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Vehicle exhaust emissions inspection system for roadworthiness enforcement

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Vehicle Exhaust Emissions Inspection System for Roadworthiness Enforcement

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Faculty of Information Technology

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Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the research proposal contains no material previously published or written by another person except where due reference is made in the research proposal itself.

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Approval

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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 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.

This research presents a model that utilizes a carbon monoxide sensor to assess the level of carbon monoxide gas produced from a vehicle exhaust to the air and register these to back-end server hosted on the cloud. The model has an LED which will display a color (red, amber or green) to display the severity of the gas level in the exhaust. This model was tested against conventional testing equipment and found to have an accuracy of 91%.

KEYWORDS: Machine to Machine, Internet of Things, Air pollution, Sensor, Microcontroller, Arduino

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Chapter 1: Introduction

1.1 Background

"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 Organization (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.

Figure 1.1 shows measurements of carbon content as measured from a car window and illustrates the high concentrations of the gas in the breathable air:

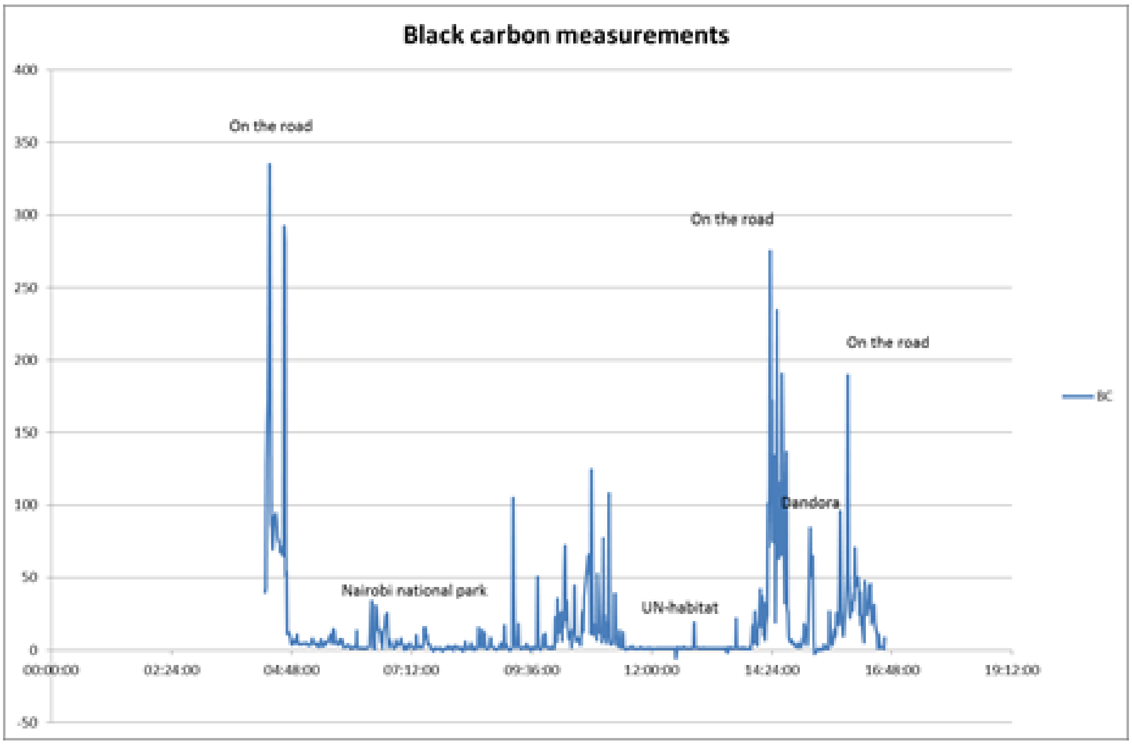

Figure 1.1: Black Carbon Content against Location (adapted from Svensson, 2016)

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). It continues to state that the pollution will have a huge economic and health impact and that 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 Program, 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.

1.2 Problem Statement

Jamah (2016), indicates that the National Environment Management Authority was to start enforcing the requirement that all vehicles be inspected to ensure they do not release excessive exhaust fumes. This inspection was set to begin by August of 2016. This is yet to kick off.

Apart from the difficulty of such enforcement, it has been shown that emission tests conducted in controlled environments such as laboratories, miss the key parameters of exhaust that vehicles produce while on actual roads (ACEA, 2016).

The lack of a portable exhaust emission-monitoring device therefore presents a key problem to the National Environment Management Authority in their quest to enforce the Air Quality Regulations which were gazetted in 2014.

1.3 Research Objectives

i. To investigate the challenges in assessing roadworthiness of vehicles,

ii. To review current methods used to inspect vehicle exhaust emissions,

iii. To propose an IoT-based system for the inspection of the level of pollutants in vehicle exhaust emissions,

iv. To test the effectiveness of the proposed model.

1.4 Research Questions

i. What are the major causes of air pollution that emanate from vehicle exhaust emissions?

ii. How is inspection for vehicle exhaust emissions currently being done?

iii. How can IoT be used to measure the degree of pollutants in vehicle exhaust emissions?

iv. How efficiently does the proposed IoT-based system acquire, communicate and evaluate the degree of pollutants from vehicle exhaust?

1.5 Justification

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.

1.6 Scope and Limitations

Air pollutants that emanate from vehicle exhaust are numerous. This proposal will be limited to attempting to accurately acquire and evaluate the level of carbon monoxide emanating from vehicle exhaust. This is because carbon monoxide is a deadly gas and coupled with its invisibility – as compared to particulate matter – makes it impossible to be measured in any other way.

Chapter 2: Literature Review

2.1 Introduction

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.

2.2 Air Pollution

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.

Table 1.1 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 1.1 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).

2.3 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 worst. 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 and Kariuki, 2001).

2.3.1 Air Pollution caused by Vehicles

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).

2.4 Air Pollution Monitoring Systems

Several air pollution monitoring systems have been proposed. Majority of these employ the use of sensor networks to detect the presence of pollutants in the air. Kularatna and Sudantha (2008) have proposed a system that uses semiconductor sensors, a network capable application processor and a transducer independent interface. This system uses three gas sensors whose results are seen on the graphical user interface of the Network Capable Application Processor (NCAP). This system is capable of warning when the pollutant levels exceed predetermined maxima.

Another system called Ozone Web can be used to monitor and track ground level ozone incidents on a Pan-European scale. Users are able to follow air quality locally and on a continental scale. The system also includes information on the health implications of the ozone values users are experiencing. This is in response to a policy requirement that countries alert citizens on a national level when ozone levels reach particular levels (EEA, 2016).

There is therefore a general shift towards the use of sensors to detect pollution in the air. Prasad et al (2011) as well as Raju et al (2013) have both put forward papers presenting pollution monitoring systems via the use of sensors. This is because of the versatility of sensor networks in recording real time data and sending it for analysis in an upstream server.

2.5 Vehicle Emissions 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).

This cycle is shown pictorially in Figure 2.2:

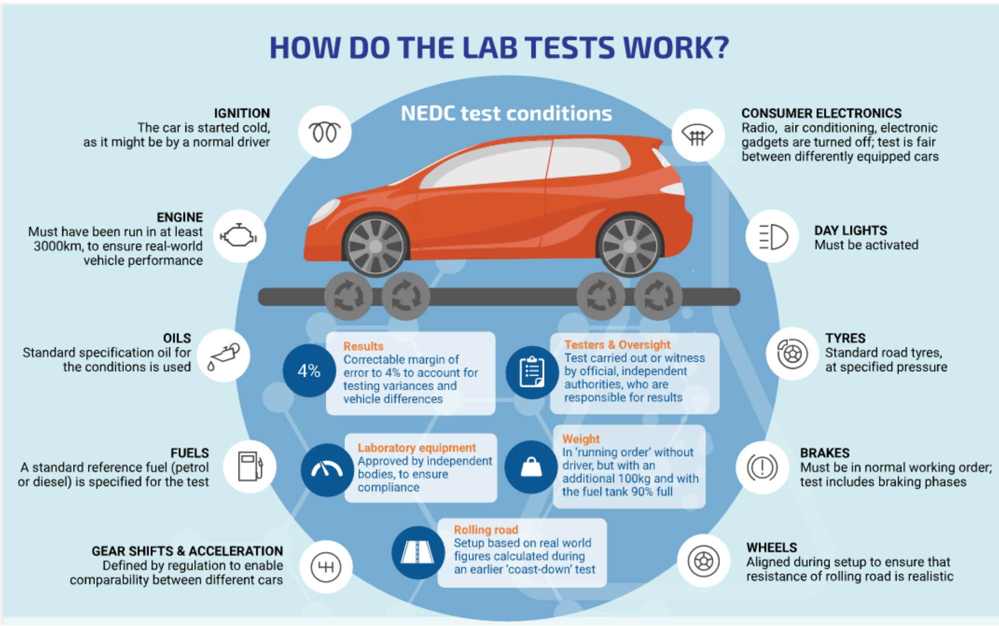

Figure 2.2 The European Union New European Driving Cycle. (Adapted from ACEA 2016)

2.5.1 Laboratory Testing Systems

Laboratory testing systems have been put under scrutiny in the recent past following the Volkswagen 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 & 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).

