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Industrial Air Pollution Monitoring System Based on Wireless Sensor Networks

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Abstract

Environmental conditions have a major impact on our well-being, comfort and productivity. Present state of the air quality control in almost all manufacturing industries in our country is based on taking samples one or few times a day, which means that there is no information about time distribution of polluted materials intensity during day. This paper proposes an industrial air pollution monitoring system based on wireless sensor network system that enables sensor data to be delivered within time constraints so that appropriate observations can be made or actions taken. Obtaining these accurate real-time results in-situ allows regulatory agency to take necessary action whenever pollution occurs. The analysis focuses on six substances, known as criteria air pollutants – ozone, particulate matter, sulphur oxides, nitrogen oxides, carbon monoxide, and lead. The sensors self-organize themselves in a radio network using a routing algorithm, monitor the area to measure the gas levels in air and transmit the data to a central node, sometimes called a pollution server or base station (interfaced with coordinator), or sink node, that collects the data from all of the sensors. With the results from the data acquisition system in hand, the regulatory agent need to implement a number of decisions based on the final statistics. The data obtained from the experiments were analysed in real-time analysis and the results from two sensor nodes taken for a 24 hours period were promising. The usage of this system will reduce human health effects of industrial air pollutants and potential damage to other aspects of the environment.

Keywords: Wireless sensor networks; air pollution; monitoring system; air quality; sensors.

1. Introduction

The Tanzania Development Vision (TDV) 2025 aims to transform the nation from a least developed country to a middle-income country by 2025 through transformation from a weather and market dependent agricultural economy to a self-sustaining semi-industrialized economy [1]. This shift in focus from an agricultural economy to a semi-industrialized one was essential for the ailing industrial sector of Tanzania. Population increase, economic development, poverty, environmental-sustainability, climate change and energy use are intimately knotted in the developing and a low-income country where achieving the balance between the economic growth and environment is an important area of concern. Tanzania has also been experiencing the similar problem due to continuous increase in the population and industries. No development can be sustainable if it triggers the violation of nature's tolerance limits. The National Environmental Policy [2] highlights the strong linkage between the development and the environmental sustainability and stresses the need to manage the environment and its natural resources in ways that enhance the potential for growth and opportunity for sustainable development of present and future generations. In addition, it explains the clear cause-and-effect relationship between poverty and environmental degradation and confirms that environmental degradation leads to widespread poverty; equally, poverty is a habitual cause of environmental degradation as it undermines people's capacity to manage resources wisely.

A very glaring constraint has been lack of adequate and sound research data to guide effective decision-making and policy interventions formulation in environmental management. Urgent attention is thus needed to intensify quality and relevant environmental research. The development of an environment research agenda to serve as a guide for stakeholders in the prioritization of their research activities is widely considered to be an important prerequisite for stimulating quality and relevant environmental research.

Increased emissions of reactive trace gases from man's energy related and industrial activities have led to a wide variety of air pollution problems on urban, regional and global scales [3]. Both primary emissions and their secondary products produced in the oxidative atmosphere can lead to health and environmental consequences. Industries are major sources of water, air and soil pollution. About 80% of all of Tanzania's industries are located in urban areas. Distinguishable from domestic, institutional and other sources of pollution, industrial wastes may contain heavy metals like mercury, chromium, lead and cadmium; salts of cyanide, nitrite and nitrate; organic matter, micro-organisms and nutrients; and toxic chemicals such as pesticides. By international standards, Tanzanian industries are highly polluting, the main reasons being that there are very few industries in the country which have incorporated provisions for treating the wastes they generate and the factories have been built without including technologies which help to reduce waste. In this study, six of the pollutants are well studied and, ubiquitous in our daily lives, including carbon monoxide (CO), nitrogen dioxide (NO_2), ground level ozone (O_3), sulfur dioxide (SO_2), particulate matter (PM) and lead (Pb). The six common pollutants and their health effects are depicted in Table 1.

Stringent legislation is forcing manufacturing industry to be aware of the impact its operations have on the environment in order to control and reduce the effect of those operations [5, 6]. The concerns which lie behind the legislation may relate to human health effects of pollutants, potential damage to other aspects of the environment (for acid rain and ozone generation with their consequent effects), amenity issues (for example black smoke or visibility degradation) and global issues such as climate change. The legislation takes the form of emissions limits or guidelines below which it is expected the process will operate [7]. Demonstrating compliance with these limits is then the reason for the monitoring effort.

Conventional methods for monitoring air pollution generally require high investment costs for laboratory analytical instruments, extensive maintenance, training and highly specialized personnel. The use of automatic equipment is valid for measuring the temporal trend of air pollutants, which is related to the reactivity and transport on regional and local scale, but it is very expensive for the evaluation of the long-term toxicological risk on human health. In fact, continuous equipments require high costs of maintenance and, since they are often highly sophisticated, they can be only used in a limited number of sites. That does not allow a detailed mapping of exposure in large areas. In addition, data gathered by automatic analysers are not suitable for a rapid interpretation and unless used to compare the values with pre-defined limits or air quality standards, they are not always useful. Hence, there is a growing demand for the real-time environmental pollution monitoring and control systems. In view of the ever-increasing pollution sources with toxic chemicals, these systems should have the facilities to detect and quantify the sources rapidly.

