Microcontroller-Based Fault Tolerant Data Acquisition System For Air Quality Monitoring And Control Of Environmental Pollution

Tochukwu Chiagunye, Eze Aru Okereke, Ilo Somtoochukwu

ABSTRACT: The design applied Passive fault tolerance to a microcontroller based data acquisition system to achieve the stated considerations, where redundant sensors and microcontrollers with associated circuitry were designed and implemented to enable measurement of pollutant concentration information from chimney vents in two industry. Microsoft visual basic was used to develop a data mining tool which implemented an underlying artificial neural network model for forecasting pollutant concentrations for future time periods. The feed forward back propagation method was used to train the ANN model with a training data set while a decision tree algorithm was used to select an optimal output result for the model from its two output neurons.

KEYWORDS: Pollution, Fault Tolerant, Data Acquisition, Microcontroller, Environment.

1.0 INTRODUCTION.

Air pollution has always accompanied civilizations and dates back to prehistoric times when man first created the first fires. Environmental pollution was a direct result of the industrial revolution, where the industrial revolution era caused the emergence of great factories and increased consumption of immense quantities of coal and other fossil fuels [1]. The resulting air pollution coupled with large volumes of industrial chemical discharges which when added to the growing load of untreated human waste constituted environmental pollution. Modern technological systems rely heavily on sophisticated control systems to meet increased safety and performance requirements and this is particularly true in safety of critical infrastructures where a minor or often benign fault could potentially develop into catastrophic events if left unattended or incorrectly responded to. In spite of many advances and new concepts in the field of systems and controls design, complex systems sometimes do not render the services they were designed for, or they simply run out of control thus creating situations whose effects range from energy to material waste, loss of production, damage to the environment or even loss of human lives. Therefore to prevent fault induced losses or performance drop and minimize potential risk the control techniques and design approaches need to be developed to cope with system component malfunction. An optimal control system which possesses the capability described above is often known as a fault tolerant control system [2]. A real time monitoring scheme for air pollution using solid state gas sensors with ARM module which connects the measured air pollution levels to GIS and internet so that the pollution levels can be known in real time with one click on net from any place [3] become necessary at this time.

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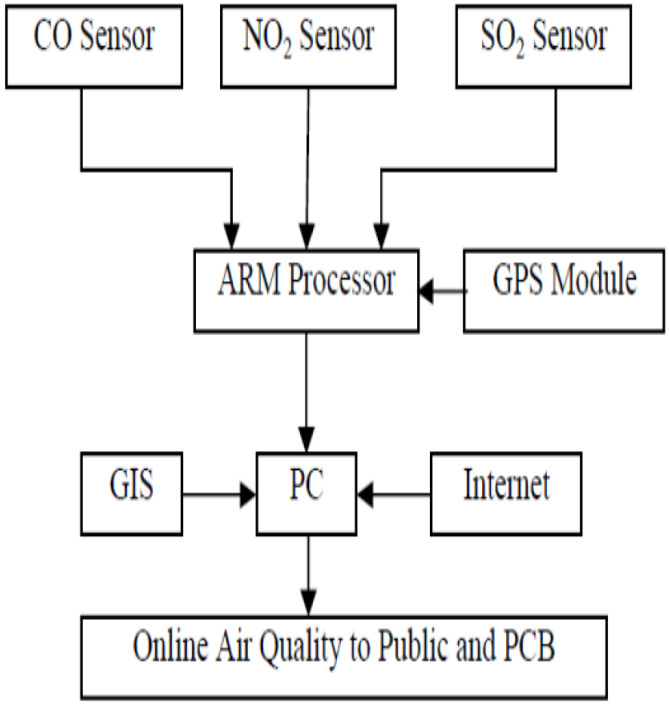


Fig 1: *Block Diagram of the Air Quality Monitoring System*

The study was meant for Chennai City and the vehicular air pollution was measured continuously and published on a website developed for the study. The Chennai city map was digitized with GIS & GPS software by moving around the city while the digitized map was fed into the internet. The three gas sensors which measured the gases namely, CO, NO2 and SO2 were linked with GPS through the ARM circuit and the data is transferred through laptop and then was uploaded to the internet so that people throughout the world can view the pollution level of the particular place in Chennai at any time using the website. An ARM Processor is a type of processor which is used to link different types of outputs. It also helps in uploading the linked data to the internet. This ARM Processor and outputs are collectively

known as the ARM Module. The above said three sensors and GPS are linked through the ARM module, which is then fed into the server from where it is uploaded to the internet. This research work "an Optimal Fault Tolerant Environment Monitoring and Pollution Control System" proposes a hybrid fault tolerant design for monitoring air pollutants such as SO_2 , NO_2 , CO etc in industries whose operations if not controlled could result in dangerous emissions of these pollutants which are dangerous to the health of the people living in that vicinity and environment.

