Vehicle Exhaust Emissions Inspection System for Roadworthiness Enforcement

Reuben K. Mwenda (*Author*)
Strathmore University
Faculty of Information Technology
Nairobi, Kenya
reuben.kiogora@strathmore.edu

Dr. Joseph Orero (*Author*)
Strathmore University
Faculty of Information Technology
Nairobi, Kenya
jorero@strathmore.edu

***Abstract*— Air pollution has been a growing concern as Kenya tries to industrialize. Increase in the number of vehicles and factories as well as constructions in Nairobi make this all the more critical. This polluted air has far reaching consequences which include illnesses that lead to death. Measuring the concentration of air pollutants is necessary to establish the quality of air in the city. By extension, measuring the concentration of pollutants being emitted through vehicle exhaust fumes can help establish if the vehicle is worthy to be on the road.**

To best measure the degree of these pollutants, random on-the-road inspection of vehicle inspection of vehicle exhaust emissions is key. However, this has not been achieved by the Kenyan law enforcement agencies. The ability to inspect the emissions from cars on the road will help law enforcement remove unroadworthy vehicles from the roads and thus minimize air pollution caused by vehicles.

Conventional inspection methods are done in controlled environments such as laboratories. Vehicles are driven in and are inspected while they remain stationary. These controlled tests fall short of revealing the true state of a vehicle's exhaust emissions: the fumes emitted while a car is on open road are different in composition from those emitted in such a controlled environment. In addition, manufacturers can tweak their vehicles to emit gases that are within the prescribed thresholds as was done by Volkswagen in order to meet and exceed the US Environment Protection Agency standards.

This study will present a model that utilizes sensors to assess the level of pollutants produced from a vehicle exhaust to the air and register these to back-end server hosted on the cloud. The model will have an LCD screen on which law enforcement can view levels of pollutants as measured by the sensors. The information will be stored in the cloud server will be available to law enforcement anywhere.

***Keywords*— Machine to Machine, Internet of Things, Air pollution, Sensor, Microcontroller, Arduino (key words)**

I. INTRODUCTION

"The air in Nairobi is poisonous and cause serious ailments including heart and lung diseases as well as cancer. The amount of cancer-causing elements in the air within the city is 10 times higher than the threshold recommended by the World Health Organisation (WHO), says Marie Thynell, Associate Professor in Peace and Development Research at School of Global Studies." (Svensson, 2016).

Svensson (2016), continues to state that the economic survey of 2014 indicated that respiratory infections caused the highest number of illnesses in Kenya in 2013 with 14,823,864 cases being reported. The study notes that air pollution scenario in Nairobi and other cities within the region is uncontrolled and worrisome.

In a study appearing in the Guardian Newspaper, it is stated that from the data available, Nairobi's pollution is around thirty times that in London (Vidal, 2016). Vidal, (2016) continues to state that "the pollution will have a huge economic and health impact. We will see more and more cancers and heart disease, many more asthma cases and respiratory diseases."

In another study of the air quality in major roads which was done by the United Nations Environmental Programme, it was found that many areas have a high concentration of poisonous gases that have adverse effects on humans and on the environment. The study lists the major pollutants as vehicles, industries as well as households. (Kilonzo, 2015)

In yet another article, Mureithi (2015) quotes Prof Shem Wandiga of the University of Nairobi as saying that the pollutants when inhaled in small quantities over a long period of time, have the capacity to interfere with the reproductive systems of the residents of the city.This therefore illustrates that it is imperative to properly monitor pollution levels within the city and channeling this information to authorities to take corrective measures.

Carbon fuels produce the most pollutants into the air. This when inhaled over long periods of time can cause various health issues. The inability to effectively monitor pollution levels implies that controlling the polluters is not possible.

Using a system in the inspection of vehicles will assist in ensuring that those that exceed a specified level of pollution in their emissions are not allowed on the roads.

This will lower the air pollution in the city and therefore implies that lesser money is spent on treating diseases that are caused by air pollutants. This money will eventually be channeled back to the economy.

The aim of this work is to propose an IoT-based system for the inspection of the level of pollutants in vehicle exhaust emissions

II. Literature Review

A. Air Pollution

Air pollution is the presence in or introduction into the air of a substance which has harmful or poisonous effects. The major sources of air pollution include factories, construction work and vehicles.

The industrial revolution effectively changed the constitution of the atmosphere in terms of chemical composition. Daly and Zannetti (2007) state that if the natural atmosphere (the atmosphere as it was before the industrial revolution) is considered to be ‘clean’, then this means that clean air cannot be found anywhere in today’s atmosphere.

