2017

Multi-sensor fire detection system using an Arduino Uno microcontroller

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A MULTI-SENSOR FIRE DETECTION SYSTEM USING AN ARDUINO UNO MICROCONTROLLER

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067482

Submitted in partial fulfillment of the requirements for the Degree of Master of Science of in Information Technology(Msc.IT) at Strathmore University

Faculty of Information Technology

Strathmore University

Nairobi, Kenya

June, 2017

Declaration and Approval

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 thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Zephaniah Shiwalo Obanda

……………... [Signature]

8th June 2017

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Abstract

Untimely response, constrained navigation due to poor urban planning and traffic jams, highly flammable construction materials, insufficient capacity by the fire department and lack of access to automated fire detection systems by residents due to purchasing costs are among the factors that affect fire-fighting services in Kenya and across the African continent. The aftermath of a fire outbreak could very acute leading to widespread loss of property and loss of lives. Residential areas contain numerous flammable materials such as clothing, books, wooden cabinets, beddings and plastics while also housing sources of ignition that include cooking gas and electronic devices thus are prone to severe fire accidents. Fire outbreaks have an inception period of about 3 to 5 minutes which is the optimal time to detect it and put it out after which it might get out of control. This implies that timely identification of a potential fire outbreak is crucial to managing it. Currently, most residential establishments as well as business premises are not fitted with fire detection systems owing to lack of awareness, high purchasing costs and inefficiency of the devices given the high false alarm rates which have a cost attached to them such as the unnecessary deployment of fire-fighting personnel. The fire detection devices are highly susceptible to false alarms because reliance on one sensor that reads only one percept from the environment for instance smoke or heat. However, the advancement of the Internet-of-Things has led to the development of 'smart' technologies where multiple sensors can be incorporated into objects like fire detectors additionally enabling them to communicate wirelessly with other objects and carry out programmed tasks. This research aimed at proposing a prototype of a fire detection system using a multi-sensor approach. This research applied rapid prototyping methodology for development of the prototype. Data was collected from secondary sources and experimentation. The prototype used an MQ2 gas sensor, a Grove temperature sensor, a Grove light sensor and an Arduino microcontroller, a GSM and GPS shield. In the event of a fire outbreak, the device will be able to send an SMS alert to the home owner as well as the firefighting department with GPS coordinates of the residence. The prototype recorded 83% success rate and 17% false alarm rate based on 6 test cases of which only one failed.

Acknowledgements

I would first like to immensely thank my supervisor Dr. Vitalis Ozianyi from The Faculty of Information Technology at Strathmore University for his consistent guidance and patience through the entire research period. I would also like to thank my mother Esther Mulinge, my father Dr. Ibrahim Shiwalo and my brother Daniel Mulinge for constantly motivating and supporting me. May God bless you all.

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Abbreviations/ Acronyms

IoT	**-**	Internet-of-Things
CO_2	**-**	Carbon dioxide
RADAR	**-**	Radio Detection and Ranging
Nm	**-**	Nanometers
PPM	**-**	Parts Per Million
AC	**-**	Alternating Current
DC	**-**	Direct Current
MQTT	**-**	Message Queue Telemetry Transport
SMS	**-**	Short Messaging Service
USB	**-**	Universal Standard Bus

Chapter 1 : Introduction

1.1Background information

Various trends exist in the world of information technology for instance those that involve the size and performance of microprocessors, those relating to the use of information technology in business and finally those that deal with the physical size of computer systems. However, a more interesting trend has developed over the years where by low cost microcontrollers with sufficient processing capabilities have been developed to connect to the Internet. Microcontrollers serve as a core component to the concept of the “Internet-of-things” commonly abbreviated as IOT (Pfister, 2011). The Internet-of-things (IoT) is a new revolution of the Internet. The main goal of IoT is to enable things (objects) to be connected anytime, anyplace, with anything and anyone ideally using any path/network and any service. The object or things mentioned above could be vehicles, doors, water sprinklers and much more. Objects make themselves recognizable and they obtain intelligence by making or enabling context related decisions thanks to the fact that they can communicate information about themselves (Vermesan, 2013).

The microcontrollers which have communication and data transfer capabilities through methods such as GSM and Bluetooth together with other devices such as sensors, have made IOT a reality today. IoT is largely used in home automation systems such a controlling thermostats, windows and various electrical gadgets. These capabilities can be extended to solving other problem areas in the world today one being that of accidental residential fire outbreaks.

Household/domestic fires have become a regular occurrence in the world today. The most common causes being cooking equipment, faulty electrical wiring, flammable fluids and children playing around with matches and lighters close to fire accelerants. In the United States for instance, between 2010 – 2014, cooking equipment was the leading cause of home structure fires (Ahrens, 2016). The Kenya Red Cross an International humanitarian organization in 2011 released a report which showed that Nairobi experienced 11 fatalities and more than 472 injuries as a result of major fire incidences. There were other smaller fires within the same year but with a lower number of casualties. 4667 households were razed down, destroying property and families needed urgent Humanitarian aid to salvage the situation (Kenya Red Cross, 2011).

Challenges such as congestion of the city leading to limited access routes, lack of toll free emergency lines, limited firefighting equipment as well as poor individual firefighting skills has have made firefighting an uphill task in the Kenyan context. Traffic jams and bad driver attitudes have also negatively impacted the timely arrival of the firefighting department (Mbugua, 2015). Most Kenyan households do not have basic firefighting equipment despite it being a requirement by the law increasing the risk of massive losses in case of a fire accident. Newer apartment complexes have however adopted fire extinguishers as the primary intervention against fire while overlooking any fire detection measures. Based on observation, despite the existence of fire detection devices, the adoption of these devices especially in Africa remains low. This is largely attributed to cost of acquisition and lack of enough awareness about how these devices are crucial because they could save lives and reduce losses related to accidental fires.

The purpose of a fire detection system is to gain immediate knowledge of a fire and to then minimize damage property. This can only be achieved if these devices operate with high reliability and accuracy. This is however not the case. Fire detection devices have myriads of challenges particularly high false alarm rates and the lack of “intelligence” that IoT seeks to introduce to such objects (devices). In most cases, the high false alarm rate is due to the fact that these detectors rely on a single sensor to detect the presence of a fire which makes it susceptible to deceptive phenomena that might mimic a fire, while those that attempt to combine different sensors are relatively over-priced. Other reasons for the false alarms include equipment failure, human error and malice. In countries such as Switzerland that have adopted fire detection devices, 85% False Alarms to 15% Real Alarms is the lowest known rate recorded by the devices as at 2014 with countries like Sweden recording values as high as 94% (Rutimann, 2014).

It is clear then that the solution to this problem pegged on the modernization and upgrading of fire detection devices. Therefore, it is coherent that a prototype of an intelligent residential fire detection system that is more accurate in detecting fires, has timely interventions such as alerting fire response personnel, is cost effective and that can transmit data to a server is developed. This data if collected over time can be mined and used to improve the efficiency in fire and emergency response teams across the globe. The evolution of the Internet of things has brought along low cost hardware particularly micro controllers such as the Arduino Uno, transmitters, receivers and sensors for instance the flame and temperature sensors that are able to be customized and programmed to detect accidental fire outbreaks. This research aims at harnessing these capabilities and using them to combat the challenges facing fire detection.

1.2 Problem Statement

Residential properties in Kenya and around the world are prone to fire which often causes numerous losses especially if the fire spreads to neighboring homes. Secondly, nuisance alarms and false alarms have been a long-standing problem facing fire alarm professionals as well as fire detection devices especially smoke detectors (System Sensor, 2016). The response by the firefighting department is often slow and unreliable owing to the fact that the department is underequipped. In case of a residential fire, the level of unpreparedness by individual home owners is alarming because most residences are not fitted with firefighting systems. Insufficient data and reports on fire accidents due to the lack of technology incorporation into the fire rescue services is also a long standing problem across many fire departments not just in Kenya but across Africa. The aftermath of residential fires to families is often monumental resulting into major losses. The above problems can be mitigated by developing a modern yet simple multi-sensor fire detection system that is reliable, can detect a real fire and has a low false alarm rate.

1.3 Research Objectives

i. To establish the behavioral characteristics of fire including causes and interventions.
ii. To investigate the challenges associated with fire-fighting and response services.
iii. To review existing techniques applied in the detection of fire at residential level and review their challenges.
iv. To develop a prototype that incorporates multiple sensors to detect residential fire outbreaks.
v. To test the developed prototype.

1.4 Research Questions

i. What are the major causes of residential fires?
ii. What are the major challenges faced by fire-fighting departments?
iii. What solutions exist in combating residential fire emergencies and what limitations do the solutions have?
iv. How can a smart residential fire management system be developed?
v. How can the proposed fire detection prototype be tested?

1.5 Justification

The Kenya Red Cross places the number of lives lost globally at 230,000. The organization launched an innovation challenge on its official website whose main aim is the development of feasible solutions to fire menace showing the severity of fire as a threat (Kenya Red Cross, 2015). In November 2014, ABC news network in the United States reported that research at Underwriter Laboratories has shown that modern construction such as engineered beams and wood materials which are cheaper and stronger have added to the danger of fire outbreaks since they are highly flammable. Furthermore, in 2015, there were 1,345,500 fires reported in the United States (National Fire Protection Organization, 2016). These fires caused 3,280 civilian deaths, 15,700 civilian injuries, and $14.3 billion in property damage. Kenya being a developing country, the likelihood of adopting modern construction technologies in the future to minimize cost as well prevent environmental degradation is high. This implies that fire is an impeccable danger not only faced now but bound to be severe if sustainable measures are not put in place to address it.

Given that the world is moving towards integration of physical objects ("Things") through the evolution of IoT, an opportunity arises to develop simple and affordable solutions to the fire problem based on this trend. The cost of installing residential fire detection systems is relatively high. This project will provide a more cost effective solution to the problem. It is important to note that the impact of fire not just at residential level can be catastrophic yet modern techniques are yet to be adopted in residential areas because contractors and individual owners of the apartments consider them expensive. This project bridges the acquisition gap by exploring the Internet-of-Things and creating a simple solution to this menacing problem.