2.0 Literature Review

Numerous researchers carried out elaborate study on Fault Tolerant Control at theoretical level without applying the concepts to real life applications by manipulating redundancies to achieve fault tolerance in control systems. Only a few researchers enumerated below applied the fault tolerant concept to real applications such as [4] who presented an over view for obtaining fault tolerance for different type of systems ranging from simple modular redundancy schemes to advanced model based fault diagnosis techniques, [5] developed a reconfigurability analysis for reliable fault tolerant control design, [6] applied fault tolerant flight control techniques to a quad rotor UAV test bed. [7] developed an integrated fault tolerant robotic control system for high reliability and safety in embedded systems etc. they all failed to apply redundancies in design for achieving hybrid fault tolerance. Also Environmental monitoring using sensors have been carried out in various countries and islands to measure particular parameters of interest as well as the development in air pollution/ industrial remote monitoring systems with applications in numerous regions, such as [8] who proposed a conceptual architecture for a versatile, flexible, cost efficient, high-speed instrument for monitoring air quality, [9] who made a concise attempt to modify low cost available pollution devices to work for indoor and outdoor environments etc The most important of these research endeavors that motivated the researcher and of which this work is largely based is the work carried out by [10] who proposed an optimal method for monitoring air pollutants using a single microcontroller interfaced with a GPRS modem for communication with a pollution server for mapping and data analysis from remote users via the internet. It became imperative to apply the approach to monitoring industrial air pollution in Nigeria since it provided a simple framework that allowed flexibility and wide application utilizing off-the-shelf hardware and software approaches and to also improve the design by incorporating fault tolerance to the design of the remote data monitoring unit to tackle the Nigerian problem of poor maintenance culture by improving the reliability and life span of the deployed system as well as the need for constant maintenance for field reporting with aim to providing real time information and warning to industries where the system is deployed to enable them keep to standard.

3.0 Materials and Methods

Most air pollution and quality monitoring schemes are based on sensors that report the pollutant levels to a server via wired modem, router or short range wireless access points. As this study proposes a fault tolerant system design approach utilizing redundancies from the integration of microcontrollers, several air pollution sensors, GPRS-Modem, GPS module that would utilize the wireless mobile public network were used to achieve the goal of applying intelligence in monitoring and control of environmental air pollution. The prototype model for the fault tolerant unit is depicted in fig. 2, it exploits redundancy in design by employing multiple sensors and microcontrollers to measure the pollutant concentration levels. The first part of the system can be classified as a data acquisition system of nodes/pairs of sensors and attendant microcontrollers which are used to measure pollutant parameters at any particular point of interest. The sensors should measure the same data or pollution level and send to its controlling microcontroller. The microcontrollers sends their data through a GSM modem to a central remote terminal unit which is basically a microcontroller based system with a GPRS transceiver where a model matching algorithm would be applied and the result sent to a pollution server which stores same in a database for data mining, trend analysis and air quality index deduction.