The table below shows the chemical composition of the pre-industrial natural atmosphere compared to the current compositions:

Gas	Symbol	Percent by volume (Current Atmosphere)	ppm (Natural Atmosphere)	ppm (Current Atmosphere)
Nitrogen	N_2	78.1		
Oxygen	O_2	20.9		
Argon	Ar	0.92		
Neon	Ne		18.2	
Helium	He		5.2	
Krypton	Kr		1.14	
Xenon	Xe		0.09	
Carbon dioxide	CO_2		280.0	370.0[3]
Methane	CH_4		0.750	1.77[4]
Nitrous oxide	N_2O		0.270	0.318[5]
Water Vapor	H_2O	Variable (0.004 to 4)		

Table 1 Atmospheric Chemical Compositions (Daly & Zannetti, 2007)

The department for Environment Food and Rural Affairs (DEFRA) lists the various causes of air pollution. These include particulate matter (PM) which is categorized on the basis of the size of the particles. Exposure to this kind of pollutants is associated with respiratory and cardiovascular illnesses. Oxides of Nitrogen also cause pollution. These are produced by all combustion processes in the air. High levels of Nitrogen dioxide causes inflammation of the airways and long terms exposure to this pollutant may affect lung function. Ozone, which is not emitted from human-made sources, is also listed as an air pollutant. It arises from chemical reactions between various air pollutants primarily oxides of nitrogen and volatile organic compounds initiated by strong sunlight. High exposure to this pollutant can lead to irritation of the eyes and nose. Ozone also reduces lung function and increases incidences of respiratory symptoms and mortality.

Sulphur Dioxide, which is produced by the burning of fuels containing sulphur such as coal and heavy oils also pollutes the air. High exposure to this pollutant causes constriction of the airways of the lung and it affects the ecosystem as well. Another pollutant is Carbon monoxide which is formed from incomplete combustion of carbon containing fuels. This is chiefly produced by vehicles as well as residential and industrial combustion. Finally, lead, as emitted from combustion of coal as well as the combustion of steel and iron contributes to air pollution. High levels of this may result in toxic biochemical effects which have adverse effects on the kidneys, gastrointestinal tract, joints and reproductive system and acute or chronic damage to the nervous system (DEFRA, 2014).

B. Air Pollution in Nairobi

A Nairobi County and JICA survey team report (2009) found that the leading cause of death in Nairobi is respiratory ailments at over 35% of all deaths. This is directly related to air quality.

Cambodia et al. (2003) found that the major air pollutants in Nairobi are lead, oxides of Nitrogen and particulate matter. All these were found to exceed by more than half the World Health Organization guideline of 2005.

Mulaku and Kariuki (2001) indicate that the greatest cause of the air pollution found in Nairobi is the large quantity of vehicles operating within the city. The most disturbing fact regarding Nairobi's air pollution is that there is no regular air quality management system and no large efforts to decrease the amount of pollution regularly entering the air. According to a UN study on air quality management capability, "out of 20 mainly developing countries samples...Nairobi's capacity was rated as the worse" (Mulaku and Kariuki, 2001). Predictions indicate that the air pollution will only get worse with the "increasing population, growing industrial area, deforestation on the city's fringes, increased construction works and increased vehicular traffic" (Mulaku & Kariuki, 2001).

The principal air pollutant emissions from petrol, diesel, and alternative-fuel engines are carbon monoxide, oxides of nitrogen, un-burnt hydrocarbons and particulate matter. Modern cars, if kept in good condition, produce only quite small quantities of the air quality pollutants, but the emissions from large numbers of cars add to a significant air quality problem (gov.uk, 2003).

Reichmuth (2016) states that passenger vehicles are a major pollution contributor, producing significant amounts of nitrogen oxides, carbon monoxide, and other pollution. He adds that in 2013, transportation contributed more than half of the carbon monoxide and nitrogen oxides, and almost a quarter of the hydrocarbons emitted into our air (Reichmuth, 2016).

C. Vehicle Emisssions Inspection Systems

According to Majewski and Burtscher (2016), Vehicle emissions measurement systems can be grouped largely grouped as laboratory testing system which includes regulatory testing, emissions research and engine and emission control system development, and field testing which includes mobile emission laboratories, on-vehicle measurements, inspection and maintenance programs and occupational health measurements.