This paradigm is changing with the materialization of lower-cost, easy-to-use, portable air pollution monitors (sensors) that provide high-time resolution data in real-time [8]. These attributes provide opportunities to enhance a range of existing air pollution monitoring capabilities and perhaps provide avenues to new air monitoring applications. Sensors tied to advances in computing and communication also provide enhanced availability and accessibility of air monitoring data. Sensor devices are currently available to monitor a range of air pollutants and new devices are continually being introduced. Indeed, the attraction toward lower cost sensors is sufficiently great that, even before sensor performance has been characterized, widespread data collection and data sharing using new sensors is already occurring [9]. Miniaturization and high level system integration has many benefits both to the user and to the public, from a rather measurement requirement driven definition of the monitoring location as compared to space availability or reduced visual obtrusion in public spaces, ultrashort set-up time and lower operating expenses and minimized energy consumption. Operating ambient air quality monitoring networks typically required proprietary systems and software for data access and integration. As a web server enabling anybody with an internet connection and a web browser and the access privileges, to read and analyze data, look at maintenance and calibration logs, update the system conveniently from anywhere in the country or respond to pre-definable push services ranging from maintenance information for service staff to local broadcasting of environmental data.

The use of wireless sensor networks (WSN) can make air pollution monitoring less complex and more instantaneous readings can be obtained [10, 11]. WSN monitoring schemes have the advantage of easy installation, convenient maintenance and cost effective. Moreover, they are up-to-date, flexible as to information and inspection as compared to traditional wire monitoring system [12]. This reduces the flexibility of the system and makes it difficult to ensure proper control and monitoring. Monitoring provides raw measurements of air pollutant concentrations, which can then be analysed and interpreted. This information can then be applied in many ways.

Analysis of monitoring data allows us to assess how bad air pollution is from day to day, which areas are worse than others and whether levels are rising or falling. We can see how pollutants interact with each other and how they relate to traffic levels or industrial activity [13, 14]. By analysing the relationship between meteorology and air quality, we can predict which weather conditions will give rise to pollution episodes [15]. WSN monitoring schemes have the advantage of easy installation, convenient maintenance and cost effective. Moreover, they are up-to-date, flexible as to information and inspection as compared to traditional wire monitoring system. In this work, LoRaWAN, which is a low power wide area network (LPWAN) specification intended for wireless battery operated Things in a regional, national or global network, is preferred over other wireless technologies. LoRaWAN targets key requirements of Internet of Things such as secure bi-directional communication, mobility and localization services. The LoRaWAN specification provides seamless interoperability among smart Things without the need of complex local installations and gives back the freedom to the user, developer, businesses enabling the roll out of Internet of Things.

This paper proposes an industrial air pollution monitoring system based on wireless sensor network system that enables sensor data to be delivered within time constraints so that appropriate observations can be made or actions taken. Obtaining these accurate real-time results in-situ allows regulatory agency to take necessary action whenever pollution occurs. Consequently, controlling wasted resources, capital, and safeguarding the surrounding environment from harmful pollution. The major motivation behind our study and the development of the system is to help the regulatory agencies in Tanzania to make sure manufacturing industries, which have not incorporated provisions for treating the wastes they generate and the factories that have been built without including technologies, which help to reduce waste they do so. This project is built for low cost, quick response, low maintenance, ability to produce continuous measurements. The main goal of this project is to monitor the air pollution, hazardous gases and increase awareness about pollution by using air pollution monitoring system. Present state of the air quality control in almost all industrial centers in our country is based on taking samples one or few times a day, which means that there is no information about time distribution of polluted materials intensity during day. This is the main disadvantage of such system. In the area, there are two methods to use to monitor air pollution at present. The one is passive sampling (non-automatic), and the other is continuous online monitoring (automatic). The advantage of the passive sampling method lies in that the monitor equipment is simple and inexpensive, but it can only get on-site monitoring parameters in a certain period, cannot provide real-time values. Meanwhile, the results of monitoring effect by the man factor largely and it will seriously damage the health of the monitoring man in the site of high concentration of harmful substances.

Table 1. The six common pollutants and their health effects [4].

Pollutant	Health Effects	Sources
Carbon Monoxide (CO)	Unlike the other air pollutants, carbon monoxide does not appear to affect the respiratory system. However, exposure to elevated levels of carbon monoxide can adversely affect the functioning of the heart, resulting in cardiac ischaemia, increased hospital admissions, and possibly increased cardiac mortality. Outdoor concentrations of carbon monoxide rarely reach dangerous levels, whereas indoor concentrations are more likely to occur at harmful levels.	Carbon monoxide is produced by the incomplete combustion of fossil fuels, largely from motor vehicles and other mobile sources.
Nitrogen Dioxide ($N0_2$)	Exposure to elevated levels of nitrogen oxides can contribute to respiratory illness, aggravation of asthma in children, and reduced lung growth.25 Nitrogen oxides react with other air pollutants in the atmosphere to form smog.	Nitrogen oxides are produced by the combustion of fossil fuels.
Ozone (O_3)	Ozone irritates the respiratory tract. Exposure to ozone in sensitive people can cause chest tightness, coughing, and wheezing. Children who are active outdoors during the summer, when ozone levels are elevated, are particularly vulnerable. Other groups at risk include individuals with pre-existing respiratory disorders, such as asthma and chronic obstructive pulmonary disease. As a result of these negative health effects, ozone contributes to premature mortality, increased hospital admissions for acute respiratory diseases, aggravated asthma, and reduced lung function.	Ground level ozone is a key component of smog, and is formed by atmospheric reactions involving nitrogen oxides, volatile organic compounds, and sunlight. Sunlight intensity and higher temperatures exacerbate the formation of ozone. These factors explain why smog is generally a worse problem during summer months.