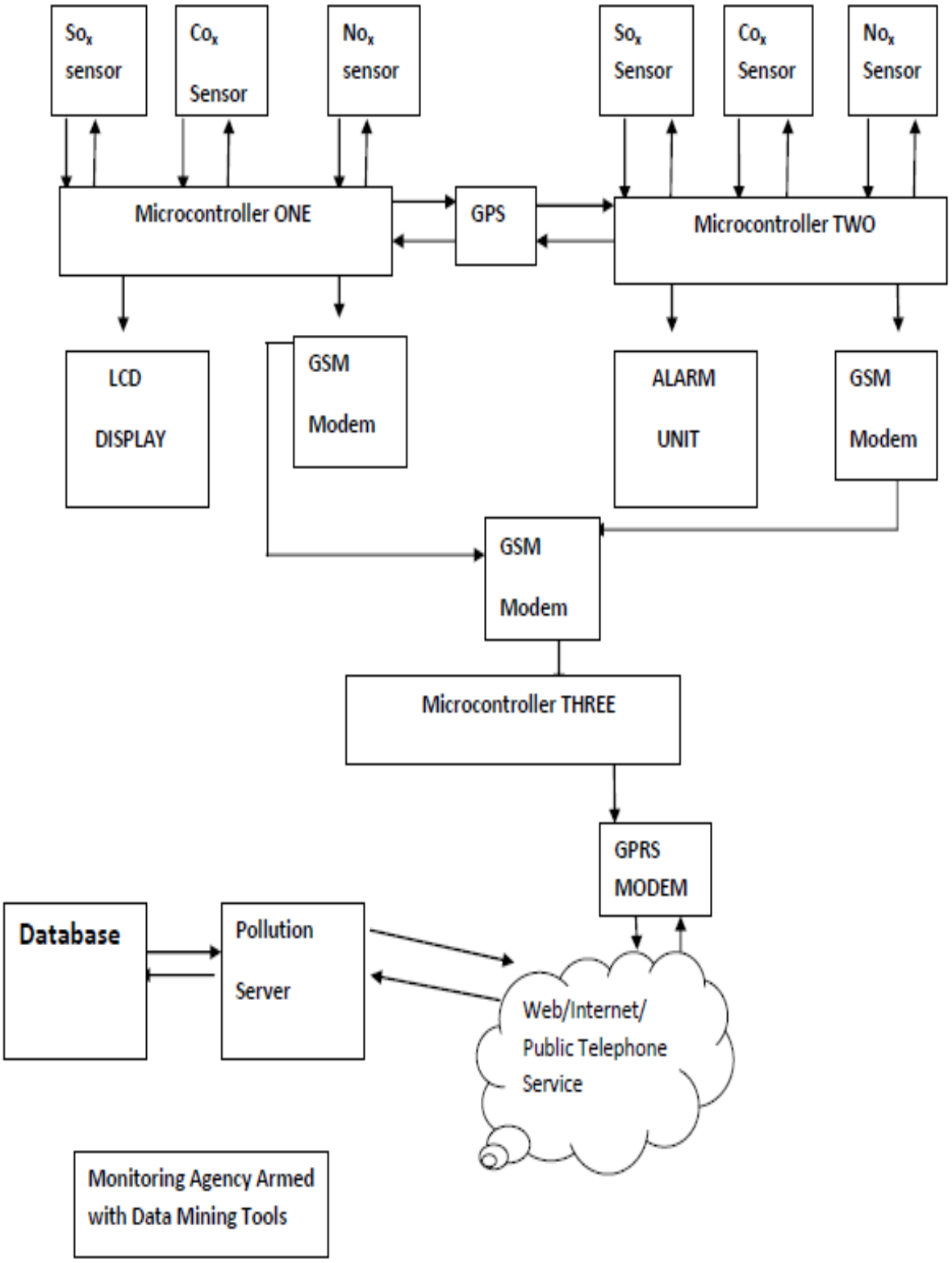


Fig 2: *Physical Model of the Fault Tolerant Data Acquisition Unit*

The logical flow chart for the control operation of microcontroller one, two and three of the fault tolerant data acquisition model are shown in fig.3 and fig.4 respectively