Figure 2.4 A Vehicle on a dynamometer during a lab test. (Adapted from fueleconomy.gov, 2016)

2.5.2 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).

2.6 Machine to Machine Architecture

Machine to Machine (M2M) 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. This architecture can be widely broken down into three parts: Machine, Network and Machine.

The machine part of the diagram consists of the sensing technology and the processor that drives the sensors. The data collected is then communicated over a network. This network is broken down into the access network, the gateway and the core network.

The Access network connects the sensors and the actuators. This can either be a wired network, wireless capillary network or wireless cellular network. The gateway connects the access and the core network. The core network - which can be the Internet - connects to the back-end server - that can be hosted on the Internet. A detailed architecture is illustrated in Figure 2.7:

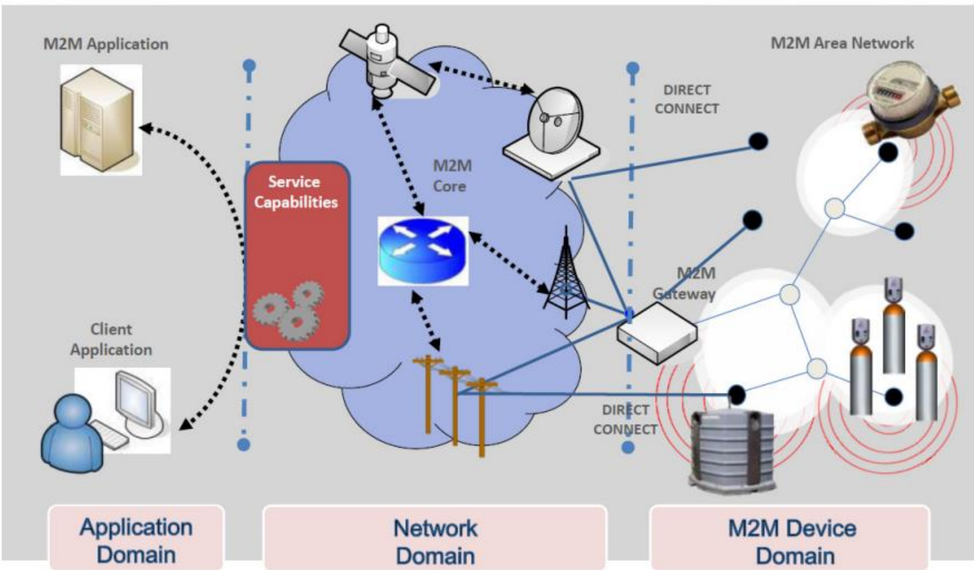

Figure 2.7 Detailed M2M System Architecture. (Adapted from Dohler, 2013)

2.6.1 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 will use the Arduino Uno MCU.

The Arduino Uno 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. To communicate with a computer, this microcontroller has serial communication via pins 0(RX) and 1 (TX) ("Arduino UNO," 2016).

2.6.2 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.

2.6.3 M2M Architecture: 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.

2.6.4 M2M Architecture: Back-end Server

The back-end server provides the computing power or 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 advice 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.

2.7 Conceptual framework

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.

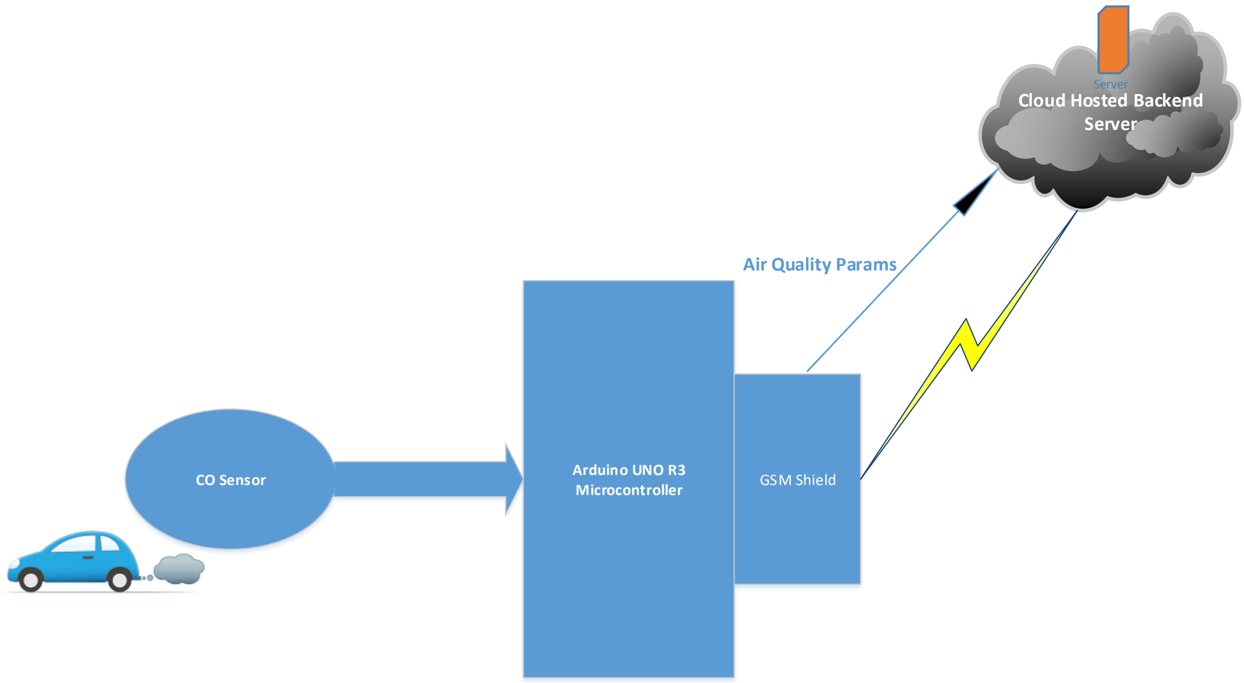

Figure 2.12 Conceptual Framework

Chapter 3: Research Methodology

3.1 Introduction

The methodology used in the research will be directed by the research objectives as listed in chapter 1 as well as the comparative works as elaborated in chapter 2.

3.2 Research Design

This research is an applied research and proposes to develop a portable air quality inspection device that will use a carbon monoxide sensor and relay the data collected to a backend server. The server will run simple analytics on the data collected by using a simple expert system and suggest courses of action on a web interface. The sensor will be connected to an Arduino Uno microcontroller which will provide the computational power required. Data will be transmitted to the backend cloud-hosted server via a GSM card that will also be connected to the microcontroller. A digital screen also connected on the Arduino board will display the results.

3.3 Population and Sampling

3.3.1 Research Site

The portable air quality inspection device proposed in this research can be used on any vehicle. However, since air pollution is most critical in Nairobi, this research will focus on obtaining measurements from vehicles within Nairobi City.

3.3.2 Population

Odipo, (2015), notes that there are approximately 400,000 vehicles that use the roads in Nairobi daily. This will form the population that will be the basis of this research project.

3.3.3 Sampling

Quota sampling is proposed to be used in this research. In quota sampling the researcher first identifies the stratums and their proportions as they are represented in the population then convenience or judgment sampling is used to select the required number of subjects from each stratum. (StatPac, 2016). Therefore, in this case, all the vehicles that will be obtained from the National Environment Management Authority will be used as samples.