1.6 Scope and Limitations

Despite there being several categories of buildings, this research mainly focused on residential buildings as opposed to business premises and factories which in most cases contain highly valuable and costly assets and thus might require a fire detection solution with very high performance standards. High performance standards therefore implies that costly devices have to be used to develop the prototype which goes against the researcher's goal of developing a cost effective solution. The developed prototype was tested using relatively small fires due to the risk that is attached to starting large fires in a building.

Chapter 2 : Literature Review

2.1 Introduction

The Internet of things is a growing area in technology today and as is widely applauded as the future of technology. The growth of smart cities for instance in the UAE, smart cars and other technologies with the ‘Smart’ tagline is an indication of this growth. Another indicator is the huge amount of resources deployed by companies such as IBM to facilitate research in this area. Various organizations and research associations have offered an extensive variety of projections about the potential effect of IoT on the Internet and the economy amid the following five to ten years. Cisco, for instance, projects more than 24 billion Internet–connected objects by 2019.

The Internet-of-Things (IoT) can therefore be defined as “the Internetworking of physical devices, vehicles (also referred to as "connected devices" and "smart devices"), buildings and other items embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data” (Internet Society, 2015). The expansive implementation of IoT devices guarantees to change numerous aspects of how we live. For shoppers, new IoT items like Internet empowered apparatuses, home automation devices and vitality administration devices are moving us toward a dream of having "smart homes", offering greater security and energy effectiveness of which this research looks to add to.

The new possibilities presented by the IoT trend can be used to solve myriads of problems among them the continuous rise of residential fires. 90% of fire damages occur due to lack of early fire detection. A fire outbreak is usually silent and people will know about the fire only when it has spread across a large area (Circuits Today, 2015). Fire disasters account for loss of lives and destruction of property worth millions of shillings not just in Nairobi County but around the globe.

2.2 History and the evolution of The Internet-of-Things

The Internet-of-Things (IoT) may be a trending topic at the moment but the concept itself is fairly not new. Kevin Ashton in the early 2000’s was laying the foundation at MIT’s Auto ID Lab for what is now referred to as the Internet of things. Ashton is one of the pioneers in this field where by he researched on ways in which Proctor and Gamble (A multinational manufacturer of family, personal and household products) could improve business performance by linking RFID information to the Internet. Lopez Research LLC (2013) outlined that” the whole idea was that if all objects in daily life were equipped with identifiers and wireless connectivity, these objects could be communicate with each other and be managed by computers".

Garfinkel (2005) stated that "Most histories of RFID trace the technology back to the radio-based identification system used by Allied bombers during World War II. Because bombers could be shot down by German anti-aircraft artillery, they had a strong incentive to fly bombing missions at night because planes were harder for gunners on the ground to target and shoot down. Of course, the Germans also took advantage of the cover that darkness provided. Early Identification Friend or Foe (IFF) systems made it possible for Allied fighters and anti-aircraft systems to distinguish their own returning bombers from aircraft sent by the enemy". The above systems, and their descendants today, send coded distinguishing proof flags by radio: An aircraft that sends the right flag is considered to be a companion, and the rest are enemies. Thus, radio frequency identification was conceived.

The evolution of IoT has been supported by the confluence of several technologies and market trends that have made it much easier to interconnect many and smaller devices more cheaply and easily. These are:

i. Wide spread adoption of IP based networking: The IP network standard which is a communication network based on the IP protocol is a global standard that ensures that data packets are transmitted and sent to the right destination over the Internet through routing has provided a well-defined and widely implemented platform of software and tools that can be incorporated into a broad range of devices easily and inexpensively.
ii. Computing economics: This has been largely driven by the investment by the players in the computing industry towards research, development and manufacturing. As a result, Greater computing power at lower price points and lower power consumption is a reality today (Moore's law).
iii. Miniaturization: Advances in manufacturing have allowed for cutting edge communication and computing technology to be incorporated into very small objects. This has also facilitated the development of small and cheap sensor devices which are the driving force behind most IoT applications
iv. Advancement in cloud based computing: Cloud computing, which leverages remote, networked computing resources to process, manage, and store data, allows small and

distributed devices to interact with powerful analytic tools in the back-end. Cloud services have also become cheaper supporting their wide-scale adoption.

v. Advances in Data Analytics: New algorithms and rapid increases in computing power, data storage, and cloud services enable the aggregation, correlation, and analysis of vast quantities of data; these large and dynamic datasets provide new opportunities for extracting information and knowledge.

vi. Ubiquitous Connectivity: High speed and Low cost access to the Internet using wireless connectivity has made almost everything “connectable”.

2.3 Fire Disasters and Accidents

Fires are the accidents which occur most frequently, whose causes are the most diverse and which require intervention methods and techniques adapted to the conditions and needs of each incident. Depending on the type of fire (nature of the material ablaze), meteorological conditions (wind) and the effectiveness of the intervention, material damage can be limited to a small area, or affect wide areas (forest or agricultural fires, hydrocarbons, gas or other highly flammable products, storage or piping installations) (International Civil Defence Organization(ICDO), 2016). Each type of fire is the object of specific technical prescriptions as regards prevention, intervention and the behavior of the population affected.

2.3.1 Fire development and behavior

A chemical reaction in which a carbon based material (fuel) mixes with oxygen, and is heated to a point where flammable vapors are produced is called a fire (Artim, 2014). The vapor that is produced can then come into contact with something that is hot enough to make it ignite and result into a fire. Residential areas contain numerous fuels such as clothing, books, wooden cabinets, beddings, plastic and much more. Residential areas also contain sources of ignition which implies anything that has the ability to produce heat. This includes cooking gas, air conditioning equipment and electric lighting.

When the source of ignition contacts the fuel, a fire can be set off. After the contact, a typical accidental fire begins as a slow growth (smoldering process). The “incipient” duration of the fire is dependent on a variety of factors including fuel type, its physical arrangement, and quantity of available oxygen. During this period heat generation increases, producing light to moderate volumes of smoke. It is during the incipient stage that early detection (either human or automatic), followed by a timely response by qualified fire emergency professionals, can control the fire before significant losses occur (Hartin, 2005).

Towards the end of the incipient period, there is usually enough heat generation to permit the onset of open, visible flames. Once flames have appeared, the fire changes from a relatively minor situation to a serious event with rapid flame and heat growth. Ceiling temperatures can exceed 1,000° C (1,800° F) within the first minutes. These flames can ignite adjacent combustible contents within the room. Within 3–5 minutes, the room ceiling acts like a broiler, raising temperatures high enough to "flash", which simultaneously ignites all combustibles in the room. At this point, most contents will be destroyed and human survivability becomes impossible. Smoke generation in excess of several thousand cubic meters (feet) per minute will occur, obscuring visibility and impacting contents remote from the fire. If the building is structurally sound, heat and flames will likely consume all remaining combustibles and then self-extinguish (burn out). However, if wall and/or ceiling fire resistance is inadequate, (i.e. open doors, wall/ceiling breaches, combustible building construction), the fire can spread into adjacent spaces, and start the process over

Effective fire suppression is reliant on extinguishing the blaze some time before, or instantly after, flaring combustion. If this is not done, the subsequent harm might be excessively serious, making it impossible to recuperate from. Amid the incipient time frame, a trained individual with a portable fire douser(extinguisher) might be a viable first line of defense against the fire. However, should an immediate response fail or the fire grows rapidly, extinguisher capabilities can be surpassed within the first minute. More powerful suppression techniques, either fire department hoses or automatic systems, then become essential.

2.4 Challenges facing fire response in Kenya

Ambassador Steve Mbugua who is the director of training at bloodlink foundation in a LinkedIn article asserts that the level of fire preparedness in Kenya calls for urgent measures from both the national and county governments. The growing population of Nairobi residents has significantly impacted on poor delivery of emergency services by out spacing the capacity of the services. Even though the fire departments are called in most of the cases, the firefighters are unable to get through the narrow, crowded streets (Mbugua, 2015). The key challenges can be summarized as:

i. Lack of enough firefighting equipment.
ii. Poor accessibility of residential areas due to unplanned development.
iii. Traffic jams and poor driver attitudes.
iv. Lack of firefighting skills among individuals.
v. Lack of a direct and toll free emergency lines.

Some of the solutions proposed for the above problems include:

i. There is need to have one or two unique toll free emergency numbers like 911 for all emergencies. This will sort out the communication lapse.
ii. Massive and continued Fire safety sensitization through the media, roadshows and forums to share information on disaster preparedness and response.
iii. Improve the capacity of the firefighting department.
iv. Implementation and continuous review of fire-fighting policies.
v. Proper city planning to ensure adequate roads and water access points that could come in handy in case of a fire outbreak.
vi. Regular fire drills to test the level of fire preparedness.

2.5 Existing fire detection, control and alarm systems

One of the key aspects in controlling a fire is timely detection of the fire as it has been determined earlier on in this research. The role of the fire detection alarm systems is precisely to ensure timely fire outbreak detection. This section discusses the various fire detection, control and alarm systems as well as their advantages.

2.5.1 Fire alarm systems

A fire alarm system is intended to enable a fire to be detected at a sufficiently early stage so that people who are at risk can be made safe either by escaping from the fire or by the fire being extinguished (David Goh & Kwek, 2005). (David Goh & Kwek, 2005) in their article add that fire alarm systems protect life and property detecting a fire at an early stage, alerting and evacuating occupants, notifying the relevant personnel, activating auxiliary functions e.g. smoke controls and lift homing.

2.5.1.1 Smoke based fire alarm systems

A smoke detector is a device that senses smoke, typically as an indicator of fire. The contribution in development of smoke detector was from research made by Walter Jaeger in 1930. In the early 1940's, the first smoke detector was developed by Meili and Jaeger that required high voltage power input. Then in 1965, Duane Persall created the first affordable home smoke detector that using individual battery powered that can be replace and install easily by the users. Francis Robbins Upton then invented the first automatic fire alarm in 1890 that give great contribution to today smoke alarm detector (Azmil, 2015).

(Fields Fire Prevention Inc., 2011) A member of National Fire Protection Association (NFPA) categorizes smoke detectors into 3 categories namely: ionization, photoelectric and a combination of both. A smoke detector is define as "a device that senses smoke, typically as an indicator of fire" (Gorli, 2017).