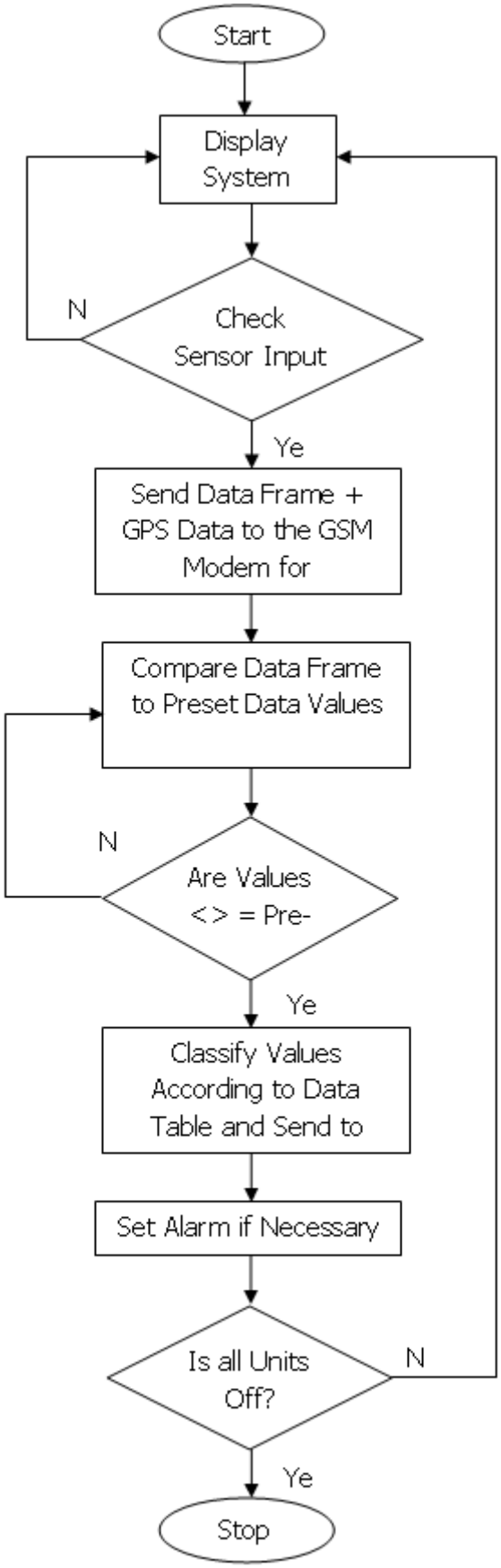


Fig. 3 *Flow Chart for Microcontroller One* and Two

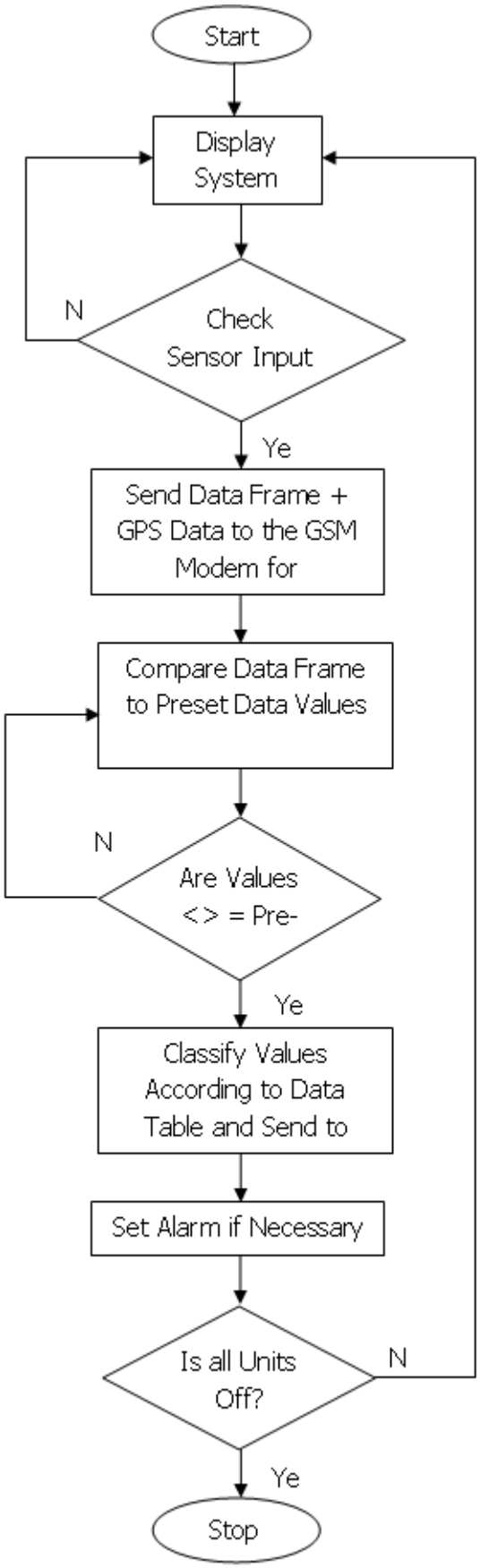


Fig. 3 *Flow Chart for Microcontroller One* and Two

FDI Model Employed

At nominal condition the control law for the data acquisition system is thus < O, C, U> where U implies the algorithm to be implemented to achieve the objective of measuring pollutant concentration and its onward transmission to a pollution server. O, represents the set of objectives while C, represents the constraints the system behavior will satisfy over a period of time, < O, C (Θi), U> represents the control law in a fault free state, while < O, C (Θ p), U> defines the control law in a fault condition. The constraints set C contains the following rules for fault detection and isolation for the data acquisition system If sensor transmits a null reading, then discard the value and implement algorithm one. If sensor transmits a reading below the lowest threshold value, then hold value and implement algorithm one before transmission. If sensor transmits a reading above the highest threashold value. Then hold value and implement algorithm one with parameter changes before transmission. If sensor transmits a reading in the normal range but it is in fault condition. Hold value and implement algorithm two before onward transmission. The overall system objective of the fault tolerant system is to modify the fault condition control law < O, C (Θp), U> to a new control law with a degradable performance by implementing a new algorithm from the set of algorithms U, this fault tolerant control law is therefore < O, C (Θp), U (ϕ)> where ϕ is the algorithm selected for handling the fault condition in C. The application of an algorithm can only be possible when the particular fault condition in the constraints has been detected and isolated.

4.0 System Design

The system design phase can be broadly divided into two Subsystems; Hardware Subsystem and Software Subsystem. Also, the Hardware Subsystem is subdivided into three modules; power module, input/ signal conditioning module and output module.

Power Supply Module

The power supply unit shown earlier provides a rectified 9V and 12V output for use by the entire system. The input to the power system can be from a rechargeable battery source or from the mains supply. In this case since we are talking about an industrial implementation, the assumption would be that the system only needs to work so long as the factory/industry is in operation, therefore there is need for mains power supply in that case to power the system. A 12V AC transformer with a full bridge rectifier consisting of four diodes in a bridge configuration was connected to the transformer to convert the AC input to DC while also providing reverse polarity protection. The nominal 9V supply rail is then fed into the input of a three terminal voltage regulator with filtering