Sulphur Dioxide (SO_2)	Exposure to sulphur dioxide causes severe problems for people with asthma and is also associated with increased risk of lung cancer and chronic bronchitis. Sulphur dioxide also reacts with other air pollutants in the atmosphere to form particulate matter.	Most sulphur dioxide emissions are produced by the combustion of fossil fuels containing sulphur, including coal, oil, gasoline, and diesel, as well as coal-fired electricity plants and metal smelters.
Particulate Matter (PM_{25} & PM_{10})	Particulate matter causes premature mortality from cardiovascular and respiratory diseases, increased hospital admissions for cardiovascular and respiratory diseases, increased prevalence of bronchitis, increased risk of lung cancer, aggravation of asthma, and decreased lung function. Children in particular are likely to suffer from a range of respiratory ailments as a result of exposure to particulate matter. The elderly and individuals with heart ailments are also particularly vulnerable. It is important to note that there is no threshold concentration of fine particulate matter below which no health effects are found. In other words, there is no safe level of fine particulate matter – negative health effects will occur in some people even at very low levels, and the proportion of people impacted will rise as levels of fine particulate rise.	Fine particulate matter is created primarily by the combustion of fossil fuels, while coarse particulate matter originates from road dust, diesel engines, and crushing and grinding operations.
Lead (Pb)	Among children, lead exposure can cause cognitive deficits, developmental delays, hypertension, impaired hearing, attention deficit disorder, reduced intelligence, and learning disabilities. While lead has been considered a major threat to children’s health for many years, only recently has evidence begun to accumulate about the dangers posed by lead to menopausal women and the elderly.27 As bones become thinner with age, lead is released into the blood, contributing to an array of negative health effects including cataracts, Alzheimer’s, Parkinson’s and other forms of dementia, high blood pressure, and impaired kidney function	In the past, leaded gasoline was the primary source of lead emissions to the air. Today, the majority of lead emissions to the air are from lead smelters. Dust, paint chips, consumer products, and lead shot are other important sources of exposure to lead.

2. Related Works

The public concern on air pollution increases significantly due to the serious hazards to the public health, as described in [16]. Heart disease, Chronic Obstructive Pulmonary Disease (COPD), stroke and lung cancer are highly related to air pollution. People breathing in air of poor quality could suffer from difficulty in breathing, coughing, wheezing and asthma. In addition to the human health, air pollution also has a major effect on the global environment and the worldwide economy. An outdoor ambient real-time air quality monitoring system was proposed, implemented and tested by [17]. In this system, the concentration of O_3, NO_2, CO and H_2S are sensed and transmitted back to the backend server through the GPRS wireless communication link every minute. Authorized air pollution information is available to the public through the customized Web and mobile Apps. A solar panel was utilized to solve the power constraint issue of the sensor nodes (stationary). In [18], an outdoor WSN based air quality monitoring system (WSNAQMS) for industrial and urban areas was proposed. The sensor node consists of a set of gas sensors (O_3, CO and NO_2) and a ZigBee wireless communication link based on the Libelium’s gas sensing capable mote. Data are uploaded to the central server through the ZigBee communication link. Authorized air pollution information is available to the public through Email, SMS and customizedWeb App. This framework is claimed to be simple and reusable in other applications. Also the failure sensor nodes can be identified efficiently and the energy consumption of each sensor node is minimized. Moreover, a simple Clustering Protocol of Air Sensor (CPAS) network was proposed, which proved to be efficient (in simulation) in terms of network energy consumption, network lifetime, and the data communication rate. The QoSs of the network such as delay, accuracy and reliability (fault tolerance) were also considered.

In [19], an innovative system named Wireless Sensor Network Air Pollution Monitoring System (WAPMS) to monitor air pollution in Mauritius through the use of wireless sensors deployed in huge numbers around the island was proposed. The proposed system makes use of an Air Quality Index (AQI) which is presently not available in Mauritius. In order to improve the efficiency of WAPMS, a new data aggregation algorithm named Recursive Converging Quartiles (RCQ) were designed and implemented. The algorithm is used to merge data to eliminate duplicates, filter out invalid readings and summarise them into a simpler form which significantly reduce the amount of data to be transmitted to the sink and thus saving energy. For better power management the authors used a hierarchical routing protocol in WAPMS and caused the motes to sleep during idle time. In order to overcome these difficulties, a new approach was suggested in this paper. This should be able to provide effective solutions to many problems related to the evaluation of atmospheric pollution, especially in developing Countries where investment and maintenance costs are major problems.

An Environmental Air Pollution Monitoring System (EAPMS) for monitoring the concentrations of major air pollutant gases has been developed by [20], complying with the IEEE 1451.2 standard. This system measures concentrations of gases such as CO, NO2, SO2, and O3 using semiconductor sensors. The smart transducer interface module (STIM) was implemented using the analog devices' ADuC812 micro converter. Network Capable Application Processor (NCAP) was developed using a personal computer and connected to the STIM via the transducer independent interface. Three gas sensors were calibrated using the standard calibration methods. Gas concentration levels and information regarding the STIM can be seen on the graphical user interface of the NCAP. Further, the EAPMS is capable of warning when the pollutant levels exceed predetermined maxima and the system can be developed into a low cost version for developing countries.