3.4 Data Collection Methods

3.4.1 Interviews and Questionnaires

Data collection will be done in two phases. The first involves interaction with the National Environment Management Authority to evaluate the methods that are used for vehicle inspection and their accuracies. Other issues like the lack of portable devices to be used in these inspections will also be raised. This phase will primarily rely on:

i. Questionnaires that will be designed and targeted at the National Environment Management Authority.
ii. Interviews will also be used to allow for flexibility that comes up as a result of issues and concerns being raised by the interviewees.

3.4.2 Carbon Monoxide Data Collection

This phase of data collection will involve capturing the levels of carbon monoxide and comparing this with the measurements obtained using the conventional testing methods. This will help in establishing the viability and quality of the proposed model.

In this research, only the carbo monoxide content in parts per million will be collected from the exhaust fumes of a vehicle. To collect this, a sensor will be placed on the exhaust pipe and carbon monoxide levels will be read. However, in the prototype, this data will be sent to the cloud and not displayed on a computer screen.

3.5 Research Quality

To ensure validity, objectivity and reliability of the research, the final product will be tested and the results compared with those from conventional vehicle exhaust emission inspection devices. This will ensure that the benefit of portability of the proposed device is achieve while ensuring quality is not compromised.

Chapter 4: System Design and Architecture

4.1 Introduction

This section details the design and architecture of the proposed solution by incorporating the various requirements collected in the previous chapter. To achieve this, design diagrams under the Unified Modelling Language were drawn and detailed information for each design diagram put down. Design diagrams and structures put down for the purpose of the model included a use case diagram with detailed follow-up use case descriptions, System Sequence Diagrams, and an activity diagram.

4.2 Requirements Analysis

This section outlines the various requirements that this research intends to meet based on the objectives.

4.2.1 Functional Requirements

This represents the abilities that a system must have in order to satisfy the objectives of this research. This section lays down the 'what' and not the 'how'. These requirements include:

i. The hand-held device should collect carbon monoxide level of a vehicle exhaust emission
ii. The device should send this data to a back end server
iii. The back end server should receive the data, process it and send back feedback to the device.

4.2.2 Usability Requirements

The usability requirements of a system are the needs that the system needs to meet in order to facilitate easy interaction with the user. For this model, these include:

i. The hand held device should give an easy to interpret feedback for a given vehicle:
    a. Blink red if the vehicle's CO level exceeds the set threshold and should not be on the road.
    b. Blink orange if the vehicle CO level exceeds the threshold by a small margin and should be repaired and availed for inspection in a month's time.
    c. Blink green if the vehicle's CO level is below the threshold.

4.2.3 Reliability Requirements

For optimum availability:

i. The back end server should be hosted on the cloud to guarantee maximum availability and reliability

ii. The hand held device should use a power source that can sustain at least 6 hours' operation without a need for recharge.

4.3 System Architecture

The model will utilize a carbon monoxide gas sensor to read the level of the carbon monoxide gas in the vehicle's exhaust emission and transfer this data to the Arduino Uno microcontroller. The microcontroller will then use the GSM shield module to send this data via GPRS to the cloud based server. The cloud based server will run an expert system that compares the received data on a preset threshold and send back to the microcontroller via GPRS a command to illuminate the LED – either Red, Orange or Green.

Figure 4.1 gives an overview of the system architecture.

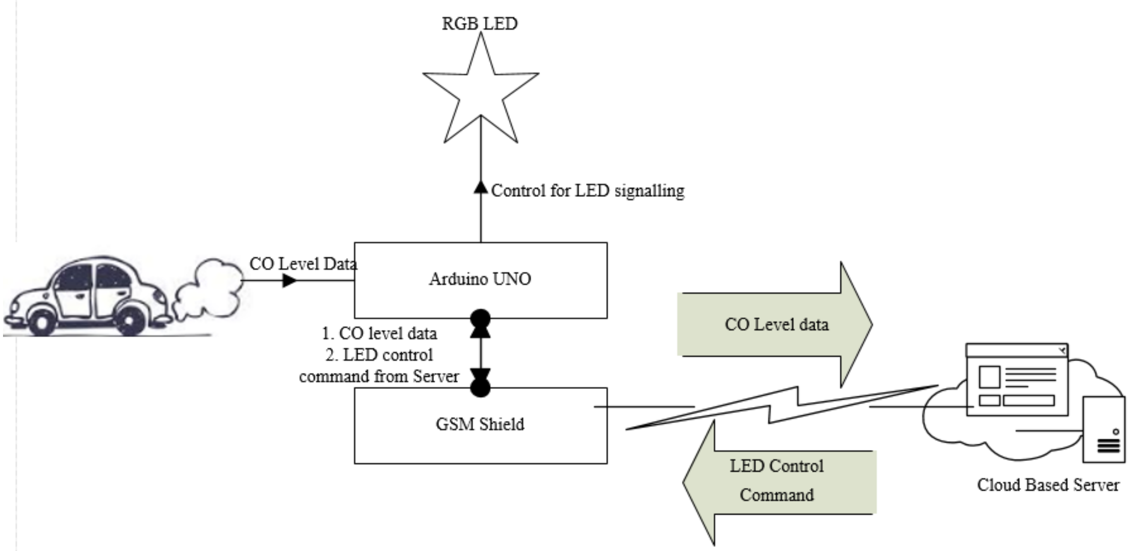

Figure 4.1 System Architecture

4.4 Diagrammatic Representation of the Model

4.4.1 Use Case Diagram

A use case diagram describes a user's interaction with the system. It comprises of the actors (something with a behavior or a role) who in the research were the enforcement officers, a boundary which represents the limits to which the system operates and the use cases which are a collection of success or failure scenarios. In Figure 4.2, the enforcement officer interacts with the 'capture carbon monoxide data' and 'decode recommendation LED signal' use cases. The Expert System also interacts with the model via interaction with the 'process carbon monoxide data' use case.

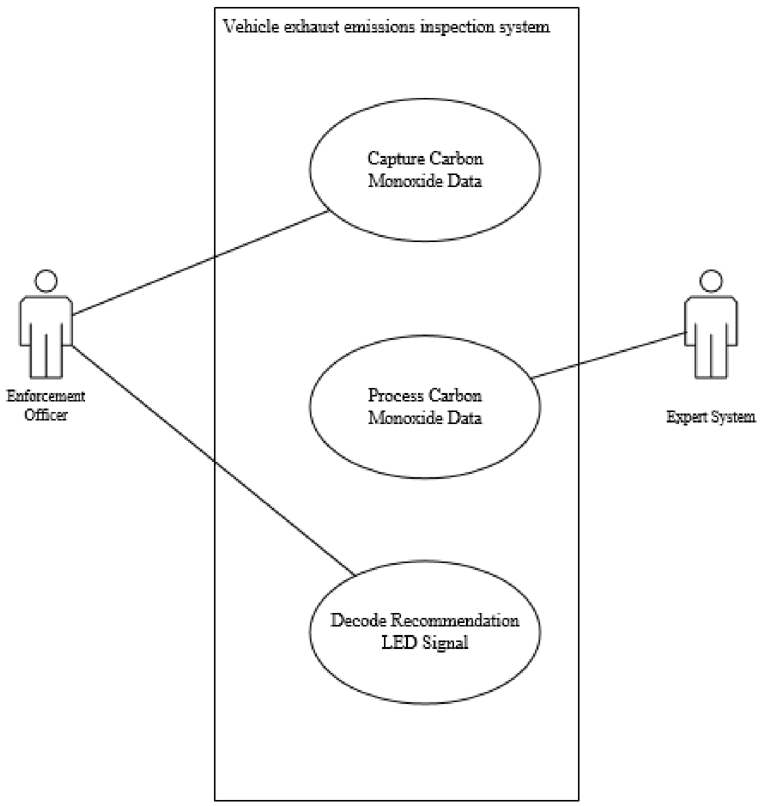

Figure 4.2 Use Case Diagram

A. Use Cases Description

Use Case: Capture Carbon Monoxide Data

Primary Actor

Enforcement Officer

Precondition:

Device is powered on and device status LED is constant green

Post Condition

Carbon Monoxide gas level is read from the sensor and communicated to the expert system

Device status LED is blinking red

Main Success Scenario

i. Enforcement office flags down a vehicle to be assessed
ii. Enforcement officer powers on device or resets it from previous reading
iii. Enforcement officer inserts the sensing device into the exhaust and instructs the driver to rev up the engine. Adequate data is captured once the device status LED blinks green.
iv. Carbon monoxide levels are captured by the sensor and communicated to the backend server via GPRS. Device Status LED blinks red.