provided by a 100uF 16V electrolytic capacitor. The 12V rail supply also drives the 12V fan via a 56ohm resistor whose job is to reduce the fan speed and attendant noise. The LM317T is an operational amplifier which has a high output current capacity configured to provide the 5V to power the microcontroller. It also acts as an adjustable linear voltage regulator as it regulates the voltage below rather than above the reference voltage. TL074 is a field effect transistor input operational amplifier that is used for low harmonic distortion and low noise in power circuits. A 470uF capacitor is used for smoothing the voltage after rectification. Therefore the Power for the circuit can be derived from a 15v AC or 15V - 22 V DC, with diodes (BR 1) providing reverse polarity protection.

Input / Signal Conditioning Module

This unit comprises the sensors as an input device and the circuit that make it possible for it to communicate with microcontroller i.e. send signals to the microcontroller. The output from the sensor is monitored at RB3/AN9 (pin 36) of the microcontroller. The specifications states that this sensor must initially be heated using a 5V supply connected across its element for 60s. The heater current is then reduced by placing just 1.4V across the element for a 90s period. The pollutant concentrations are then being measured, after which the initial 60s heating cycle begins again. In practice, this means that measurements are repeated at 2.5 minutes (i.e. 150 seconds). The heater is powered from 6v rail via two parallel resistors, while transistor ties the lower end of the heater element to 0V. The heater has a resistance of 33 ohms Q1 is on, a current of 152mA flows through it. This results in a 1V drop across the two resistor, thus giving the required 5V supply for the heater. The transistor is controlled by the microcontroller's AN0 output (pin 2) and turns on when its gate is pulled high. The AN0 switches Q3 on for 60s to provide the heating current. And the other goes low for 90s, so the measurement can be made.

Output Module

The output module ranges from internal computations by the microcontroller, where it compares measured pollutant concentration by a standard reference stored in memory to enable it display and class the current state of pollution as either good, moderate or bad, after the comparison the output is displayed on the LCD and in event of an alarm situation the buzzer sounds for a time period of 60s.A data frame is produced that contains the following,

Table i

Unit-ID	Pollution server IP-Address	Pollution-server port #	Time	Date
Latitude	Longitude	CO-Level	NO_2-Level	SO_2-Level

Which encapsulates the IP address of the Pollution Server, a port number, the three pollutants levels, latitude and longitude of the sampled location, and time and date when the samples were taken. This is then sent through the GSM modem to the remote terminal unit.