Reference [21] proposed an industrial air pollution monitoring system based on the technology of wireless sensor networks (WSNs). The system is integrated with the global system for mobile communications (GSM) and its communication protocol used is zigbee. The system consists of sensor nodes, a control center and data base through which sensing data can be stored for history and future plans. The proposed system can be deployed to the industries for monitoring carbon monoxide (CO), sulfur dioxide (SO2) and dust concentration caused by industrial emissions due to process.

In [22], a Mobile Air Quality Monitoring Network (MAQUMON) that utilized moving vehicles equipped with sensor nodes to monitor air quality in a large area was introduced. Each sensor node consisted of a microcontroller, an on-board Global Positioning System (GPS) unit, and a set of sensors to detect the concentrations of ozone (O3), Carbon Monoxide (CO), and nitrogen dioxide (NO2). The node was able to send the sensed data to the gateway in a car through the Bluetooth connection. When the car move, the sensor node detects the concentrations every minute and store the data tagged with location information into a memory. When the car moves to a Wi-Fi hotspot, the gateway in the car transmits the data to the server, and the data would be processed and published on the sensor Map portal. MAQUMON provides a record regarding air quality and pollutant dispersion within the area.

Reference [23] proposed an efficient and robust system to control the parameters causing pollution and to minimize the effect of these parameters without affecting the plant or natural environment. The proposed methodology was to model a system to read and monitor pollution parameters and to inform pollution control authorities when any of these factors goes higher than industry standards. A mechanism using GSM and LabVIEW was introduced in this proposed methodology, which would automatically monitor when there is a disturbance affecting the system. The system was implemented using LabVIEW software. The system investigates level of pH in industry effluents, level of CO gas released during industry process and temperature of the machineries. With the design of GSM, the signals can be effectively transferred and the actions in these cases can still be made accurate and effective. Moreover, a recent published work [24] proposed Industrial pollution monitoring system using LabVIEW and ZIGBEE to determine the quality of effluent management and working environment of industries, to know the key descriptors to be considered in pollution monitoring system and send the information to Pollution Control Board (PCB) and public.

However, there are serious limitations on weight and size, some systems could not immediately send the monitoring data back. These limitations result in issues and problems of the conventional air pollution monitoring systems, like non-scalability of system, limited data availability on personal exposure, and out-of-the-fact warnings on acute exposure.

3. Materials and Methods

3.1 Hardware Description

The hardware design mainly includes an AVR ATmega64 microcontroller (MCU) as a core control system and peripheral circuit design. The ATmega64 MCU has enhanced low-power AVR RISC architecture, data throughput up to 1MIPS/MHz, which can alleviate the contradiction between system power consumption and processing speed. The analysis focuses on six substances, known as criteria air pollutants – ozone, particulate matter, sulphur oxides, nitrogen oxides, carbon monoxide, and lead. The input analog signals from ozone, particulate matter, sulphur oxides, nitrogen dioxides, carbon monoxide, and lead sensors are fed to the signal conditioning circuit for amplification of weak signals, digitized using analog to digital converter AD7705 chip and fed to the MCU. The sensors chosen for this work are MQ-131, MQ-135, 4S-SO_2, MICS-2714, MQ-7 and SGP gas sensor for measuring ozone, particulate matter, sulphur oxides, nitrogen dioxides, carbon monoxide, and lead concentrations respectively. The microcontroller performs computations and transmits the information to the base station computer in real-time through LoRaWAN wireless communication module for data analysis, processing and display. The gateway node's responsibility is to receive data acquired from different sensors and send command in order to achieve human-computer visualization interface. The smart nodes need to communicate with the coordinator node to transmit measured data. The coordinator was interfaced with the monitoring base station through RS232 cable. The overall hardware system description is shown in Figure 1.

The wireless sensors are placed in an area of interest that is to be monitored, either in a random or known fashion. The sensors self-organize themselves in a radio network using a routing algorithm, monitor the area to measure the gas levels in air and transmit the data to a central node, sometimes called a pollution server or base station (interfaced with coordinator), or sink node (interfaced with router), that collects the data from all of the sensors. This node may be the same as the other detection nodes, or because of its increased requirements, may be a more sophisticated sensor node with increased power. The most advantage of wireless sensors is that they may be implemented in an environment for extended over a time period, continuously detecting the environment, without the need for human interaction or operation. The WSN technology for this project is the LoRaWAN.