Ionization detectors

Ionization smoke alarms work by detecting the presence of large quantities of very small particles entering the ionization chamber, which when in sufficient quantity will cause an alarm to sound (Government of Western Australia, Deparment of fire and emergency services(DFES), 2012). The ionization smoke detector consists of an alpha particle producing a radioactive source, a smoke chamber, and charged detector plates. The alpha source causes the air within the smoke chamber to become ionized and conductive. As smoke particles enter the smoke chamber, the smoke particles attach themselves to the ionized air molecules and the air in the chamber becomes less conductive. When the air conductivity within the chamber drops below a predetermined level, the alarm is triggered (Fields Fire Prevention Inc., 2011).

Ionization smoke alarms are more prone to nuisance alarms from cooking (toasters, open grillers, birthday cake candles and the like) and should not be installed near kitchens (Government of Western Australia, Deparment of fire and emergency services(DFES), 2012).

Photoelectric detectors

System Sensor (2016) said that "Smoke produced by a fire affects the intensity of a light beam passing through air. The smoke can block or obscure the beam. It can also cause the light to scatter due to reflection off the smoke particles. Photoelectric smoke detectors are designed to sense smoke by utilizing these effects of smoke on light.

Photoelectric technology is generally more sensitive to the large smoke particles that tend to be produced by smoldering fires. In today's modern homes furnishings contain a significant amount of synthetic materials. These types of materials burn and give off large smoke particles. Sources of smoldering fires may also include poorly maintained electrical appliances or overloading power boards. (Government of Western Australia, Deparment of fire and emergency services(DFES), 2012) Notes that most residential dwelling fires tend to produce large amounts of visible smoke. The deparment of fire and emergency services in Australia thus concludes that that is why photoelectric smoke alarms are considered superior to ionization technology in providing early warning in a residential house fire.

2.5.1.2 Summary of smoke detectors

It is important to continuously test smoke detectors on a monthly basis to ensure that they are still in a good working condition. Some smoke detectors come with a test button that blows smoke into the detectors. Smoke detectors should be cleaned or vacuumed to avoid dust accumulation that affects their performance. Since smoke detectors are battery powered, best practice guidelines outlines that the battery should be replaced at least twice a year (Office of Prevention and Fire Control, 2014). Placement of detectors in any kind of building is key to the effectiveness of their functionality. (System Sensor, 2016) A manufacturer of smokes detectors affirms that smoke detectors should be installed in all areas of the protected premises. NPFA 72 (National Fire Alarm and Signaling Code) is a document that covers "the application, installation, location, performance, inspection, testing, and maintenance of fire alarm systems, supervising station alarm systems, public emergency alarm reporting systems, fire warning equipment and emergency communications systems (ECS), and their components" (National Fire Protection Association, 2013).

The National Fire protection Association (2013)The further outlines that "in general, when only one detector is required in a room or space, the detector should be placed as close to the center of the ceiling as possible. Central location of the detector is best for sensing fires in any part of the room. If a center location is not possible, the detector may be wall mounted within 12 inches from the ceiling if the detector is listed for wall mounting". Finally, smoke detectors should not be placed in excessively dusty or dirty areas, outdoors, excessively wet or humid areas, elevator lobbies and areas with combustion particles.

2.5.1.3 Thermal Detectors

Heat detectors are the oldest type of automatic fire detection device. They began with the development of automatic sprinkler heads in the 1860's and have continued to the present with a proliferation of different types of devices. Heat detectors are the least expensive fire detectors, have the lowest false alarm rate of all fire detectors. But are also the slowest in detecting fires. Heat detectors are best suited for fire detection in small confined spaces where rapidly building. High heat output fires are expected and in other areas where ambient conditions would not allow the use of other detection devices or where speed of detection or life safety are not the prime consideration (Bukwoski, 2010).

Heat detectors respond to the convected thermal energy of a fire and are generally located at or near the ceiling. They may respond either at a predetermined fixed temperature or at a specified rate of temperature change. 11 In general, heat detectors are designed to sense a prescribed change in a physical or electrical property of a material when exposed to heat.

2.5.1.4 Overview of Lumkani fire detection system

South Africa and more specifically Cape Town's largest slum, Khayelitsha is good example of a country that has adopted fire alarm systems as a measure to control devastating outbreaks. With displacement of over 5000 people on the 1st of January 2013 due to a fire outbreak, a group of students set out to design an alarm system that could stop future slum fires from spiraling out of control. The Lumkani Fire Detector as it was named functions differently as opposed to traditional fire detectors by using the rate of heat increase to determine the possibility of a dangerous fire. The detector also contains a cellular and radio network built into the alarm. So far, Lumkani devices have been installed in over 3,500 homes in South Africa, and have already protected two communities from dangerous fires (Rodriguez, 2014).

2.5.2 Advantages of fire detection systems

The main advantage of installing fire detection and alarm systems is the early warning benefit. The fire detection and alarm systems can be installed just about any where in a building (Honeywell International, 2015). Early warning is essential to effective fire safety because fires can occur anytime and any place. Subsequently, this aids in:

i. Increasing evacuation time for building occupants before a fire spreads out of control.

ii. Dispatching emergency medical help to those in need.
iii. Allowing fire department personnel to respond promptly.

2.6 Hardware design and web-based Communication modules of a real-time multi- Sensor fire detection and notification System

(Sowah, 2016), in a research publication published on the IEEE depository alongside two other researchers outlined an attempt to use a multi-sensor approach to fire detection. They affirm that the need to produce a more reliable fire detection system devoid of false alarms has led to the adoption of multi-sensor approaches. Unlike fire detection approaches relying solely on smoke, this approach relies on the detection of more than one fire signature. When a fire alert is detected, the system automatically reports them to the fire and rescue service and also notifies the owner(s) through SMS messaging on their cellphones. The system also provides the fire and rescue service with a map assisted navigation system to help locate the scene of a fire outbreak which is very helpful when there is poor house and street addressing system in a neighborhood.

2.7 Limitations of Fire Detection Systems

There are several fire-detection, alarm and signaling-system challenges. This sub-section looks at a few of the limitations faced by fire detection devices (systems) majorly those found in smoke detectors.

2.7.1 Smoke detectors

Nuisance alarms represent one of the most significant problems facing the fire alarm industry today and in particular smoke based detection systems. Each year, nuisance alarms result in countless service calls and fire department dispatches, not to mention millions of dollars in fines. Left unchecked, nuisance alarms can become life threatening for a building's occupants, as they may become confused between nuisance alarms and true emergency situations (System Sensors, 2007).

Nuisance alarms are not the same as false alarms. However, since nuisance alarms and false alarms both generate an alarm signal, the two terms are often misapplied. A nuisance alarm is caused by conditions resembling smoke, but are not generated by sources of fire. Examples include dust and steam. Conversely, a false alarm is the result of conditions that do not resemble smoke whatsoever, including defective products, vandalism, In 2007, in reference to Single- and Multiple-Station Alarms and Household Fire Alarm Systems, the NFPA 72 Technical Committee appointed a Task Group (TG) to review the effectiveness of smoke detection used in dwellings for life safety and escape. The report observed that Nuisance alarms are the leading cause of occupants disabling their smoke alarm. Secondly disabled smoke alarms account for 20% of the smoke alarms installed in U.S. homes. Thirdly, cooking is the leading cause of nuisance alarms. Fourthly, Ionization and photoelectric technology are both sensitive to cooking aerosols and finally. The report also observed that Ionization technology installed too close to a cooking appliance have a higher frequency of nuisance alarms than photoelectric type detectors. A nuisance alarm may be the activation of a properly functioning smoke detection device to a non-hazardous source not imminently threatening to life or property The occupants usually perceive the frequent nuisance alarms as annoying and disconnect the power from the smoke alarm.

2.7.2 Heat/Thermal detectors

Unlike smoke detectors that have an array of challenges, there are two main challenges faced by fire detectors that function based on heat. The first challenge is that they lack sensitivity. Usually, a fire has to be quite large before it can be detected. This significantly reduces the chances of salvaging a building experiencing a fire accident. Secondly, they are not suitable for places that could suffer heavy losses due to small fires e.g. computer rooms (Goh, 2014).

2.8 IoT Reference Model and Associated Technologies

In its simplest form IoT involves Sensors (Devices/Things), Connectivity and Intelligence. There are core technologies and standards that support innovation and research in the field of IoT. Understanding these technologies is key before any form of innovation is developed in this area. The IoT (Internet of Things) World Forum Architecture Committee that comprises leading Tech giants such as Cisco, IBM, Rockwell Automation, Oracle, Intel and an assortment of others recently published a seven tier IoT reference model/framework.

Beginning at the lowest level , there are physical devices and controllers (the things), then there is connectivity and, above that, edge computing where, for example, you might want to do some initial aggregation, de-duplication and analysis. These lower three levels can be considered operational technology (OT) whereas the remaining four levels are IT. The lowest level in the information technology part of the stack is storage and this is followed in turn by data abstraction, applications, and collaboration and (business) processes. Figure 2.1 below shows a simplified IoT Reference Model.

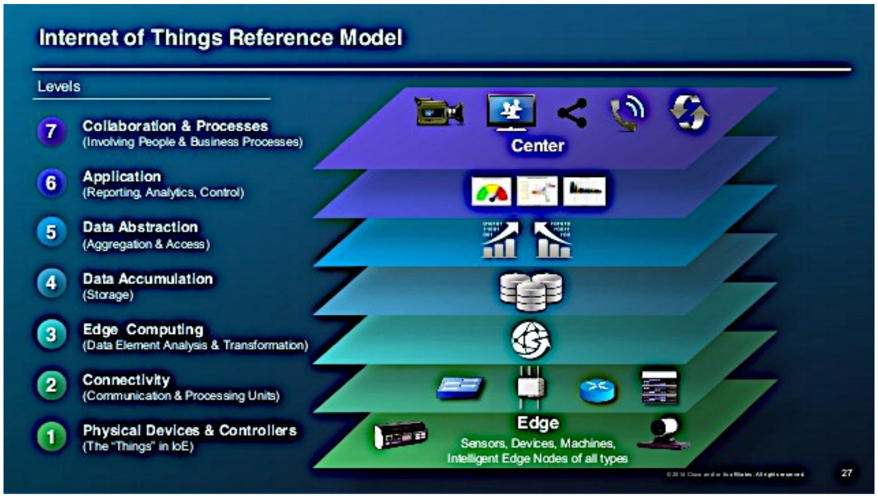


Figure 2.1 IoT Reference Model (Adapted from: Bauer, 2017)

2.8.1 Sensors

Most objects or "things" have operated in the "dark" for a long duration of time with information such as their location, state of operation and position staying hidden and unknown. Breaking this constraint has brought about the growth in IoT. Sensing systems comprise of several sub parts including micro-controllers, modem chips, power sources and other related devices. Sensors convert a non-electrical input into an electrical signal that can be sent to an electronic circuit.