Extensions

If at any time the device fails, enforcement officer power cycles the device and takes the measurement again.

Special Requirements

RGB ‘device status’ LED capable of displaying red or green light.

Use Case: Process Carbon Monoxide Data

Primary Actor

Expert System

Precondition

Carbon Monoxide data has been received from the hand held device

Post Condition

The action LED on the hand held device blinks red, orange or green.

Main Success Scenario

i. Expert system receives carbon monoxide data from the hand held device
ii. Expert system compares received data with preconfigured threshold
iii. Expert system sends command to the hand held device to blink red, orange or green.

Extensions

If at any time the device fails, enforcement officer power cycles the device and takes the measurement again.

Special Requirement

RGB 'action' LED capable of displaying red or green light.

Use Case: Decode Recommendation LED Signal

Primary Actor

Enforcement Officer

Precondition

The hand held device has received control command from the expert system

Post Condition

The 'action' LED is blinking either Red, Orange or Green

Main Success Scenario

i. The hand held device receives command from expert system to turn on the RGB LED on in a certain color
ii. This command is passed from the GSM shield to the Arduino UNO microcontroller
iii. The 'action' LED blinks either Red, Orange or Green.

Extensions

If at any time the device fails, enforcement officer power cycles the device and takes the measurement again.

4.4.2 Context Diagram

A context diagram is the first data flow diagram in every process. It shows the context in which the system fits as just one process. It shows all the external entities that receive information from or contribute information to the system.

The context diagram for the model of this study is shown Figure 4.3 and shows the context in which the model will operate. The enforcement officer reads the carbon monoxide level, which is processed by the system, and the system gives back a recommendation:

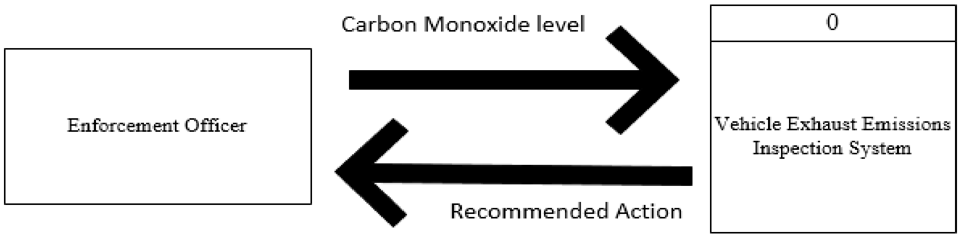

Figure 4.3 Context Diagram

4.4.3 Level 0 Data Flow Diagram

A level 0 Data Flow Diagram shows all the major processes that comprise the overall system: that is, the internal components of process 0 and illustrates which external entities interact with which major processes. Shown in the next page, Figure 4.4 shows how the major processes in the model, that is, capture carbon monoxide data, process carbon monoxide data, encode recommendation signal and decode recommendation signal processes are interrelated by data flows.

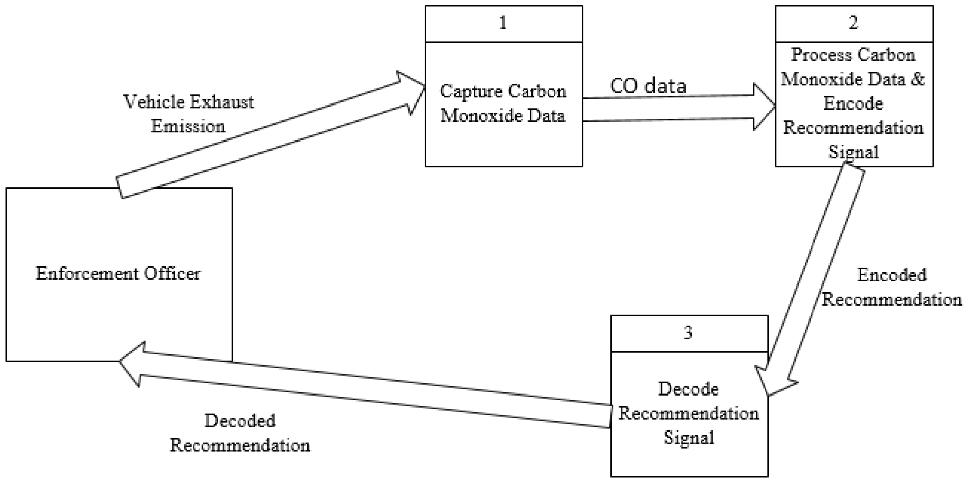

Figure 4.4 Level 0 Data Flow Diagram

4.4.4 Sequence Diagram

A sequence diagram is part of a bigger family of diagrams referred to as interaction diagrams. A sequence diagram illustrates interactions in a fence format where each new object is placed to the right. It serves best to show the sequence or time ordering of messages flowing within the model.

The vehicle exhaust emissions inspection system can be represented in a sequence diagram as shown on the next page in Figure 4.5. The inspection officer powers on the hand held device and initiates the 'Take Carbon Monoxide Reading' process. The device blinks green to indicate that a reading has been successfully obtained. Data transfer to the backend is then initiated by the device to the Expert System in the cloud. This system then sends back a recommendation to the device which indicates the action to be taken by blinking the relevant LED on the device.

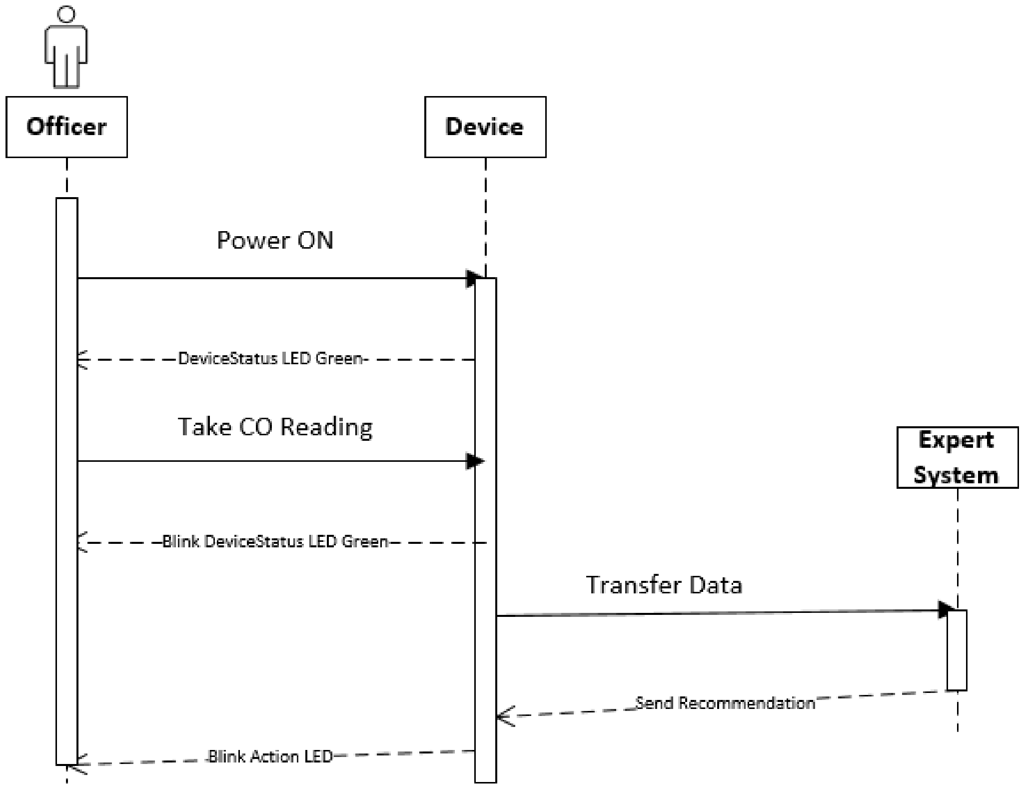

Figure 4.5 Sequence Diagram

4.5 Hardware Design

The hand held device will comprise the components listed below:

i. Arduino Uno Revision 3 Microcontroller
ii. GSM shield
iii. 9 Volts direct current battery power source
iv. 2 Red Green Blue Light Emitting Diodes: one to indicate device status and the other to give recommendation
v. Resistors
vi. MQ-7 Carbon Monoxide gas sensor
vii. A reset push button

These components were wired as shown in the diagram Figure 4.6:

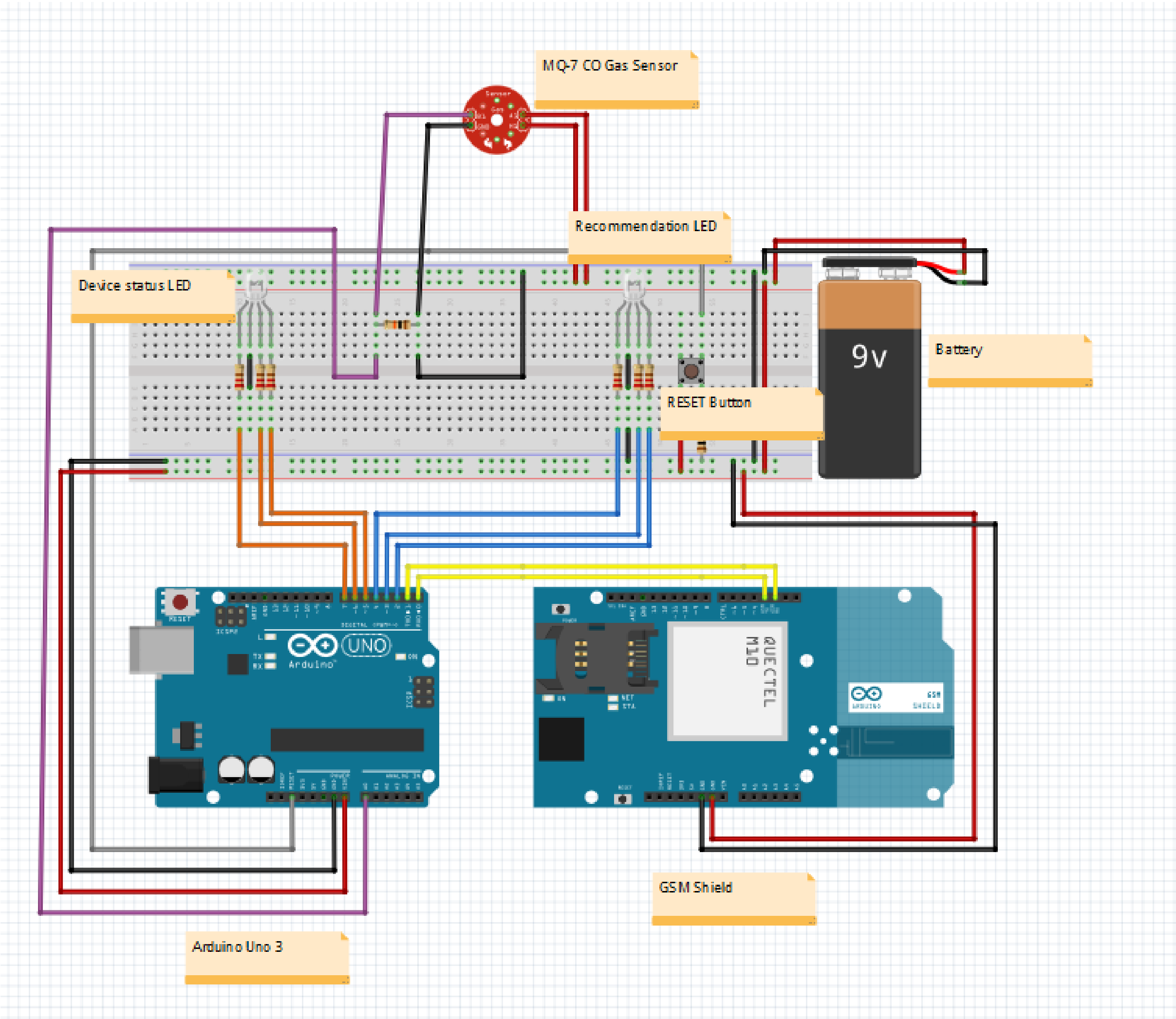

Figure 4.6 Hardware Design

4.6 Expert System Design

The Expert System, which will be set up on the cloud server, will run comparison between the data collected by the sensor (Carbon Monoxide level detected in the vehicle exhaust) against the threshold of 1.0% by volume. This server will blink either a green, orange or red light on the inspection device depending on the degree of carbon monoxide measured.

Data to train the Expert System rules will be primarily collected from the National Environment Authority's standards literature that dictate the levels of Carbon Monoxide that should not be exceeded by vehicles on the road. This will guide the definition of the three classes: dangerous (blink red on the device)– meaning that the vehicle should not be on the road and should be immediately impounded, allowable (blink amber on the device) – meaning the car exceeds the safe limit by an allowable margin but needs to be repaired and availed for inspection within some predetermined length of time and safe (blink green on the device) – meaning that the vehicle's exhaust emissions contain a safe level of carbon monoxide.