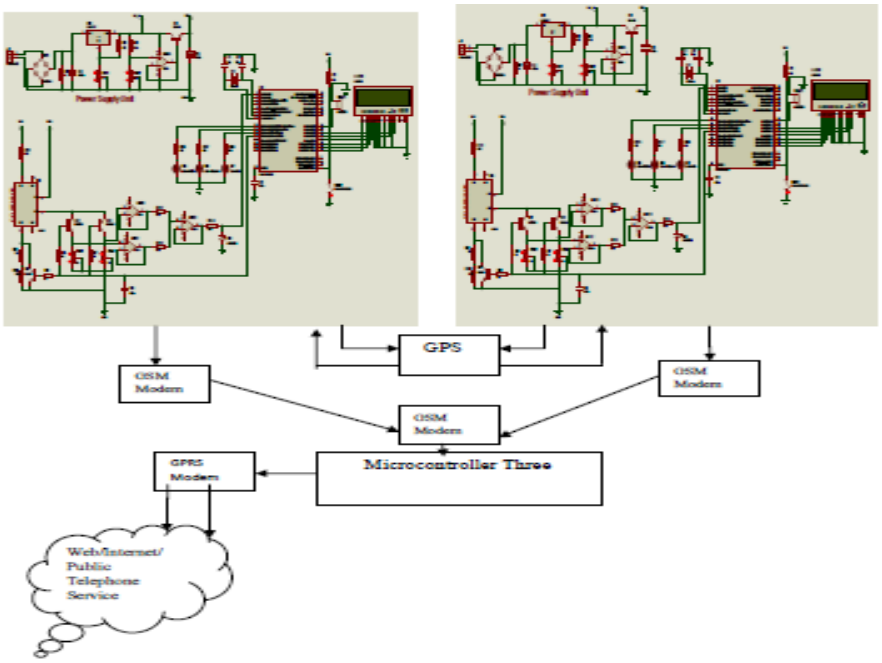


Fig 5: *Complete Fault Tolerant Data Acquisition System*

Software Subsystem Model Creation

The concept of model creation simply deals with creating an empty data forecasting model, similar to the way a relational table is created.

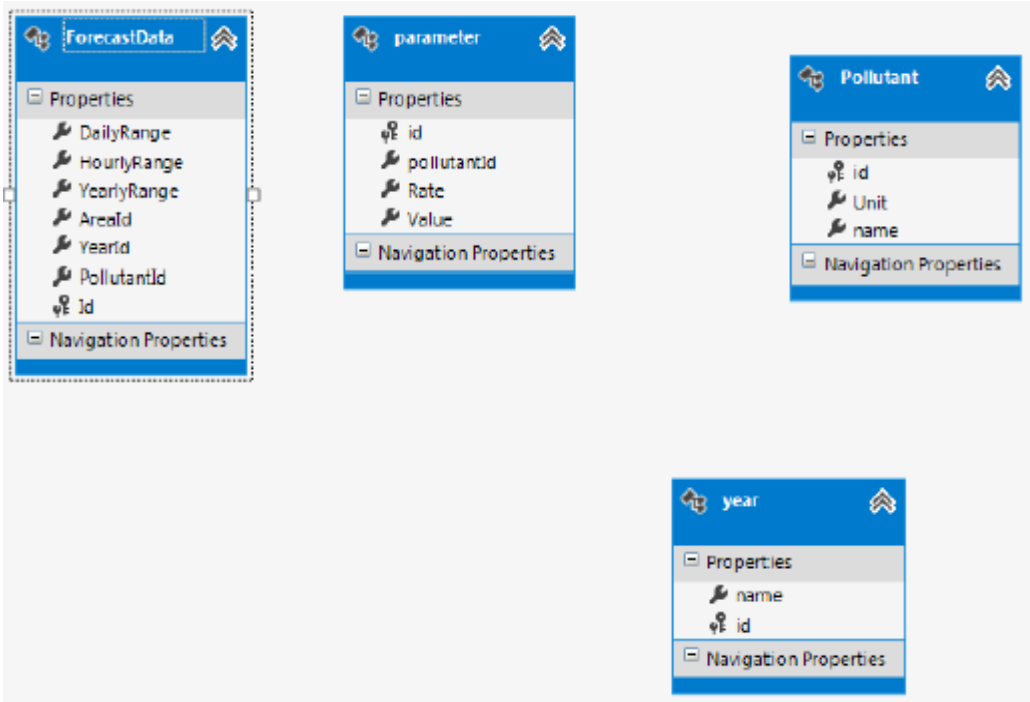
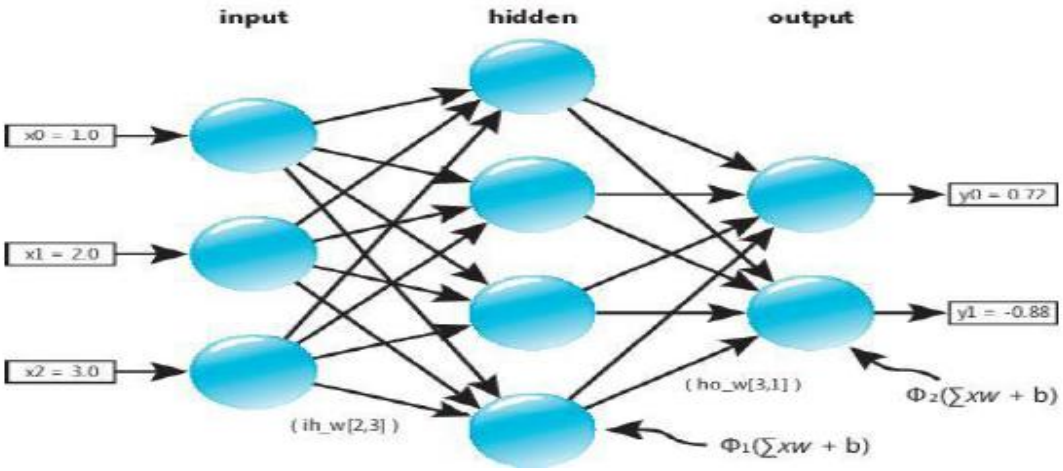