The IEEE (2015) defines a sensor as "an electronic device that produces electrical, optical, or digital data derived from a physical condition or event". Data recorded from sensors is subsequently electronically transformed, by another device, into information (output) that is useful in decision making done by "intelligent" devices or individuals (people)". Every sensor has a technological complement called an actuator.

The actuator is a device that coverts an electrical signal into action, often by converting the signal into a form that may be non-electrical for instance motion in robots. For instance, motors which are a key part of this project are examples of actuators that convert electrical energy into mechanical energy. Sensors work differently and capture different types of information. Accelerometers for example measure linear acceleration detect the direction of movement within objects while gyroscopes deal with positioning and rotation of objects.

In order to achieve the maximum potential of sensor capabilities, combining them to create a complex system of sensors is mandatory. A good example is Canary which is a home security system that combines motion, light, temperature and humidity sensor. In the same system, computer vision algorithms analyze patterns in behaviors of people and pets, while machine learning algorithms improve the accuracy of security alerts over time

2.8.1.1 Types of Sensors

Sensors are mostly classified as active or passive based on their power sources. The active sensors such as RADAR units generate their own energy then sense the response of the environment to that energy. Passive sensors on the other hand receive energy that is produced external to the sensing device. Choosing the most suitable sensors for an application is dependent on but not limited to:

i. Accuracy: Accuracy is a measure of how precisely the sensor reports the signal in relation to the stimuli being captured. For instance, when soil temperature is 30 degrees Celsius, a sensor that reports 30.5 degrees Celsius is more accurate than one that reports 31 degrees Celsius.
ii. Range: This is the band of input signals within which a sensor can perform accurately. Signals beyond the specified range lead to inaccuracy and potential damage to the sensors.
iii. Repeatability: This implies that essentially when a sensor is fed with the same input under constant environmental conditions then the output should be consistent.
iv. Resolution: The smallest incremental change in the input signal that the sensor requires to sense and report a change in the output signal.

Table 2.1 Summary of Sensors

Sensor Types	Sensor Description	Examples
Position	The sensors are utilized to quantify the position of an object in either absolute terms or relative.	Potentiometer, Inclinometer, proximity sensor
Occupancy and Motion	They are used to detect the movement of people and objects while occupancy	Eclectic eye, RADAR

	sensors detect the presence e.g. people and animals in an area under surveillance.	
Velocity and acceleration	Velocity can be in terms of speed and motion. Velocity sensors can also be categorized as linear or angular indicating how fast an object is moving along a straight line or how fast it rotates. The second sensor measures changes in velocity.	Accelerometer, gyroscope
Force	These sensors are used to detect whether physical force has been applied and its magnitude.	Force gauge, viscometer, Tactile sensor (touch sensor)
Pressure	Pressure sensors measure the force applied by liquid or gases.	Barometer, bourdon gauge, piezometer
Flow	They measure the volume (mass flow) or rate (flow velocity) of fluid that has passed through a system in a given period of time.	Anemometer, mass flow sensor, water meter
Acoustic	Acoustic sensors are used for measuring sound levels.	Microphone, geophone, hydrophone
Humidity	Humidity sensors detect the amount of water vapor in the air or a mass.	Hygrometer, humistor, soil moisture sensor

Light	They are used to detect the presence on both visible and invisible light	Photo-detector, infrared sensor flame detector
Radiation	Radiation sensors detect radiations in the environment. Radiation can be sensed by scintillating or ionization detection.	Neutron detector
Temperature	These types of sensors measure the amount of heat or cold in a system. The measurements are done either by contact or non-contact temperature sensors.	Temperature gauge, calorimeter, thermometer
Chemical	Sensors under this category measure the concentration of chemicals in a system for instance Carbon dioxide sensors.	Smoke detector, Breathalyzer
Biosensors	These sensors detect a variety of biological elements such as tissues, cells and enzymes.	Blood glucose biosensor, pulseoximetry, electrocardiograph

2.8.2 Sensors for fire detection

Sensors used in fire detection devices nowadays include a large variety of sensors due to very different applications, cost levels, detection coverage and so on (Bogue, 2013). To effectively detect a fire, several sensors have to be incorporated into one system. Some of these sensors have been discussed below.

2.8.2.1 Optical smoke detectors

A smoke detector is defined as a device that senses smoke, usually as an indication of fire. Commercial security devices provide a signal to a fire alarm control panel as a functionality of a fire alarm system, while household smoke detectors, also known as smoke alarms, basically issue a local discernible or visual alarm from the detector itself (Cote, 2006).

2.8.2.2 Temperature sensors

These are the most common type of sensors and detect temperature or heat (Electronics Tutorials, 2014). As discussed earlier, temperature sensors can be broadly classified into two categories namely contact and non-contact sensors. The first category which is contact temperature sensors require physical contact with the objects to be measures such as solids and liquids. Non-contact sensors which are the primary preference for this research use radiation and convection to monitor temperature changes. A sensor comprises a system of different parts. In order to make a temperature sensor, the following parts are required: An Arduino board, LM35 temperature sensor, USB cable and a computer with Arduino software (Mojidra, 2014)

An Arduino board is a microcontroller that comes in different versions. The official Arduino website define Arduino as an open-source electronics platform based on easy-to-use hardware and software. The website goes further to explain that Arduino boards are capable of reading inputs e.g light on a sensor, a finger on a button, or a Twitter message and there after turn it into an output such as activating a motor, turning on an LED or publishing something online. You can tell your board what to do by programming and sending a set of instructions represented as functions to the microcontroller on the board. To achieve this, one needs to use the Arduino programming language (based on C++), and the Arduino Software (IDE) based on Processing. Arduino boards in particular simplify the use of microcontrollers because they are inexpensive, cross-platform and operate using a simple and clear operating environment.

The LM35 temperature sensors are precision integrated-circuit temperature devices with an output voltage linearly proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The key features of this sensor can be summarized briefly as:

Calibrated directly in Celsius (centigrade)

Rated for Full −55°C to 150°C Range

Suitable for Remote Applications

Operates from 4 V to 30 V

Low Self-Heating, 0.08°C in Still Air

Linear + 10-mV/°C Scale Factor

Less than 60-µA Current Drain

2.8.2.3 Flame Sensors

Flame sensors are primarily used fire detection within a short range. The working principle behind these sensors is sensitivity to the IR (Infrared) wavelength at 760nm – 1100nm (Reichenstein, 2014). One major advantage of these sensors is that they have a moderate false alarm rate but on the other end, they are affected by other infrared light sources such as sunlight hence their performance is affected.

2.8.3 Arduino GSM shield

The Arduino GSM Shield connects an Arduino to the internet using the GPRS wireless network. A GSM library contained in the Arduino IDE enables an Arduino board to do most of the operations you can do with a GSM phone: place and receive voice calls, send and receive SMS, and connect to the internet over a GPRS network (Arduino, 2014).

2.9 Challenges facing IOT devices

The IoT ecosystem requires interoperability to create the seamless programmability of the very devices or sensors that enables the full potential of a connected experience. This is one among many other challenges that face IoT as discussed below.

2.9.1 Security and Privacy

Physical security is a major challenge in IoT devices. This is because IoT devices are often left in the open, unattended and with no physical protection. You have to make sure they are immune to tampering by malicious parties and cannot be hacked and manipulated with a flat-head screwdriver. You also have to protect any form of data that is stored on the device. While it might be too expensive to embed a secure enclave in every IoT device, yet encrypting on-device data is important.

Data exchange security is the second area of concern. Securing data as it is being transferred from IoT sensors and devices to gateways and from there to the cloud is also important. This will require the use of encrypted transfer protocols, but IoT security is more than just encryption, and should also take into account authentication and authorization.

Cloud storage security is the final area under security. The data that isbeing stored in the cloud is just as vulnerable as the rest of the IoT ecosystem. Your platform should be able to protect the data that it stores in the cloud, which should include proper encryption and access control.

2.9.2 Connectivity

One of the first things to consider is how your IoT device will connect to the internet and the cloud platform. This will depend largely on the environment in which the device will be used, and the kind of communication infrastructure that will be available to it. For instance, if you're creating a smart home device (such as a connected toaster) you'll probably have access to a Wi-Fi home router or a ZigBee/Z-Wave IoT router, so your device will have to be able to support one or more of those transport mediums. However, in some settings — such as agricultural IoT or smart cars — there's no access to Wi-Fi networks, and cellular networks might be your only possible connection.

2.9.3 Flexibility and Compatibility

Integration of hardware and software from several vendors is one of the challenges faced by IoT developers. "Perhaps the hardest challenge to overcome is that of breaking silos between different disciplines and departments," notes Gary Mitchell, an industry-leading writer on automation, control, software, manufacturing, marketing, and leadership. He adds that "The famous 'IT/OT Convergence' that has been discussed for many years must happen" (Bisson, 2015).

It is important that your IoT device be able to blend in with the rest of the user's IoT ecosystem seamlessly, without adding complexity or frustration to the experience. This accounts for both software and hardware. For instance, consumers should not be forced to install a new app for every new smart device they add to their homes.