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
```

Chapter 5: Implementation and Testing

5.1 Introduction

The model was implemented through several steps: the first was wiring up the breadboard for the carbon monoxide sensor calibration, the second was wiring the GSM shield board to the microprocessor board and testing the network, the third was configuration of the back-end server and finally ensuring data sent from the microprocessor is received at the backend.

5.2 Model Components

The model involved various components each of which required to be wired and configured which can be largely classified as hardware components and software components and are described in the sections 5.2.1 and 5.2.2.

5.2.1 Hardware Components

- **Sensor:** The model employed an MQ-7 Carbon Monoxide sensor. This sensor employs a heated electrode to measure the concentration of the gas ranging between 10 – 10,000 parts per million.
- **Push buttons:** These were used as the 'RESET' and 'POWER' buttons for the model.
- **Light Emitting Diodes:** Two of this were used. One to show the current status of the model and the other to blink a recommendation back to the user.
- **Power Source:** A 9 Volts direct current battery power source was used.
- **Arduino Uno:** This was used as the microcontroller for the model
- **SIM900 GSM shield:** This was mounted atop the Arduino Uno microcontroller and provided GPRS connectivity to send data to the backend server.

5.2.2 Software Components

- **Arduino Integrated Development Environment:** This environment was used to write the code and upload it to the Arduino microcontroller.
- **IBM Bluemix:** This provided the IoT as well as data analytics platforms to support the backend server operations.

5.3 Model Implementation

5.3.1 Sensor Calibration

The sensor required a period of at least 48 hours to burn in the electrode to ensure proper measurements. The sensor also has an inbuilt potentiometer that controls the sensitivity. This was set to the mid position to ensure a fair trade-off. The circuit that was used to burn in the sensor is shown in Figure 5.1 in the appendix.

A picture of the code that was used to burn in the sensor and test the outputs is shown in Figure 5.2:

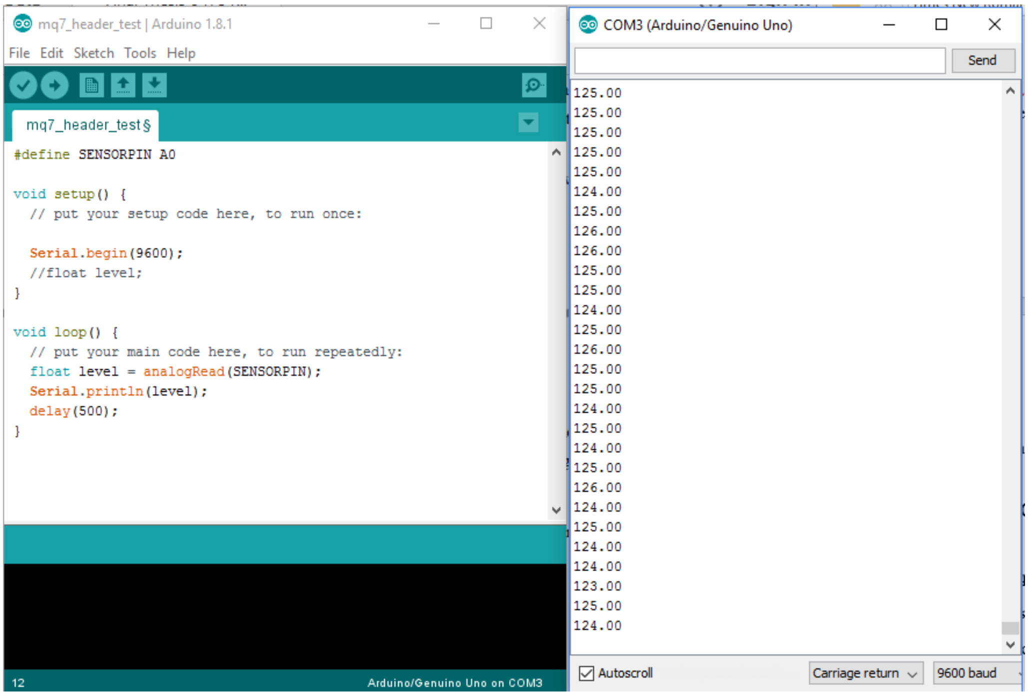

Figure 5.2 Sensor Burn-in Code & Output

5.3.2 Sensor Value Conversion

The Arduino microcontroller maps the output from the sensor (0 – 5V) into integer values between 0-1023. This yields a resolution between readings of: 5 volts / 1024 units or, .0049 volts (4.9 mV) per unit. To convert this output value to parts per million:

$$vol = sensorVal * (10000-10)/1024$$

Where:

- vol is the parts per million representation of the detected carbon monoxide
- the values 10 and 10,000 are bounds for the sensitivity of the FC-22 MQ-7 Carbon Monoxide sensor

- sensorVal is the value of the sensor reading.

5.3.3 GPRS Communication

A SIM Card from mobile phone service provider was inserted into the SIM900 GSM shield and the shield was mounted atop the Arduino microcontroller as shown in Figure 5.3 in the appendix. The code was uploaded and the serial terminal was monitored to ensure connection. This connection was successful as shown in Figure 5.4:

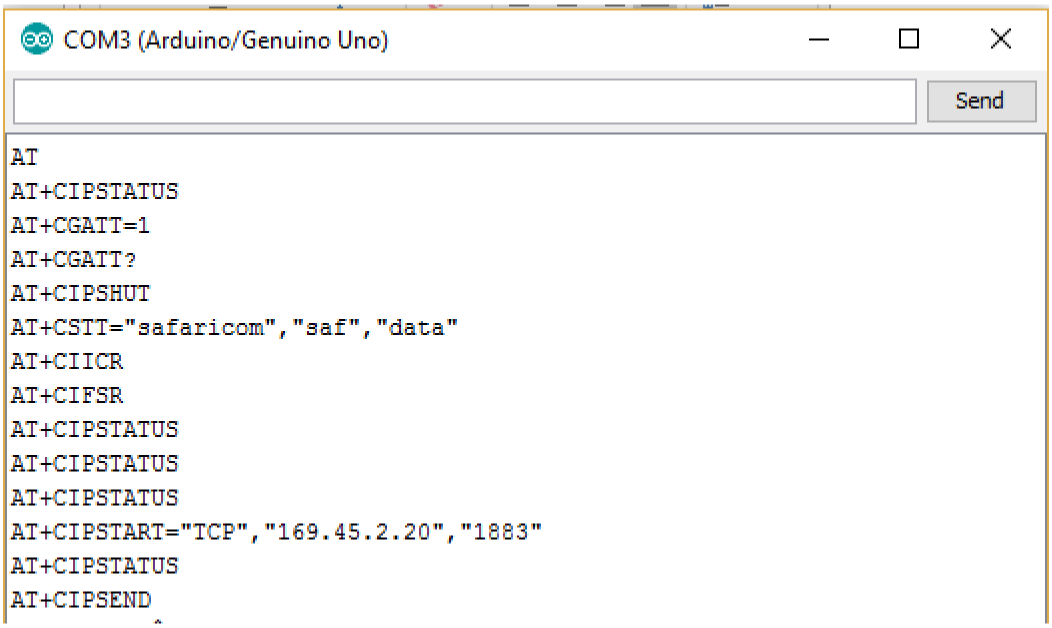

Figure 5.4 SIM 900 GSM Connection to IBM Bluemix

5.3.4 Back-end Server Implementation

IBM Bluemix was chosen to host the back end processing. This provides an IoT platform that is specialized to Internet of Things and embedded systems.

5.3.4.1 Device Creation

A device was created on the IBM Watson IoT platform to represent the Arduino node. This device was configured with a property that represents the value of the sensor. This is shown in the diagram on Figure 5.5 in the appendix. The 'level' property represents the level of carbon monoxide as measured by the sensor from the Arduino node.

5.3.4.2 Sensor Data on the Cloud

After the device was created, a connection test was done and data was received on the Watson platform as per the connection log in Table 5.1:

Connection Log

This shows the 10 most recent log messages **Refresh**

Message	Timestamp
Closed connection from 105.48.133.40. The connection has completed normally	Apr 3, 2017 1:22:29 PM
Token auth succeeded: ClientID='d:qwzv7p:co-mon:comon1', ClientIP=105.48.133.40	Apr 3, 2017 1:22:07 PM
Closed connection from 105.167.206.191. CONNECT must be the first message in a connection.	Apr 3, 2017 1:20:36 PM
Token auth succeeded: ClientID='d:qwzv7p:co-mon:comon1', ClientIP=105.167.206.191	Apr 3, 2017 1:20:28 PM
Closed connection from 196.96.37.58. The connection has completed normally	Mar 29, 2017 12:23:01 PM
Token auth succeeded: ClientID='d:qwzv7p:co-mon:comon1', ClientIP=196.96.37.58	Mar 29, 2017 12:22:40 PM
Closed connection from 105.161.242.137. The connection has completed normally	Mar 28, 2017 12:30:35 PM
Token auth succeeded: ClientID='d:qwzv7p:co-mon:comon1', ClientIP=105.161.242.137	Mar 28, 2017 12:30:14 PM
Closed connection from 196.96.106.132. The connection has completed normally	Mar 28, 2017 12:29:33 PM
Token auth succeeded: ClientID='d:qwzv7p:co-mon:comon1', ClientIP=196.96.106.132	Mar 28, 2017 12:29:12 PM

Table 5.1 Node Connection Log on IBM Watson IoT Platform

5.3.4.3 Rules Definition

As noted earlier in this document, a rule-based Expert system will be used to guide the user on the best cause of action given the level of carbon monoxide detected in the vehicle's exhaust gas.

The outline of this rule based ES is:

```
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
```

This was configured on the Watson IoT platform as shown on Figure 5.7 in the appendix.

5.4 Model Testing

This process involved testing the functionality and reliability of the proposed model. Several parameters were used to test the model developed as illustrated in Table 5.1:

Table 5.1 Model Testing

Test Class	**Inspection Check**	**Priority**
Functional	Does the model connect in a timely manner to the backend server	HIGH
Functional	Does the model communicate the correct sensor readings	HIGH
Reliability	Does the Model reconnect quickly in case of a disconnection	HIGH
Usability	Does the model turn on the correct LED Color given the level of CO detected	HIGH

5.4.1 Model Testing Results

The results of the above tests are tabulated in Table 5.2:

Table 5.2: Model Testing results

Test Class	Test Results	Comment
Functional	Pass	The model is able to connect and upload data in less that 30seconds via GPRS
Functional	Pass	Correct sensor data is communicated to the server. This was monitored on a serial terminal
Reliability	Pass	The node is able to re-establish a failed connection
Usability	Pass	Correct LED color turned on. High levels of Carbon Monoxide simulated using a potentiometer.

5.5 Model Validation

The model was validated alongside conventional testing methods used at National Environmental Management Authority. The validation tests were largely classified as high Carbon Monoxide level test – which tested the model's readings against those of NEMA against a vehicle with high Carbon monoxide, Medium and Low Carbon Monoxide level test.

The carbon monoxide volume was rounded off to the nearest hundred since that was sufficient to determine the accuracy of the model and to provide for easier calculation. Details of the vehicles and the data collected from them is tabulated in Table 5.2:

Table 5.2: Model Validation

	Vehicle Make & Model	Carbon Monoxide Level in Exhaust (ppm)	ppm from Model
1.	Isuzu TFR Lorry	11,000	8,000
2.	Nissan B12	6,200	6,500
3.	Toyota Caldina	3,000	3,500
4.	Nissan March	2,400	2,500
5	Mitsubishi Canter	7,700	8,100
6.	Toyota Corolla	3,600	4,300
7.	LandRover 110	12,000	10,000
8.	Toyota Celica	6,400	7,200
9.	Suzuki Vitara	10,500	9,200
10.	Toyota Corolla	7,300	7,500
11.	Nissan Sunny	10,500	10,000
12.	Toyota Hiace	16,000	9,800

The class boundaries are:

i. Low CO Level: 0 – 4,999 parts per million

ii. Medium CO Level: 5,000 – 9,999 parts per million

iii. High CO Level: Above 10,000 parts per million

The results are as tabulated on Table 5.3 in the next page. A total of 12 samples were observed:

Table 5.3: Model Validation Results

Tests	Correctly classified	Incorrectly classified	Percentage passed	Percentage Failed
High CO level	4	1	80	20
Medium CO level	5	0	100	0
Low CO level	2	0	100	0

The percentage passed show the percentage of the times that the model gave a reading that is approximately equal to that of the conventional testing equipment. The percentage failed on the other hand, show the percentage times that the model gave a reading that exceeded or was less than what the conventional equipment gave.

This data is represented in a confusion matrix on Table 5.4:

Table 5.4: Model Validation Confusion Matrix

		Results from Model			
		High CO Level	**Medium CO Level**	**Low CO Level**	**Total**
Results From Conventional Testing Method	**High CO Level**	4	1	0	5
	Medium CO Level	0	5	0	5
	Low CO Level	0	0	2	2
Total		4	6	2	**12**

From this matrix:

i. Total number of samples is 12 vehicles

ii. Total classified correctly is 11 / 12 vehicles

iii. Total classified incorrectly is 1 / 12 vehicles

Therefore, model accuracy can be determined to be 91.66%

Chapter 6: Discussions & Future Works

6.1 Introduction

The model of vehicle exhaust emissions was implemented using an Internet of Things approach. This model was considered more suitable in comparison to others in the research due to its light weight and portability which can enable enforcement officers to inspect vehicles on the road. There is currently no method being used by the National Environment Management Authority to enforce vehicle emissions standards on the road as a way of curbing air pollution.

This model therefore presents a way to accurately determine the level of carbon dioxide being emitted by a vehicle. The use of colored light emitting diodes provides an easy way to interpret the recommendation based on the sensor reading and eliminates any kind of ambiguity or manual intervention.

6.2 Summary

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 provides a novel way to not only remove unroadworthy vehicles from the road but also lower the overall air pollution.

Moreover, this model goes to show the pervasive nature of the Internet of Things concept and its applicability in many spheres. As more sensors are developed, the possibilities of greater interaction with the environment increases and consequently, the information that can be gleaned from the data increases exponentially.

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. This data can also be used to predict the resale value of a vehicle given the trend of its exhaust emissions.