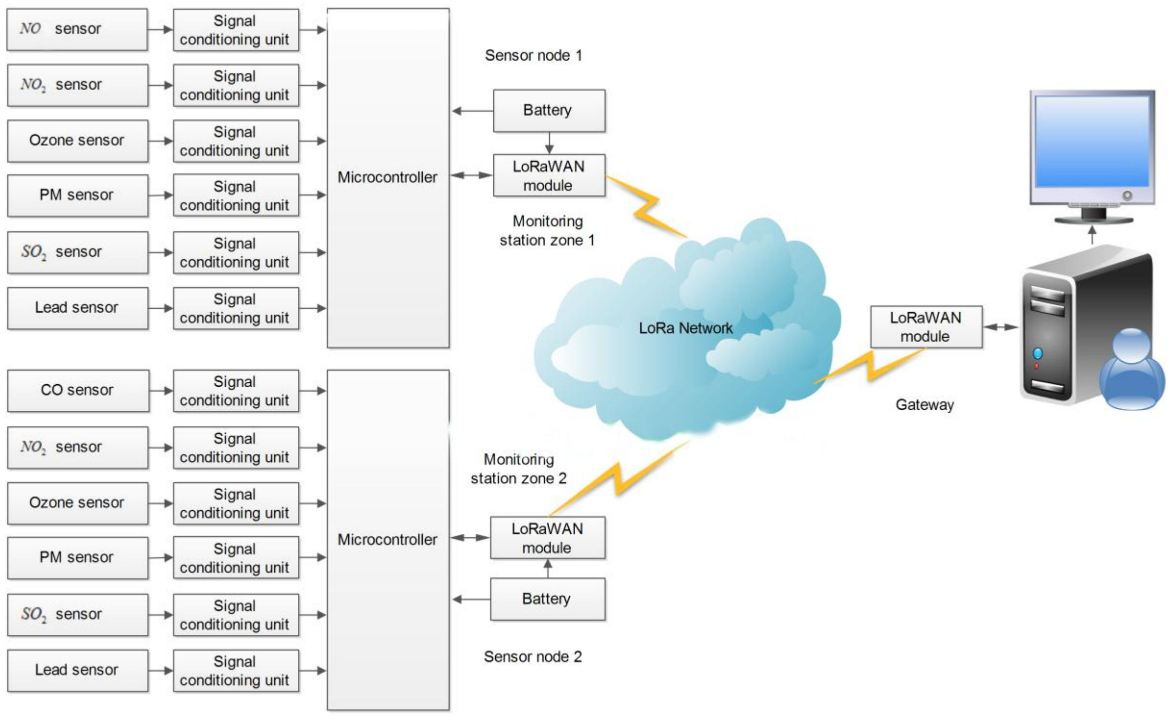

Fig 1: Overall hardware system description.

3.2 LoRaWAN Technology

LoRaWAN Technology offers a very compelling mix of long range, low power consumption and secure data transmission. Public and private networks using this technology can provide coverage that is greater in range compared to that of existing cellular networks. It is easy to plug into the existing infrastructure and offers a solution to serve battery-operated internet of the things (IoT) applications.

LoRaWAN network architecture is typically laid out in a star-of-stars topology in which gateways is a transparent bridge relaying messages between end-devices and a central network server in the backend. Gateways are connected to the network server via standard IP connections while end-devices use single-hop wireless communication to one or many gateways. All end-point communication is generally bi-directional, but also supports operation such as multicast enabling software upgrade over the air or other mass distribution messages to reduce the on air communication time.

Communication between end-devices and gateways is spread out on different frequency channels and data rates. The selection of the data rate is a trade-off between communication range and message duration. Due to the spread spectrum technology, communications with different data rates do not interfere with each other and create a set of "virtual" channels increasing the capacity of the gateway. LoRaWAN data rates range from 0.3 kbps to 50 kbps. To maximize both battery life of the end-devices and overall network capacity, the LoRaWAN network server is managing the data rate and RF output for each end-device individually by means of an adaptive data rate (ADR) scheme.

National wide networks targeting internet of things such as critical infrastructure, confidential personal data or critical functions for the society has a special need for secure communication. This has been solved by several layer of encryption:

- Unique Network key (EUI64) and ensure security on network level.
- Unique Application key (EUI64) ensure end to end security on application level.
- Device specific key (EUI128).

3.3 LoRaWAN Protocol

LoRaWAN is a protocol specification built on top of the LoRa technology developed by the LoRa Alliance. It uses unlicensed radio spectrum in the Industrial, Scientific and Medical (ISM) bands to enable low power, wide area communication between remote sensors and gateways connected to the network. This standards-based approach to building a LPWAN allows for quick set up of public or private IoT networks anywhere using hardware and software that is bi-directionally secure, interoperable and mobile, provides accurate localization and properly. One of the major issues for machine to machine, M2M communications used for applications like the Internet of Things, IoT is to enable communications over long ranges using very low power levels. One scheme for addressing this is known as LoRa. It gains its name from the fact that it is able to provide 'Long Range' communications using very low power levels. A LoRa network can be arranged to provide coverage similar to that of a cellular network. Indeed many LoRa operators are cellular network operators who will be able to use existing masts to mount LoRa antennas. In some instances the LoRa antennas may be combined with cellular antennas as the frequencies may be close and combining antennas will provide significant cost advantages.

