics result obtained from our implementation shows that the system can be used to forecast environmental data for easy decision and preventive measures. As future work, the system design presented in this paper can be expanded in a number of different aspects. For example, Data redundancy can be optimized to increase storage space by storing only deviated predicted data. Long term forecast period can also be implemented. Our implementation was only for temperature prediction other environmental parameters such as wind, cloud density can be considered.



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