2.10 Application of fuzzy logic in fire detection

In any decision-making process it is necessary to evaluate different alternatives and discard those that do not fit certain previously established criteria. If the criteria are mathematically quantifiable, a mathematical model may be created for the evaluation process (Mitrani, 2003). In a multi-sensor fire detection system encompassing three different sensors, a decision as to whether there is a positive instance of a fire or not is dependent on the input provided by the three sensors. Fuzzy logic allows us to fuse data using a series of "IF-THEN" rules and get an output/ a decision.

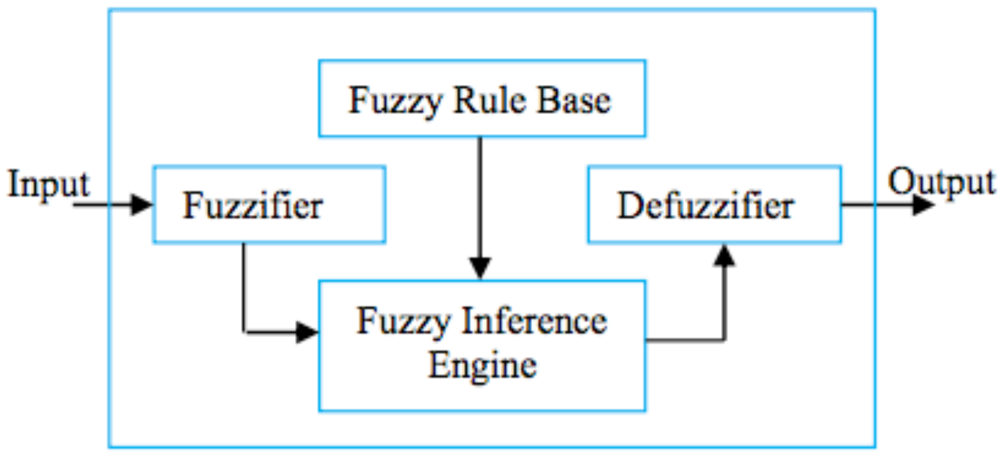


Figure 2.2 Fuzzy Logic (Loskivi, 2009)

Sowah (2014) proposes that considering the resource limited nature of the Arduino Uno microcontroller platform, three membership functions are to be chosen for each input in a multi-sensor fire detection system with 3 input sensors namely a smoke sensor, temperature sensor and flame sensor. He further adds that's when using an MQ2 gas sensor, the ambient smoke density data from the smoke sensor is to be grouped into three fuzzy sets (low, medium and high). Figure 2.3 below illustrates the three fuzzy sets including the actual values of each set.

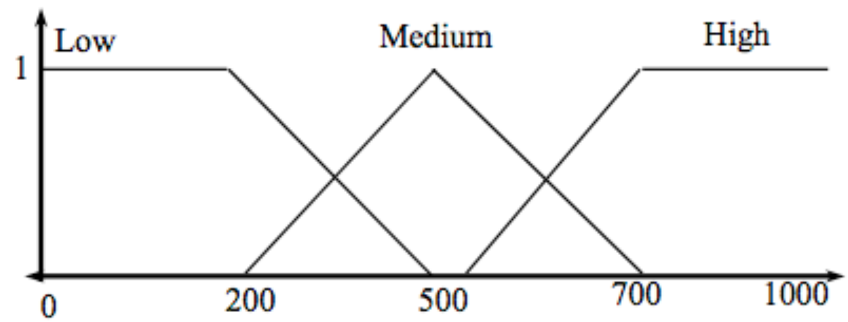


Figure 2.3 Fuzzy membership sets for Smoke Density (Krakani & Ofoli, 2016)

Figure 2.4 below shows the fuzzy sets for the ambient temperature. The temperature sensor readings have been classified into cold, normal and hot fuzzy sets. The range of possible values for the ambient temperature was set to 16^{o} C t o 90^{o} C.

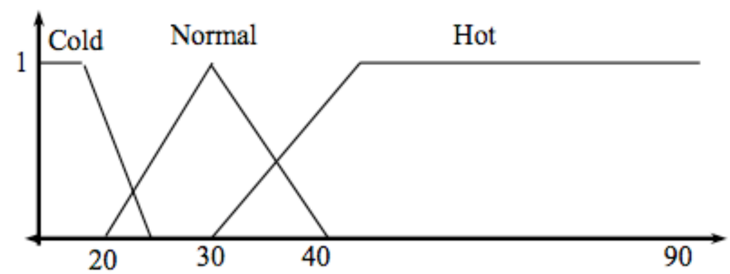


Figure 2.4 Fuzzy membership sets for Ambient Temperature (Krakani & Ofoli, 2016)

The fuzzy membership sets for flame intensity are as shown in Figure 2.5 below. Flame sensors rely on the UV radiation given off by flames. A large fire will give off more UV radiation and vice versa. The sensor output is also affected the proximity of the flame to the sensor.

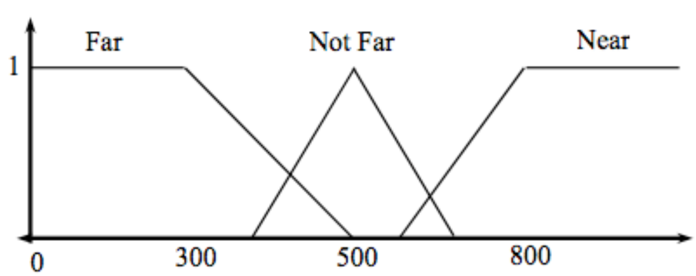


Figure 2.5 Fuzzy membership sets for Flame Intensity (Krakani & Ofoli, 2016)

2.11 Conceptual Model

Figure 2.6 below describes how the fire detection system works. An apartment is fitted with the multi-sensor fire detection device that is built using an MQ 2 gas and smoke sensor, a temperature sensor, a light intensity sensor, a GPS module and GSM shield. The MQ 2 gas and smoke sensor is used by the prototype to detect both an LPG gas leakage and smoke. LPG gas leakages are a potential cause of fire and the detection of the LPG gas is added to increase the accuracy of fire detection e.g if a leak is detected and immediately after temperatures are high then possibly a fire outbreak has occurred.

Thresholds are set on all the sensors such that when these thresholds match the current state in the room, a positive identification of a fire is made. An SMS alert is sent to the owner of the home as well as the fire department. Additionally, the fire department receives GPS coordinates that are entered into a third party application in order to get the exact location of the house experiencing the fire.

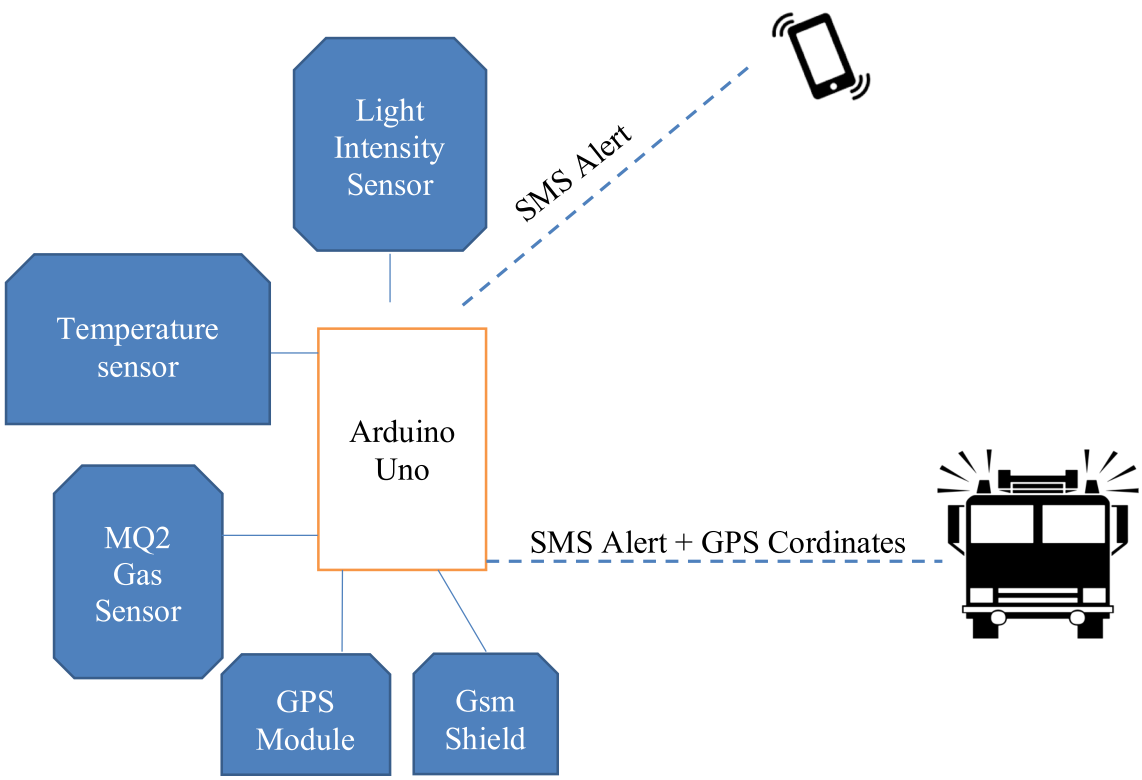


Figure 2.6 Conceptual Model

Chapter 3 : Research Methodology

3.1 Introduction

The procedures by which researchers go about their work of describing, explaining and predicting phenomena are called research methodology (Rajasekar & Philominathan, 2013). This chapter captures the research design used, target population of the study, the sample design, method of data collection, data analysis and presentation

3.2 Research Design

Applied research which was adopted for this research is designed to solve practical problems of the modern world, rather than to acquire knowledge for knowledge's sake (Lawrence Berkeley National Laboratory, 2014). The first activity that was carried out is defining and extensively discussing the research problem. This research identified a problem in the domain of fire accidents where there is need to innovate fire detection solutions that are more accurate and have a low false alarm rate.

The researcher then reviewed both conceptual literature concerning concepts and theories and empirical literature consisting of earlier studies, which are similar to the one proposed. Concepts and theories include those relating to IoT and the technologies that encompass it such as sensors and microcontrollers. This information aided in understanding the problem and consequently laid the foundation for the development of the proposed solution. Relevant data was subsequently collected and analyzed appropriately and sound conclusions were drawn.