LoRaWAN has several different classes of end-point devices to address the different needs reflected in the wide range of applications:

- Bi-directional end-devices (Class A): End-devices of Class A allow for bi-directional communications whereby each end-device's uplink transmission is followed by two short downlink receive windows. The transmission slot scheduled by the end-device is based on its own communication needs with a small variation based on a random time basis (ALOHA-type of protocol). This Class A operation is the lowest power end-device system for applications that only require downlink communication from the server shortly after the end-device has sent an uplink transmission. Downlink communications from the server at any other time will have to wait until the next scheduled uplink.
- Bi-directional end-devices with scheduled receive slots (Class B): In addition to the Class A random receive windows, Class B devices open extra receive windows at scheduled times. In order for the End-device to open its receive window at the scheduled time it receives a time synchronized Beacon from the gateway. This allows the server to know when the end-device is listening.
- Bi-directional end-devices with maximal receive slots (Class C): End-devices of Class C have nearly continuously open receive windows, only closed when transmitting. Class C

There are several key elements of the LoRa wireless system. Some of its key features include the following:

- Long range: 15 - 20 km.
- Supports millions of nodes
- Long battery life: in excess of ten years
- RF interface / physical layer : The LoRa physical layer governs the aspects of the RF signal that is transmitted between the nodes or endpoints, i.e. the sensors and the LoRa gateway where signals are received. It governs aspects of the signal including the frequencies, modulation format,

power levels, signalling between the transmitting and receiving elements, and other related topics.

- LoRa network architecture: Apart from the RF elements of the LoRa wireless system, there are other elements of the network architecture, including the overall system architecture, backhaul, server and the application computers.

The international comparison of ambient air quality standards and guidelines as compared with recommendations of the World Health Organization (WHO) is depicted in Table 2.

3.4 Monitoring Software

With the results from the data acquisition system in hand, the regulatory agent need to implement a number of decisions based on the final statistics. The measurement and control software for the base station was realized by LabWindows/CVI software development platform whereas the data acquisition control software was realized by ICCV.7 of AVR [25]. The user-interface provides features for the complete real time measurement, control, data processing, display result output, report printing and other functions. The main features include real-time measurement and display of ozone, particulate matter, sulphur oxides, nitrogen oxides, carbon monoxide, and lead. It realizes real-time acquisition and control of the precise timing and high speed sampling. The implementation of the test results should be real-time displayed in a variety of experimental curve display and can always switch observation and zoom, and save operation curve very conveniently. In addition, One can request measured information from the system at any time by querying a mobile code. Furthermore, the system can automatically calculate and generate test report of measured data to user needs. The implementation of the automatic calibration and easy to operate improves greatly the reliability of the system.

The LabWindows/CVI software delivers the versatile array of test definition, analysis and reporting capabilities required to address the evolving needs of advanced researchers, as well as the intuitive operator interface needed to establish and sustain standard, industry-compliant manufacturing quality testing. To ensure the function of the majority of the test sample material for testing, the system detects in real time the data sample to be uploaded to a computer. The computer system software supports a large number of test data processing to ensure that the detection system can detect a large number of data in real-time, secure transmission to the computer, communications interface between the computer system and USB communication ports [26]. Based on virtual instrument technology, the system combined with computer technology and instrument technology, sampling the multi input parameter signals and exporting the detailed control signal in the coordination with the hardware. Also, this software monitors and controls the applications process, hardware circuit, real-time sampling, data analysis and signal processing. According to measurement and control requirement, it generates the control signals on the basis of feedback control algorithm, expressing and exporting data, thus achieving a wide range of automatic test requirements and specific function.

4. Results and Discussion

The system was validated by installing two sensor nodes in two different zones of the manufacturing factory. The sensor nodes were equipped with pollutant sensors for detecting ozone, particulate matter, sulphur oxides, nitrogen oxides, carbon monoxide, and lead. The data obtained from the experiments were analyzed in real-time analysis and the results from two sensor nodes taken for a 24 hours period were compared. It could be observed that the levels of air pollutants were changing consistently. An analysis is presented in order to demonstrate the potential applications of the proposed innovations and to demonstrate how they are increasing the benefit when compared to a more conventional approach. Consequently, marked daily and annual variations of concentrations occur. Thus, ambient air pollutant concentrations measurements always have the character of random spatial or time samples.

The daily variations of particulate matter data monitored in two different zones are depicted in Figure 2. These readings indicate that the average particulate matter emission from zone 1 is slightly higher than zone 2. The particulate matter emission during the day was recorded higher at zone 2 and lower during morning and evening hours. Moreover, the daily variations of carbon monoxide data monitored in two different zones are shown in Figure 3. Furthermore, the daily variations of nitrogen dioxide data monitored in two different zones are as indicated in Figure 4. In addition, the daily variations of ozone data monitored in two different zones are depicted in figure 5. Lastly, the daily variations of Sulphur dioxide data monitored in two different zones are as shown in Figure 6. It can be seen from Figures 1 and 2 that there is a slight correlation of particulate matter and carbon dioxide emission zone 1 and 2 respectively. Likewise, as it can be seen from Figures 4 and 5 that there were a slight correlation of nitrogen dioxide emission in zone 1 and 2 respectively. At zone 1 and 2, most of the times, the observed data from all the nodes seems to reflect atmospheric concentration of the monitored gases. It can be seen from there readings that the pollutant emission from zone 1 and 2 are above the international ambient air quality standards and with recommendations of the World Health Organization (WHO). Table 2. Shows the international comparison of ambient air quality standards and guidelines as compared with recommendations of the World Health Organization (WHO). The daily variations of lead data monitored in two different zones were also changing consistently and accurately. The sensed data from every node is sent at regular intervals of time.