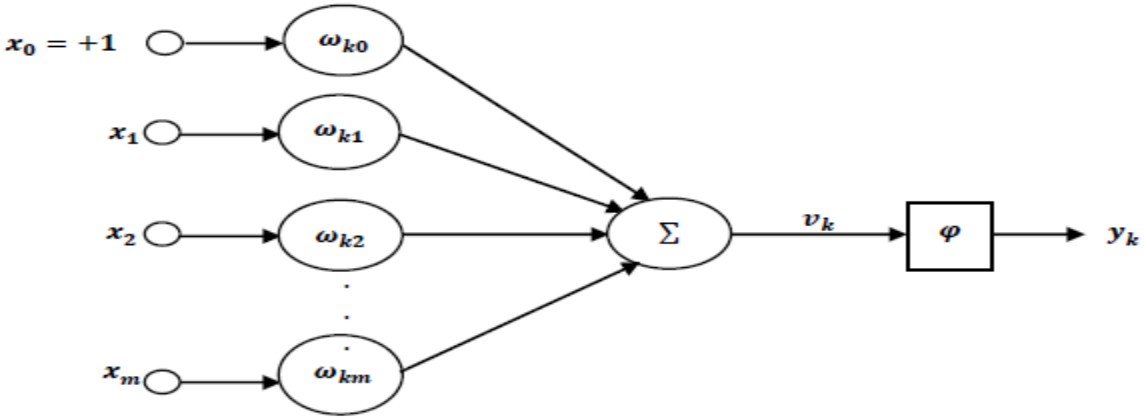
Fig 6: *Diagram of the Relational Database Model Adopted*

Model Training

Model training is also called model processing. It is used to invoke the data forecasting algorithm to uncover knowledge about the training dataset. After training, patterns are stored in the model. Artificial neural network is used to train the network for trend analysis and forecast of pollutant data for consecutive years. The ANN consists of 3 inputs, 4 hidden and 2 outputs. The input to the network model are pollutant data from previous years while the hidden layer consists of a sigmoid function and a hyper tan function that ensures the weight and biases helps to generate a reasonable pollutant data. Backward propagation method is adopted to train the network and reverse its learning process if the needs arises. At the output end two sections of pollutant data are produced and a decision tree algorithm is then applied to determine the most viable data to be used as a forecast. The ANN model shown below depicts the model algorithm implemented in the AQMS software developed for this research for forecasting.