3.2.1 Data Collection Tools

Research data is data that is collected, observed, or created, for purposes of analysis to produce original research results (Pyror, 2012). Therefore, the accuracy of research is hugely dependent on the kind and quality of data used. This research employed both primary and secondary data. Primary data can be defined as original research that is obtained through first-hand investigation and includes information collected from interviews, experiments, surveys, questionnaires, focus groups and measurements (Sapsford, 2006). The primary data used in this research was collected through an experiment. The experiment involved using an LM35 temperature sensor that recorded daily temperature readings for one week in a compartment (Apartment). The readings were recorded after every hour and aggregated on a daily basis. This data was later used to inform the development of the prototype. Experiments were also done using the MQ2 gas sensor and the Grove Light sensor. The results are discussed in Chapter 4 of this research.

Secondary data is a type of quantitative data that has already been collected and is available for use by other parties (Sapsford, 2006). In this research, this data was used to understand existing technologies used for fire detection and in particular those that apply IoT techniques. This data will be collected by review literature from credible sources such as the IEEE repository.

3.2.2 Data Analysis

The primary data which will be analyzed in this research is quantitative in nature and more specifically it can be classified as interval data. The data analysis manager that will be adopted for this research is Microsoft Excel. The researcher opted for Microsoft Excel because newer versions of the software provide powerful analysis and visualization tools. The process that will be adopted for the data analysis is as summarized in Figure 3.1.

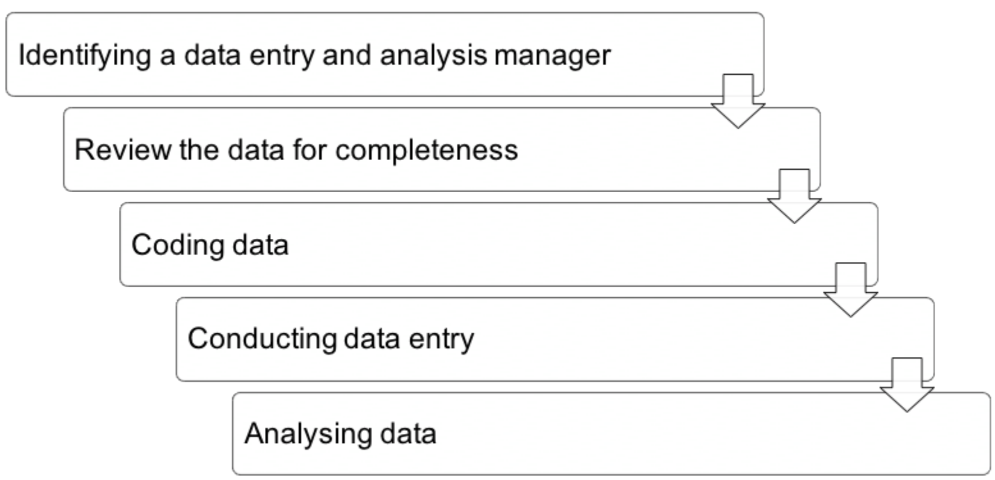


Figure 3.1: Data analysis process

The incipient step in the data analysis process was tabulation of the data in order to give a comprehensive picture of then data that aided in identification of patterns in the data. The data was then checked to ensure data integrity. Data integrity is a broad scope that covers both accuracy and consistency of the data. More specifically the data was checked for logical integrity to ensure correctness and rationality of the data which qualifies the data as usable. Finally, the data was entered into Microsoft Excel for analysis.

3.2.3 Data Presentation

Data presentation is a method of summarization, organization and communication of information using a variety of tools, such as diagrams, distribution charts, histograms and graphs (Alabi, 2013). Tabulation which involves presentation of data in tabular form was employed because of its ability to condense a large mass of data bring out distinct patterns in data in an attractive form. It enables comparison to be made easily among classes of data and takes up less space than data presented in narrative form. Diagrammatic presentation was used in this research particularly pie charts. The main advantages of pie charts is that they display relative proportions of multiple classes of data and are visually simpler than other types of graphs.

3.2.4 Prototype Development

Prototyping is the process of developing a trial version of system or its components in order to clarify the requirements of the system or reveal critical design considerations (Bieman, 2006). Rapid prototyping was used as the development methodology for this research. This method was adopted because of its two key advantages that include saving time and cost and allowing for easier incorporation of changes to the prototype. Figure 3.2 summarizes the prototyping structure adopted by the researcher during development

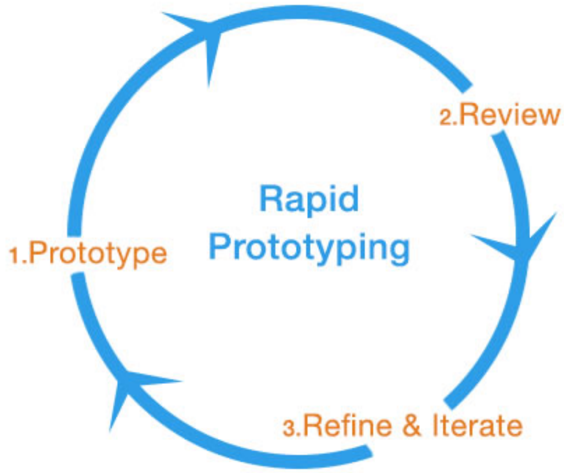


Figure 3.2 Rapid prototyping cycle (Adapted from: Chua, 2010)

The prototype was built by researcher one sensor unit at a time. The researcher first incorporated the smoke and gas sensor with the buzzer into the circuit, tested and validated the module and finally set the sensor thresholds for the sensor. He then proceeded to add the other sensors one by one in a similar implementation fashion as the incipient unit.

3.3 Population

A research population is generally a large collection of individuals or objects that are the main focus of a scientific query. The target population for this research is broad (any individual that owns a home or apartment) thus an accessible population representative of the target within Nairobi was derived using purposive sampling technique. A purposive sample according to (Palys, 2008) is a non-probability sample that is selected based on characteristics of a population and the objective of the study. Time constraints binding the researcher influenced the decision to use this sampling technique.

3.4 Sampling Design

This research aims at developing a reliable fire detection device for use at residential level not just in Nairobi but eventually across the world thus the main target for this research are home and apartment owners. According to Cytonn investments outlook report in early 2016, real estate both commercial and residential remained as the best form of investment and thus the rate of growth in the development of both mid and high end residential remains high. The researcher chose 10 individuals from different households as the purposive sample size for prototype acceptability testing(UAT). User acceptability testing was the last step in the prototype development process. This was done to ensure that the prototype can handle its required tasks in the real world scenario according to its specifications. Appendix L shows the user acceptability questionnaire used by the researcher.

3.5 Research Quality

The first criterion for whether a study is done well is reliability which is a measure of the consistency of scores over time (Goodfriend, 2015). The second criterion for high quality research according to him is validity whereby a valid research answers research questions in a scientifically rigorous manner.

This research adheres to the above criteria by having a well-designed research topic and clear objectives, focused research questions responsive to the literature review, an absence of research bias, analytical methods appropriate to the data and the questions and finally conclusions and recommendations which are both logical and consistent with the findings.

The quality of the prototype in this research was measured using success rate as the main performance metric. More specifically, the success rate is defined as the percentage of positively identified fire outbreaks.

$$Sf/_{n} \times 100$$

Where Sf = Number of positively identified fires

N = Total number of test scenarios

3.6 Ethical Considerations

Part of this research involved collection of data from the environment using a sensor. The data shown in this research paper is a true depiction of the recorded data with no alterations whatsoever. Finally, the prototype collects GPS coordinates of individuals which is confidential information. The researcher ensured that this information was protected.

Chapter 4 : System Analysis and Design

4.1 Introduction

The System analysis and design chapter in this research reports on the planning process for development of the prototype through understanding and specifying in detail what the prototyped system should do and how the components of the system should be implemented and work together. The chapter also contains data analysis for data collected in the research. Finally, a visual modeling language (UML) has been used to visualize the proposed solution in multiple dimension, so that the prototyped system can be completely understood before construction begins.

4.2 Requirement Specifications

Requirements specification is a complete description of the behavior of the prototype to be developed. Requirements are categorized in several ways. This section covers functional and non functional requirements of the prototype.

4.2.1 Functional Requirements

Functional requirements explain what has to be done by the prototype by identifying the necessary task, action or activity that must be accomplished. They include:

i. The prototype should read analog temperature, gas, smoke and UV light data from the environment.
ii. The prototype should convert the sensor data into digital form and send it to the IBM Bluemix IoT cloud platform
iii. The prototype should send a text alert and sound the buzzer during an LPG gas leak.
iv. The prototype should the sound buzzer and send a text notification to relevant parties if a fire accident occurs.
v. The IoT cloud platform which is part of the prototype should save sensor readings from the device in its No-SQL database.

4.2.2 Nonfunctional requirements

Nonfunctional requirements are requirements that specify criteria that can be used to judge the operation of a system, rather than specific behaviors. The requirement of NFRA in IoT system design is distinct since the design relies on physical components, network protocols and software integration (Mahalank, 2016). The key non-functional requirements identified for the prototype are security, performance, availability and reliability.