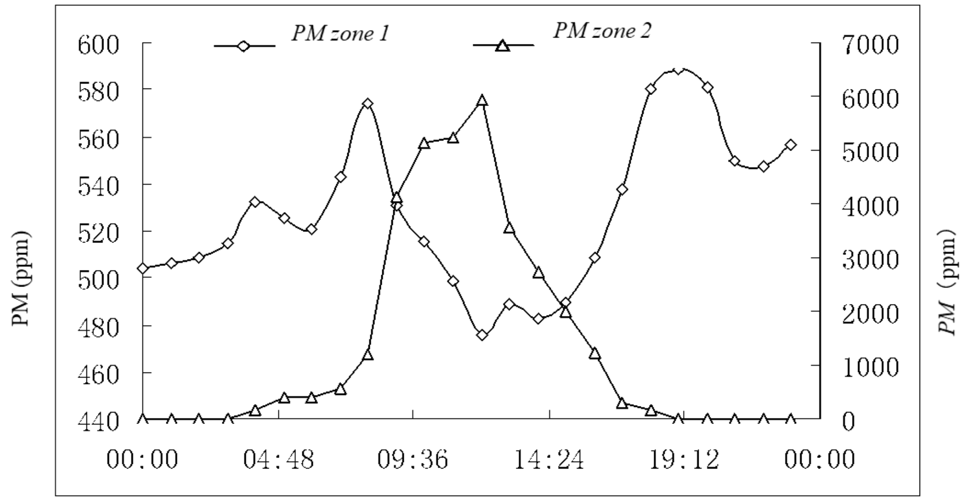

Fig 2: Daily variations of particulate matter data monitored in two different zones.

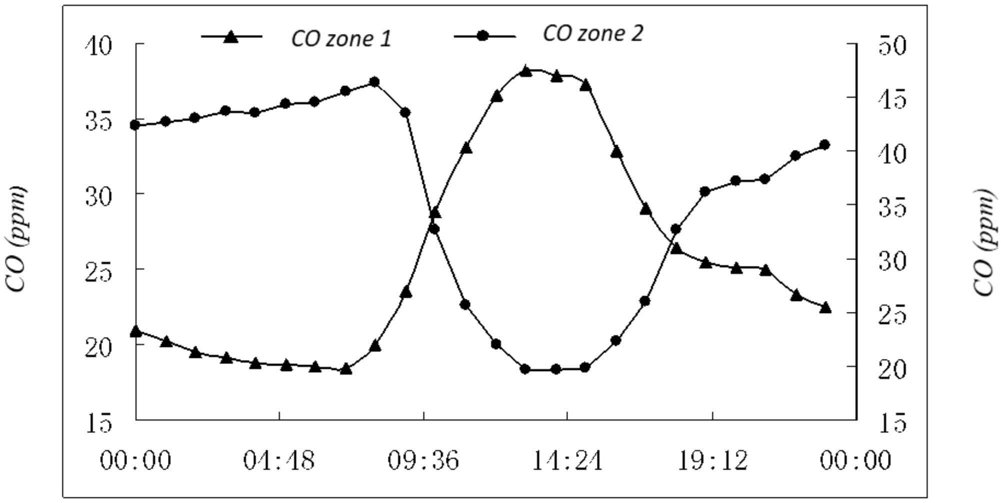

Fig 3: Daily variations of carbon monoxide data monitored in two different zones.

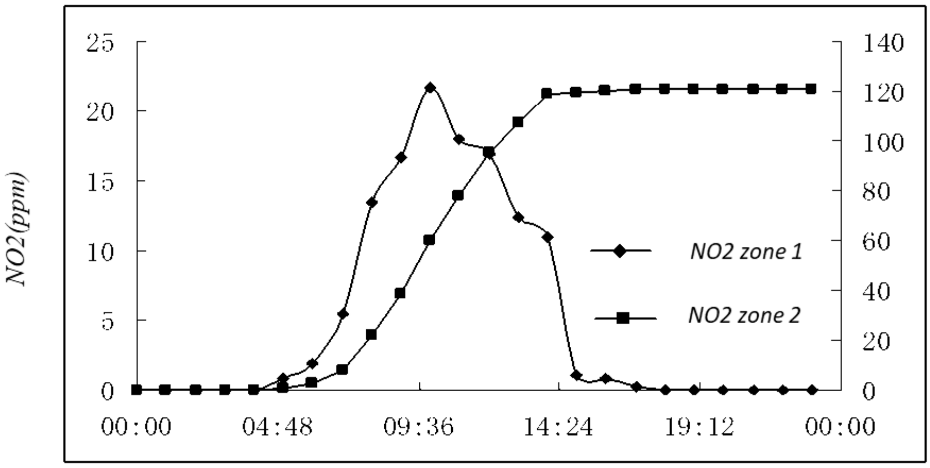

Fig 4: Daily variations of nitrogen dioxide data monitored in two different zones.