The advantage of laboratory test is that it enables consumers to compare emissions and fuel consumption of different car models. A laboratory test is also standardized and can be easily repeated.

The European Union enforces some of the most stringent laws concerning vehicle emissions. The New European Driving Cycle (NEDC) measures the emissions of passenger cars for both carbon dioxide and other pollutants in a laboratory setting. All conditions for vehicle set-up, testing and the handling of test results for cars are defined by the European Union law (ACEA, 2016).

D. Laboratory Testing Systems

Laboratory testing systems have been put under scrutiny in the recent past following the Volkwagen scandal - where the manufacturer was found to have built a gadget to know when the car is under test and adjust its emissions appropriately.

In addition, as noted before, vehicles, especially diesel cars, are producing many times more health-damaging pollutants than claimed by laboratory tests with some emitting up to 12 times the European maximum when tested on roads (Walker and Ruddick, 2016).

In a laboratory test, the vehicle's wheels are placed on a machine called a dynamometer which simulates the driving environment much like an exercise simulates cycling. The amount of energy required to move the rollers is adjusted to account for wind resistance and the vehicle's weight.

On the dynamometer, the vehicle is taken through standardized driving routines which simulate typical trips on road. Each routine specifies the speed the speed the vehicle must travel during each second in the test. A pipe is connected to the tailpipe to collect the engine exhaust during the test and the carbon is measured to calculate the amount of fuel burned during the test (fueleconomy.gov, 2016).

E. Field Testing Systems

Measurement equipment and methods used for measuring engine emissions in the field vary widely, from mobile laboratories, with capabilities comparable to those of stationary emission laboratories, to simple, low-budget tools, which can offer only very approximate results.

Portable emission measurement systems (PEMS) can be installed on a vehicle to measure real life emissions with a laboratory level of accuracy. PEMS systems include laboratory-class analyzers packaged in one or more portable units and a simplified sampling system. PEMS analyzers can provide results as both raw gas concentrations and mass-based emission factors (Majewski and Burtscher, 2011).

F. Machine to Machine Architecture

Machine to Machine uses sensing technology to observe and take measurements from the environment. This measurement data is then relayed over some communication link to a back end server which manipulates this data to find trends and patterns.

Pictorially, the Machine to Machine architecture can be represented as below:

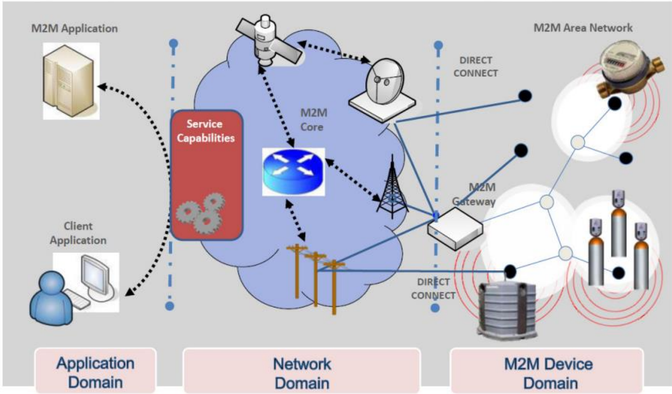

Figure 1 Detailed M2M System Architecture. (Adapted from Dohler, 2013)

G. M2M Architecture: Microcontrollers

At the heart of IoT systems is a processor unit or microcontroller (MCU) that processes data and runs software stacks interfaced to a wireless device for connectivity (Kavita C. et al, 2016).

This research uses the Arduino Uno MCU. This is a microcontroller board that has 14 digital input/output pins (of which 6 can be used as Pulse Width Modulation outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. In addition, this microcontroller has 32KB of memory.

H. Sensors

M2M relies on sensors to collect data. Therefore, the choice of sensors depends on the kind of data that is needed.

For this model, to sense the level of Carbon Monoxide in the vehicle exhaust fumes, the MQ-7 Carbon Monoxide Sensor will be utilized. Other sensors that can be used to enrich the information generated from such a model include the Particulate Matter Detector (GP2Y1010AU0F) and the MiCS-2714 Gas Sensor for particulate matter and oxides of nitrogen measurements respectively. These sensors need to be interfaced with the Arduino board in order to collect data.

I. M2M Communication

As noted above, the data collected is little in quantity. This needs to be communicated over some link to the back end server that runs some analysis on the server.

Since we will be using the Arduino board, a GSM shield will be used to provide GPRS connectivity over the internet to the online server. In addition, this will allow the system to send and receive text messages.