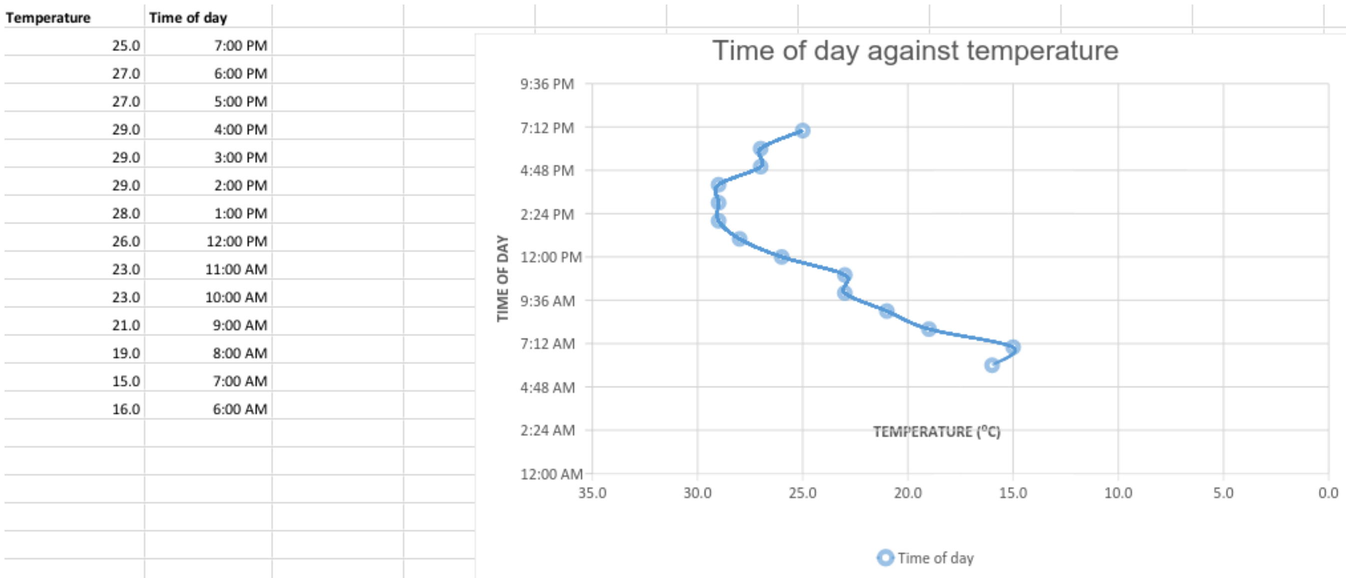
4.3 Analysis of the Characteristics of a Fire in a Compartment

As outlined earlier, the first objective of this research was to identify the behavioral characteristics of a fire and better understand the combustion process. It is of great significance to note that despite the clear fact that the characteristics of fire in regards to the chemical composition vary depending on the type of accelerant, there are common characteristics that are standard across all types of fires. The purpose of this objective was to clearly identify components of a fire that can be detected in order to trigger a fire alarm. Secondly, understanding the characteristics of the fire was meant to better understand the type of sensors to be used as well as the threshold values that will be set on the detection device to improve accuracy. Credible secondary data from reviewing literature was used to provide insight on some of these characteristics. The common elements/ characteristics identified were smoke, heat and light(flame).

The composition of smoke depends on the nature of the burning fuel and the conditions of combustion. Smoke is a collection of tiny solid, liquid and gas particles. Although smoke can contain hundreds of different chemicals and fumes, visible smoke is mostly carbon (soot), tar, oils and ash. It is, however, the presence of carbon monoxide in the smoke that enables for detection.

Although average temperatures have risen dramatically due to global warming, the standard room temperature in most climates is between 21 degrees Celsius and 26 degrees Celsius (Doiron, 2007). Figure 4.1 below shows temperature readings taken from an LM35 temperature sensor in Nairobi on Tuesday March 14th 2017. These reading are important as they aid in understanding the normal rate of change in temperature thus subsequently aiding setting temperature thresholds for fire detection the LM35 precision temperature sensor in order to accurately detect fire accidents.

The researcher noted and concluded that changes in temperature during the day occur at the rate of 1-4 Degrees Celsius during the day after every hour (Both rise and drop). The researcher also noted that the average maximum temperature during the week stood at 31degree Celsius. This implies that the temperature threshold for the device should be above 31 Degree Celcius to avoid false alarms while increasing the accuracy of the device. Table 4.1 summarizes the findings made by the researcher on temperature.



Temperature	Time of day
25.0	7:00 PM
27.0	6:00 PM
27.0	5:00 PM
29.0	4:00 PM
29.0	3:00 PM
29.0	2:00 PM
28.0	1:00 PM
26.0	12:00 PM
23.0	11:00 AM
23.0	10:00 AM
21.0	9:00 AM
19.0	8:00 AM
15.0	7:00 AM
16.0	6:00 AM

Figure 4.1 Temperature changes during the day

Table 4.1 Summary of temperature results

	Max	**Av g**	**Min**
Temperature			
Max Temperature	31°C	30°C	29°C
Mean Temperature	24°C	28°C	31°C
Min Temperature	18°C	17°C	15°C

The final component in the breakdown of fire characteristics is the flame which is the glowing gaseous part of a fire. At ignition, the flame produced emits UV radiation. UV detectors typically operate with wavelengths shorter than 300 nm.

4.4 Analysis of Challenges Smoke Detectors Against Those Faced by Smoke Detectors

As discussed in the literature, there were several challenges faced by single sensor fire detection device more so smoke detectors. Table 4.2 summarizes key challenges faced by smoke detectors against those that the proposed system should be able to solve.

Table 4.2 Analysis of current technology vs proposed solution

Challenges	**Smoke Detectors**	**Proposed System**
Relies on a Single Sensor. (Single Metric for Fire Detection)	Yes	No
Beeps on positive fire detection.	Yes	Yes
Sends text alert with GPS coordinates	No	Yes
Detects LPG gas Leakage	No	Yes
Sends data to cloud for Analysis	No	Yes
Cooking vapors (trigger smoke alarms)	Yes	No
Water and Steam(A common cause of false alarms) offsets alarm	Yes	No
Chemical Fumes (Bug sprays used by some pest control companies can release fumes that will set off fire alarms. Many cleaning chemicals contain ingredients that will trigger false alarms in smoke detectors.)	Yes	No

4.5 System Architecture

The Multi-sensor fire detection architecture compromises all the core components of a typical IoT architecture based on the IoT Reference Model discussed in Chapter 2. The temperature sensor, the MQ2 gas and smoke sensor, the Grove light sensor, the buzzer, the GPS module and the SIM900 GSM module are all connected to the Arduino Uno microcontroller and cumulatively constitute the physical element of the system.

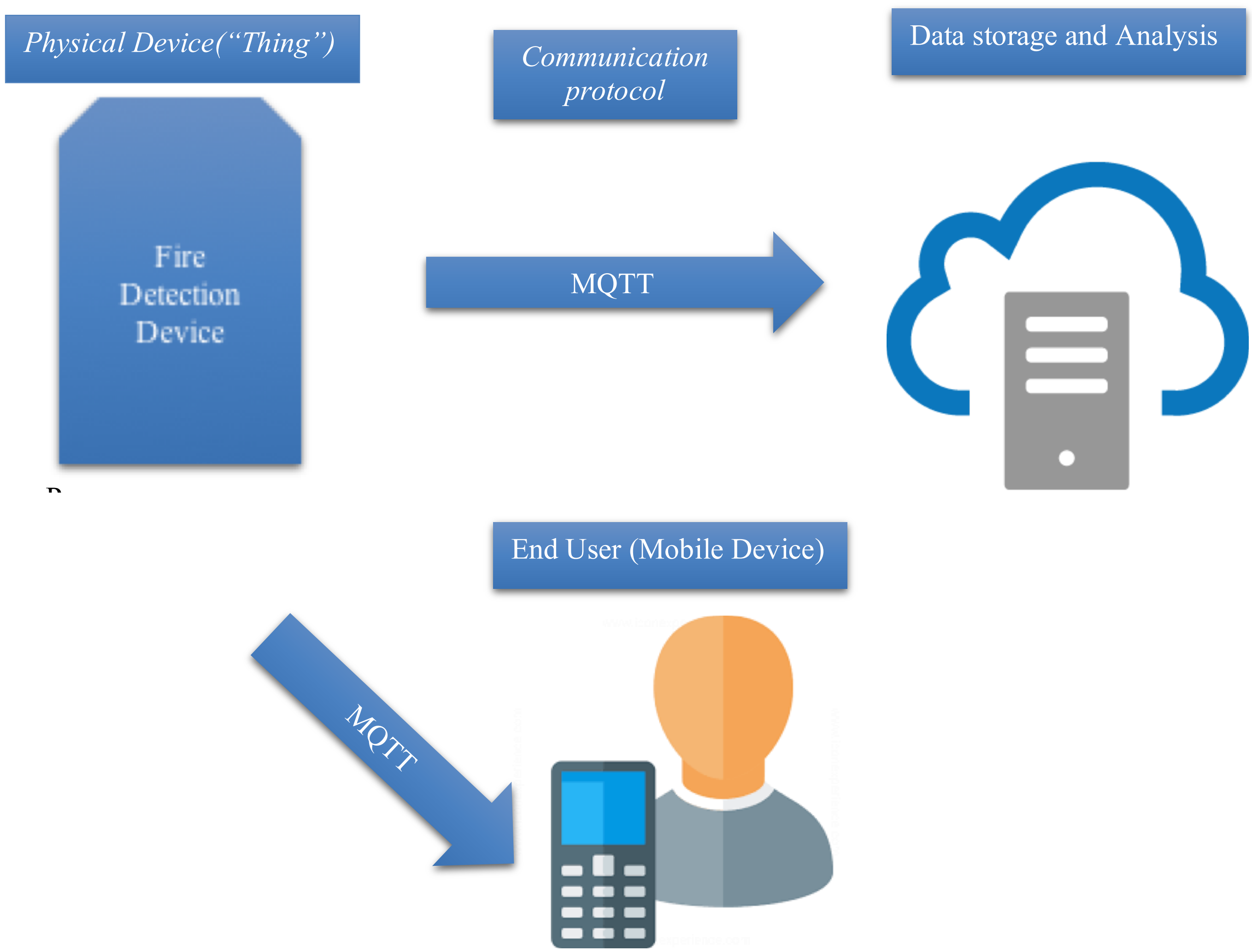


Figure 4.2 System Architecture

The Arduino Uno microcontroller converts the analog values from the sensors and converts them into digital values. The IoT platform (IBM Buemix) implemented which is a fully managed, cloud platform service created to ease and derive value from IoT devices was used to record data from the device. The fire detection device connects to the cloud platform using the the lightweight and secure MQTT protocol. Generally, IoT devices can create a lot of data. In fact, sensor technology on smart devices already accounts for about 30 percent of the world's data. Bluemix provides a NOSQL database thaw was used for storage of device data by the prototype developed in this research.