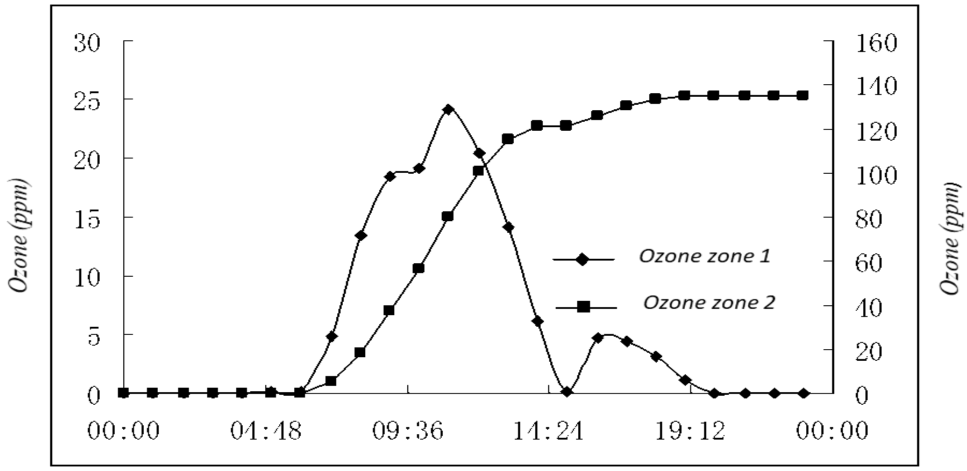

Fig 5: Daily variations of ozone data monitored in two different zones.

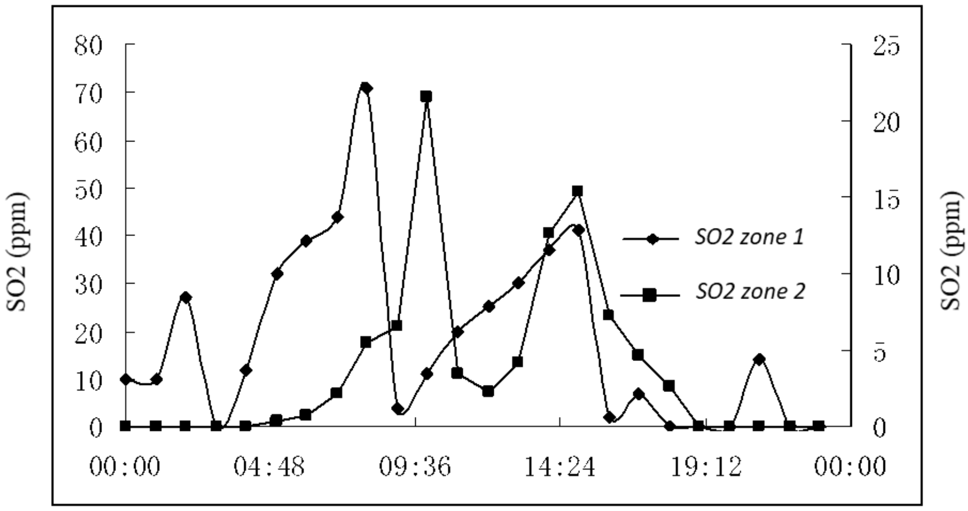

Fig 6: Daily variations of Sulphur dioxide data monitored in two different zones.

The converse of this to announce warnings to the public when conditions are such that excessive concentrations of contaminants may exist, so that the public can take appropriate action. For example, if a warning is sent out that atmospheric conditions are such that sulphur dioxide levels downwind of a smelter are excessive, susceptible populations such as asthmatics would know not to go outside. On one hand, the results obtained from this work will help the regulatory agencies for industries in inspection for demonstrating compliance with the set limits. On the other hand, the factory owners will use these results in setting their factory to comply with regulatory agencies well before inspection. When regulatory standards include emission limits, emission sampling can be used to determine compliance or non-compliance with the standards. Real time atmospheric and meteorological monitoring is sometimes used to avoid or reduce major air pollution events where multiple sources may exist. When it becomes evident that excessive air pollution levels are likely, major emitting industries may be restricted or shut down. When emissions are continuously monitored, the data can be used to fine tune the air pollution control system, or the plant operation itself.

Table 2. International comparison of ambient air quality standards and guidelines as compared with recommendations of the World Health Organization (WHO).

Pollutant	World health Organization	European Union	Australia	United States	Canada
Carbon Monoxide (CO)	9	9	9	9	13
Nitrogen Dioxide ($N0_2$)	21	21	30	53	53
Ozone (O_3)	50	60	80	80	65
Sulphur Dioxide (SO_2)	50	48	80	140	115
Particulate Matter (PM_{25} & PM_{10})	25	50	25	65	30
Lead (Pb)	-	0.5	0.5	1.5	-
Note: A dash (–) indicates that no standard or guideline has been established for a particular parameter					

5. Conclusions

This work has been established as a practical real-time and cost-effective method of measuring air pollutants in manufacturing industries. It is useful for factory owners, workers and regulatory agencies to ensure compliancy with the standard environmental regulations. This study provides detailed and reliable data on key air pollutant parameters such as ozone, particulate matter, sulphur oxides, nitrogen dioxides, carbon monoxide, and lead. It has opened up new possibility to design smart devices that improve environmental conditions faced at industries as well as increase efficiency. The major motivation behind our study and the development of the system is to help the regulatory agencies in Tanzania to make sure manufacturing industries, which have not incorporated provisions for treating the wastes they generate and the factories that have been built without including technologies, which help to reduce waste they do so. This in turn, will reduce human health effects of industrial air pollutants and potential damage to other aspects of the environment.

Additional research and further efforts are needed to deploy large number of sensor nodes to know detail content of all gases present in air. Moreover, the design of webpage, interface SD Card to store data and interface GPS module to monitor the pollution at exact location and upload on the webpage for the public domain are highly recommended.

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