J. M2M Backend Server

The back-end server provides the computing power to make sense of the data collected by the sensors. This server can either be hosted on the cloud or locally. Hosting this server on the cloud ensures near 100% availability and therefore would be the preferred choice.

This server will run a simple Expert System that compares the collected amounts of pollutants from the car exhaust with a preconfigured limit. The system will then offer advise to the law enforcement on the best course of action. For example if the limit is exceeded by a large margin, the system can advise law enforcement to impound the vehicle immediately, or if the limit is exceeded by a small margin, the system can advise the law enforcement to instruct the owner to have the vehicle repaired and avail it for testing at a testing center in a week's time.

The logic of the expert system is represented in the pseudocode below:

```
START
GOOD_CO_LEVEL = XX
ACCEPTABLE_CO_LEVEL= ZZ
GET MEASURED_CO_LEVEL
MEASURED_CO_LEVEL= YY
IF YY < XX:
        BLINK GREEN ON INSPECTION DEVICE
IF YY > XX & YY < ZZ:
        BINK ORANGE ON INSPECTION DEVICE
IF YY > ZZ:
        BLINK RED ON INSPECTION DEVICE
```

III. SYSTEM DESIGN

A. Architecture

The system will use a carbon monoxide sensor to collect parameters that determine the level of the pollutant in the air. This data will be communicated to the cloud-hosted back end server via GPRS.

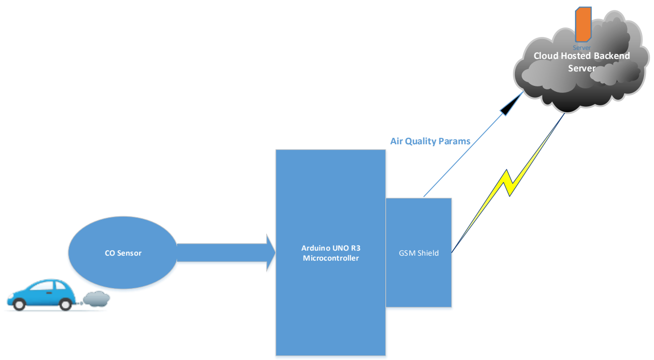

Figure 2 Conceptual Framework

B. Include other design issues.

IV. IMPLIMENATION AND TESTING

The complete Bill of Materials for the model is as below:

i. Arduino Uno R3 microprocessor
ii. MQ7 Carbon Monoxide Gas sensor
iii. GSM Shield
iv. Light Emitting Diodes
v. 9V battery
vi. 330 Ohm to 1 K-Ohm Resistors
vii. A Cloud based server

The GSM shield is fitted with a mobile service provider SIM card and wired to the Arduino UNO R3 microcontroller. This will provide internet connectivity to the cloud server and pass data collected from the sensor via the MQTT protocol. The 9V battery provides direct current to the microprocessor unit and all other components. The resistors act to protect the light emitting diodes by dropping current to a safe level.

The MQ7 gas sensor is connected to an analog pin on the MCU and is powered from the battery. The sensor's output activates the Arduino pin it is connected to when it senses carbon monoxide in the air. The MQ7 sensor can detect Carbon Monoxide gas concentrations ranging between 20 to 2000 parts per million. Its sensitivity can be adjusted by the inbuilt potentiometer.

On receiving this data, the backend server analyzes it and given the difference between the observed concentration of the carbon monoxide gas and the preconfigured one, the server sends back a signal to the device and turns on either a red, orange or green LED as described in the previous section.

V. CONCLUSIONS AND FUTURE WORKS

This model presents a basic technique to facilitate on-the-road measurement of carbon monoxide levels coming from vehicle exhausts. It allows the miniaturization of otherwise cumbersome lab equipment and provides an easy way for the enforcement officer to interpret the data (by the use of a green, orange or red LED on the device).

This model can be extended further in various ways. The first is the incorporation of more sensors to give a wholesome view of the state of the exhaust gases: for instance, a particulate matter sensor and a Nitrogen Oxide sensor can be used to capture the levels of the other two elements that contribute greatly to air pollution.

Moreover, the hand held device can be enriched with an optical character recognition camera that can be used capture the registration number of the car being inspected and a liquid crystal display screen. A small keypad can be used for simple input. However, all this should not compromise the portability of the device.

Finally, as more and more data is captured, machine learning techniques can be used to discover such patterns as models of cars that are most non-conformant and routes in which most cars are non-conformant and this can help the appropriate enforcement authority in being preemptive in their work.

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