6.3 Future Works

This model can be extended further in various ways to address the shortfalls noted above as well as adding more functionality and practicality. More sensors can be incorporated 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.

In addition, the model is very sensitive to weather, for instance, humidity, wind and so on. Sensors that can withstand better these elements can be used to build a more rugged device that can be used regardless of the prevailing weather.

6.4 Contribution of the Model to Research

Given the challenges that the enforcement agencies have experienced in attempting to keep unroadworthy vehicles off the roads, this model provided them with a portable gadget whose accuracy compares favorably with that of the conventional equipment. This model also puts to the fore the possibilities that are laid bare by the Internet of Things paradigm and shows how pervasive its application is.

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Appendix

Originality Report

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Questionnaire / Interview Guide

Vehicles are a great cause of air pollution	**YES**	**NO**
CO is one of the most dangerous gases emitted by vehicles	**YES**	**NO**
Measurement of CO in exhaust emission is representative of a vehicles roadworthiness	**YES**	**NO**
How are emission tests carried out?	**Lab environment**	**Open air**
Lab environment tests are prone to manipulation & therefore incorrect readings	**YES**	**NO**
There exists a portable device to measure CO from vehicle emissions	**YES**	**NO**
If No above; a portable device would help reduce the number of unroadworthy vehicles on the roads and therefore reduce air pollution	**YES**	**NO**

1. What other data can be collected from vehicles to establish its roadworthiness?

   ……………………………………………………………………………………..

2. What other data can help track a vehicle down once it has been categorized as unroadworthy:

a. ………………….

b. ……………………

c. …………………….

Interview Feedback

i.

Interview Guide

Vehicle Exhaust Emissions Inspection System for Roadworthiness Enforcement

Vehicles are a great cause of air pollution	**YES** *X*	**NO**
CO is one of the most dangerous gases emitted by vehicles	**YES** *X*	**NO**
Measurement of CO in exhaust emission is representative of a vehicles roadworthiness	**YES** *X*	**NO**
How are emission tests carried out?	**Lab environment** *X*	**Open air** *X*
Lab environment tests are prone to manipulation & therefore incorrect readings	**YES** *X*	**NO**
There exists a portable device to measure CO from vehicle emissions	**YES**	**NO** *X*
If No above; a portable device would help reduce the number of unroadworthy vehicles on the roads and therefore reduce air pollution	**YES** *X*	**NO**

1. What other data can be collected from vehicles to establish its roadworthiness?
   i. *Nitrogen Oxide*
   ii. *Particulate Matter*
   iii. *Sulphur Content*

2. What other data can help track a vehicle down once it has been categorized as unroadworthy:
   a. *Make & Model*
   b. *Driver's Details*
   c. *Owner's Details*
   d. *Class ie. Lorry, PSV, personal etc*

ii.

Interview Guide

Vehicle Exhaust Emissions Inspection System for Roadworthiness Enforcement

Vehicles are a great cause of air pollution	**YES** *X*	**NO**
CO is one of the most dangerous gases emitted by vehicles	**YES** *X*	**NO**
Measurement of CO in exhaust emission is representative of a vehicles roadworthiness	**YES** *X*	**NO**
How are emission tests carried out?	**Lab environment** *X*	**Open air** *X*
Lab environment tests are prone to manipulation & therefore incorrect readings	**YES** *X*	**NO**
There exists a portable device to measure CO from vehicle emissions	**YES**	**NO** *X*
If No above; a portable device would help reduce the number of unroadworthy vehicles on the roads and therefore reduce air pollution	**YES** *X*	**NO**

1. What other data can be collected from vehicles to establish its roadworthiness?
   i. *Nitrogen Oxide*
   ii. *Particulate Matter*
   iii. *Sulphur Content*
2. What other data can help track a vehicle down once it has been categorized as unroadworthy:
   a. *Make & Model*
   b. *Driver's Details*
   c. *Owner's Details*
   d. *Class ie. Lorry, PSV, personal etc*

Figure 2.1 Nairobi City's Skyline appears smoggy. (Adapted from Muindi, 2013)

Figure 2.3 A Volkswagen Golf during an emissions test. (Adapted from Walker & Ruddick, 2016)

Figure 2.5 PEMS Analyzers and Sampling System on a Passenger Car. (Adapted from Majewski & Burtscher, 2011)

Figure 2.8 Arduino Uno. (Adapted from Arduino.com, 2016)

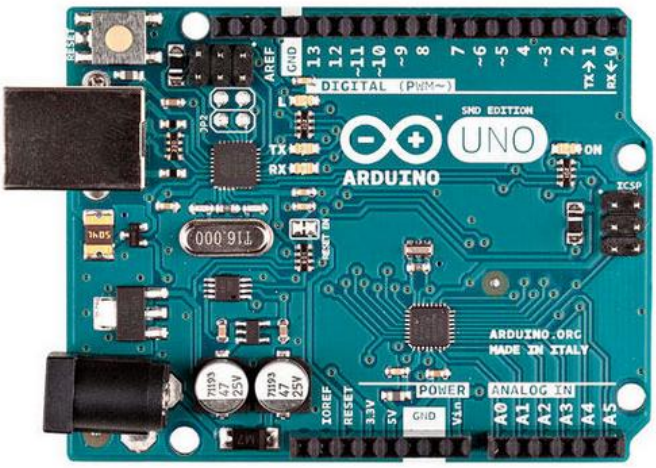

Figure 2.9 The Optical Dust Sensor. (Adapted from store.nerokas.co.ke, 2016)

Figure 2.10 MQ-7 Carbon Monoxide Sensor. (Adapted from store.nerokas.co.ke, 2016)

Figure 2.11 Arduino GSM Shield (Adapted from arduino.cc 2016)

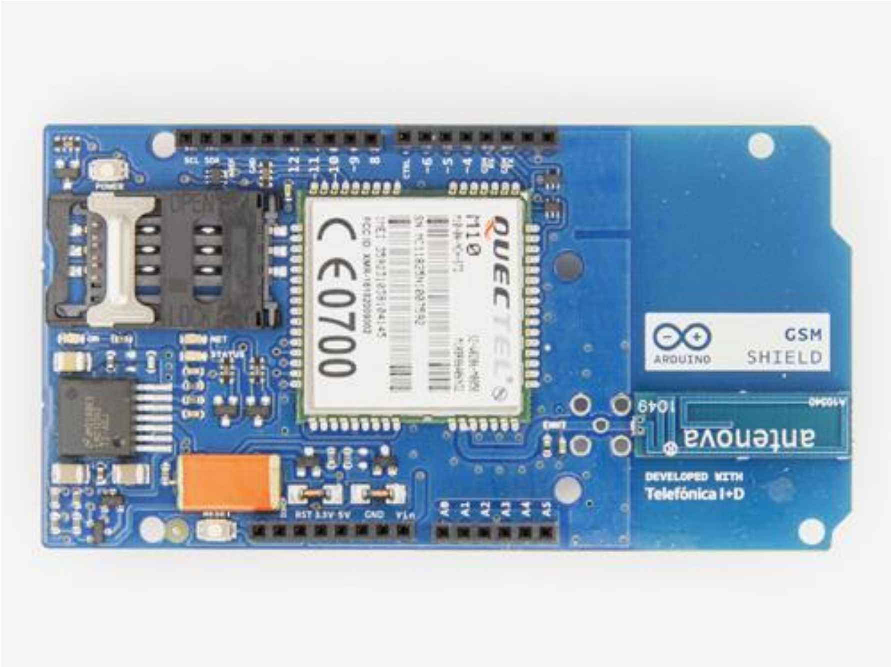

Figure 5.1 Sensor Burn-in Circuit

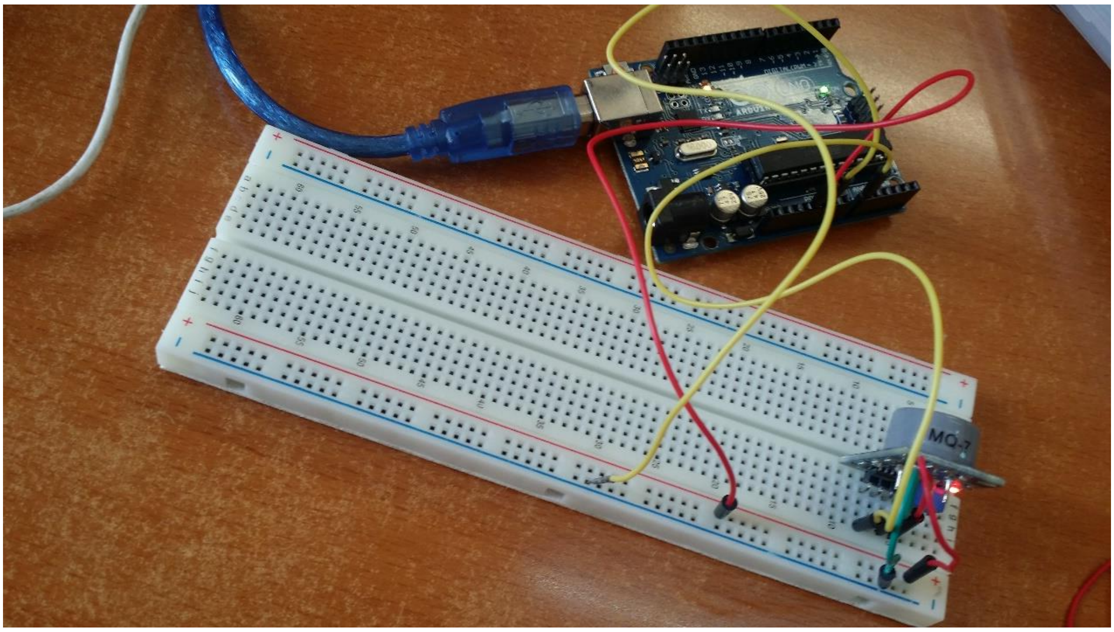

Figure 5.3 GSM Shield on Arduino MCU

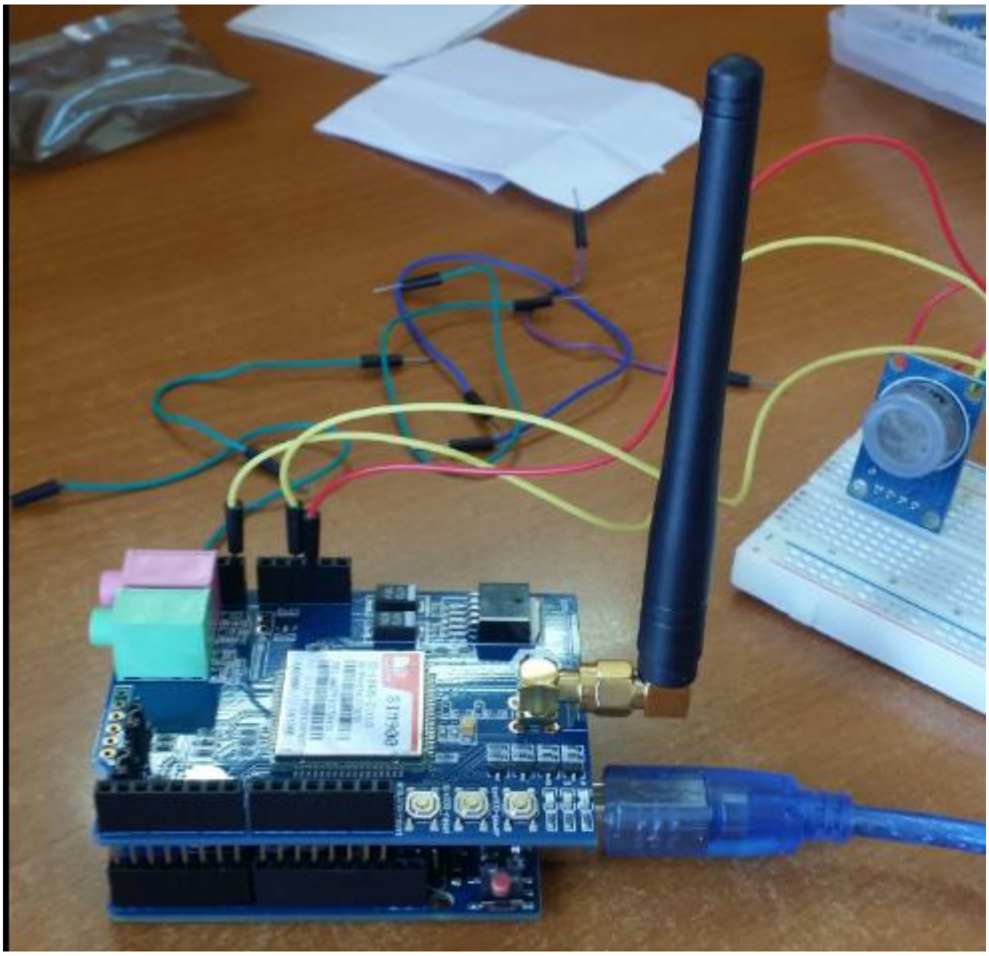

Figure 5.5 Device Creation on IBM Watson IoT Platform

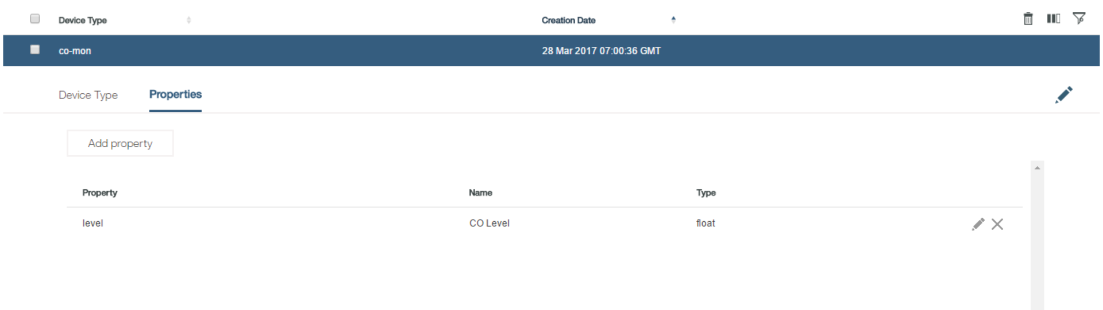

Figure 5.7 Rules Definition on IBM Watson IoT Platform