A standard neuron in the model shown above can be represented below

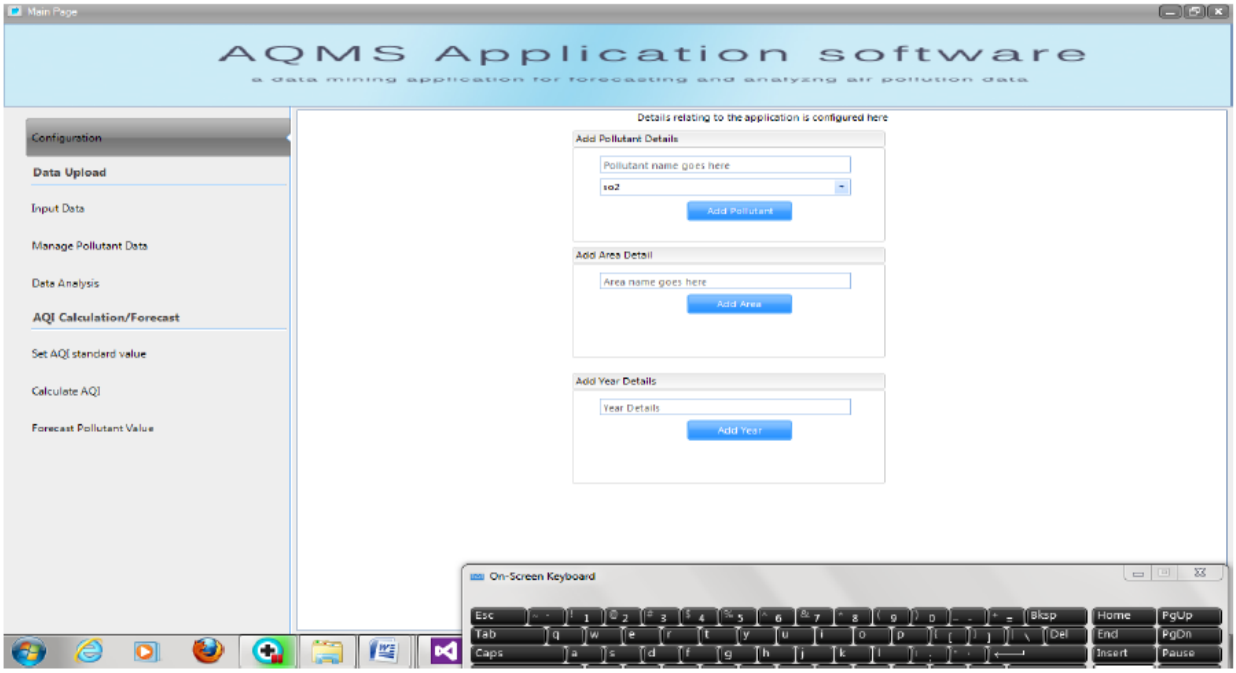


Where $x_1,x_2,x_3,....,x_m$ denotes input signals; each of W_{k1}, W_{k2}, $W_{k3},...,W_{km}$ represents weight U_k which is a linear combiner output (Σ); φ(.) is an activation function; and $b_k=w_{ko}$ is an externally applied bias. The bias has effect of applying affine transformation to the combined output $v_k=u_k+b_k$ where v_k is *induced local field*. The bias is considered as an external parameter of artificial neuron k.

5.0 AQMS Software Implementation

Implementation was done using Microsoft visual studio for the server controller (linkage between client and server) and data were extracted from the database using SQL. The diagrams below shows interface of the air quality monitoring system (AQMS).

Configuration Section



Add Pollutant Details: This section enables the user to add pollutant details which would enable the system to determine the kind of pollutant data to analyze. Pollutant name could be SO2,NO2 etc while its unit could be ug/m3 and mg/m3. Add area details: This section enables the user to add areas that would be considered during our data analysis. Add year details: This section enables the user to add years that would ensure pollutant data for year added would be supplied.

6.0 Conclusion

Studies have shown that the climate change phenomenon has been liable for these changes we have been experiencing that is caused majorly by industrial air pollution which results from a direct release of green house gasses into the atmosphere. The research endeavor came up with a better and reliable modeled design of a fault tolerant air pollution monitoring system for industries to measure pollutant concentration in the air within the industrial complex and report same to a monitoring agency whose job is to ensure that industries are doing their utmost to cut down on emissions of unwanted air pollutants which are harmful to the environment.

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