4.6 Diagrammatic Representation of the System

As outlined earlier UML (Unified Modelling Language) was used for diagrammatic representation of the proposed prototype. A use case diagram, a sequence diagram and a flow chart have been used for the diagrammatic representation.

4.6.1 Use Case

The use case diagram in this research has been used to model the functionality of the fire detection prototype using actors and use cases. Use cases can be defined as a set of actions, services, and functions that the system needs to perform. Table 4.3 is the typical course of events expected in the system:

Table 4.3 Typical course of events in the system

Step 1:	The fire detection device powered on and the sensors are reading their respective data.
Step 2:	The analog data is converted into digital data by the micro-controller.
Step 3:	The data from the sensors is then sent after every 30 seconds to the cloud platform.
Step 4:	The device checks against the predefined rule base in order to identify a fire accident or an LPG gas leakage.
Step 5:	When an LPG has leakage is detected a text is sent to the home owner.
Step 6:	If there is there no LPG gas leakage but a fire accident occurs, the detection device sends a text notification to the relevant parties(Stakeholders).

Use Case Descriptions:

This section covers all the use cases in the system summarized as system contracts in tabular form.

Used Case Name:	*Obtain Analog Sensor Readings*
Description:	The three sensors connected to the prototype record data from the environment.
Primary Actor:	Sensor Node
Trigger:	Changes in the environment within the compartment(Apartment or Home)
Pre-condition	• The Sensors are connected to a powered microcontroller. • Code is uploaded to the Arduino board
Post-condition	Accurate data is recorded by the sensor nodes.

Used Case Name:	*Calibrate Sensor Thresholds*
Description:	The sensitivity of the sensors can be adjusted to increase the accuracy of readings.
Primary Actor:	Admin
Trigger:	Inaccurate sensor readings.
Pre-condition	• Administrative privileges are required.
Post-condition	The Sensor thresholds are successfully changed.

Used Case Name:	*Perform Data Analysis*
Description:	Sensor data is sent a saved on the cloud platform. This data can be visualized and analyzed for reporting as well as improving the prototypes performance.
Primary Actor:	Admin
Trigger:	Sufficient amount of data has been stored.

Pre-condition	• Cloud platform is receiving data • The cloud platform is online.
Post-condition	Data analysis is successfully carried out.

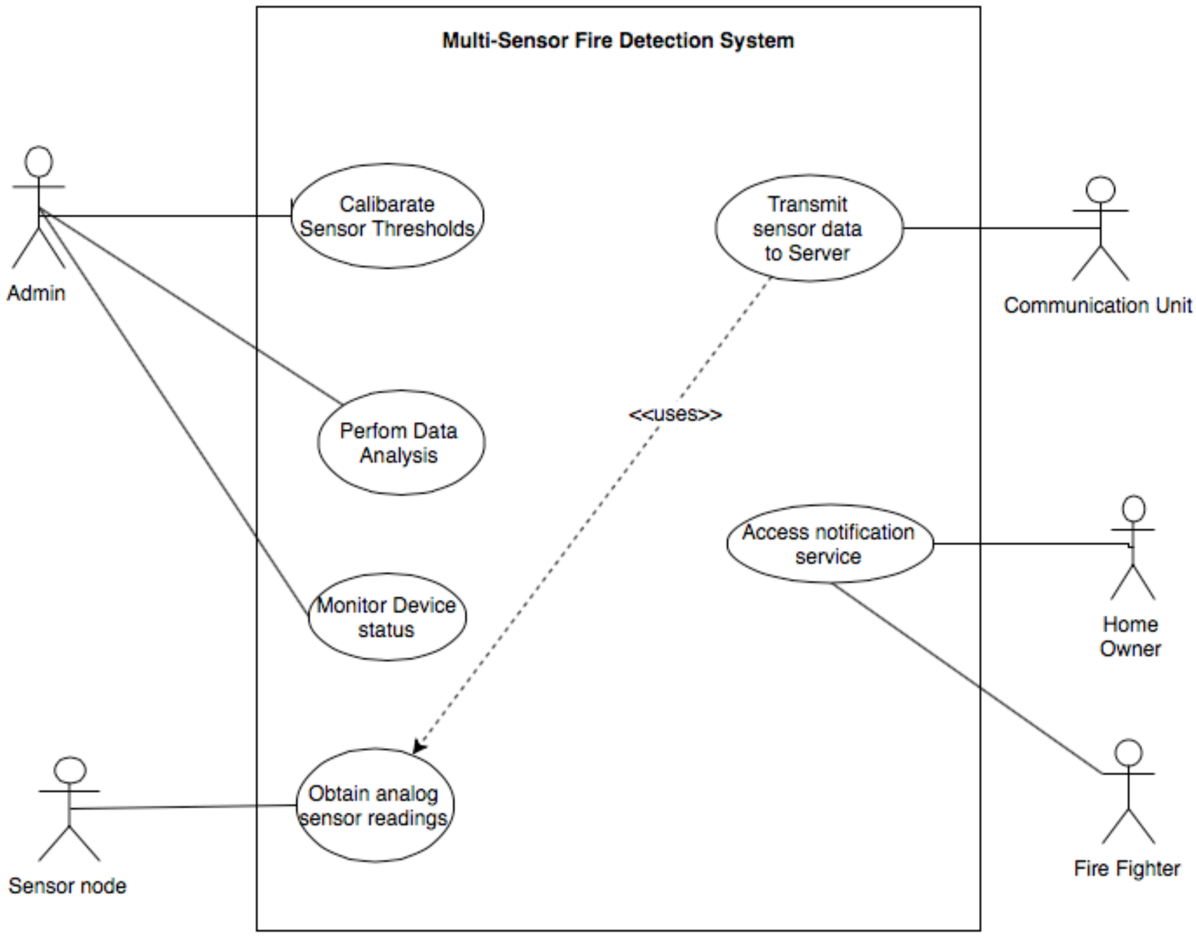


Figure 4.3 Use Case Diagram

Figure 4.3 illustrates the use case diagram that is made up of 3 human actors and two system actors. The system actors are the sensor node and the communication unit made up of the GSM and GPS modules.

Used Case Name:	*Monitor Device Status*
Description:	The Device can be either online or offline. The system allows the Admin to check the online or offline status of the device.
Primary Actor:	Admin
Trigger:	Device not sending data for prolonged duration
Pre-condition	• The Device must be configured to connect to the cloud platform. • The Device must be registered on the cloud platform.
Post-condition	Device is online.

Used Case Name:	*Access Notification Service*
Description:	LPG gas leakage and Fire outbreak intances are reported via a text message to the home owner.
Primary Actor:	Home owner
Trigger:	Fire outbreak or LPG gas leak at a home or apartment.
Pre-condition	• The home owner has a mobile phone.
Post-condition	Fire and LPG alert successfully sent.

Used Case Name:	*Access Notification Service*
Description:	When a fire accident occurs an SMS alert with the GPS coordinates of the home under fire is sent to the primary actor in this scenario from the notification service
Primary Actor:	Fire department
Trigger:	Fire outbreak at a home or apartment.

Pre-condition	• The fire department posses a mobile phone.
Post-condition	Fire alert with GPS coordinates successfully sent.

4.6.2 Sequence Diagram

The sequence diagram below is used to show the interactions between objects in the sequential order that they occur.

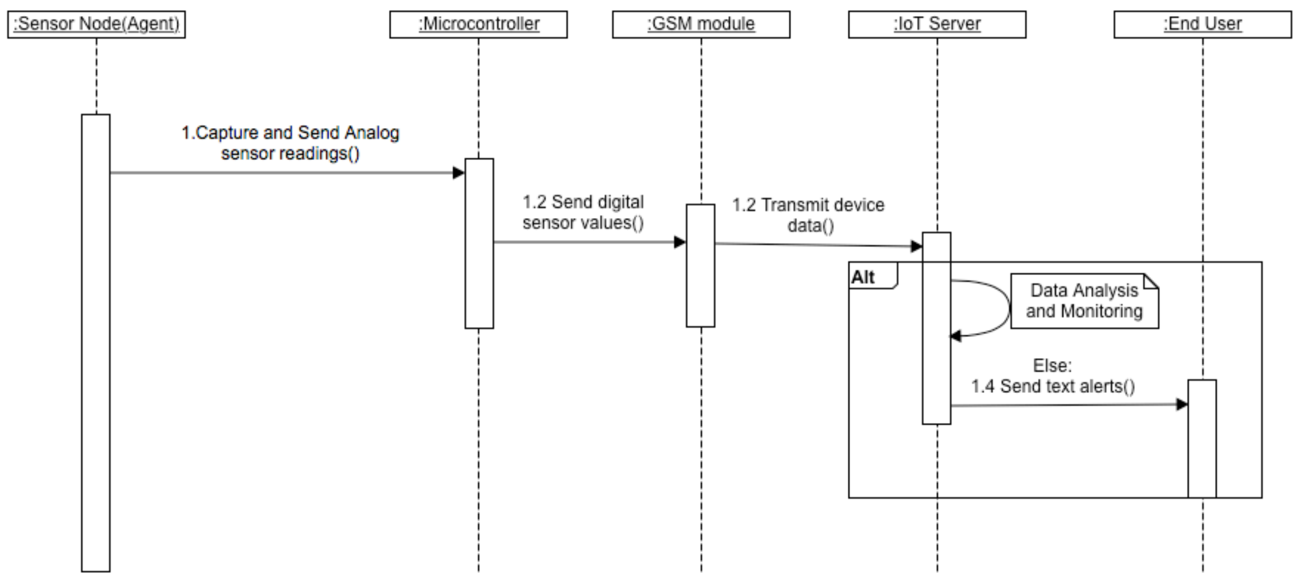


Figure 4.4 Sequence Diagram

Figure 4.4 is a depiction of how the fire detection devices captures data from the sensors, sends it to the IOT cloud platform where data is continuously saved and analyzed. The end users receive notifications when a positive fire identification is made by the device.

4.6.3 System Flow Chart

Figure 4.5 illustrates the system flow chart which is the graphical representation of the flow of data in the prototyped system and represents the work process of the system. It illustrates the capturing of data form the sensors, the conversation of the data into rules and the decision making section of the prototyped system.

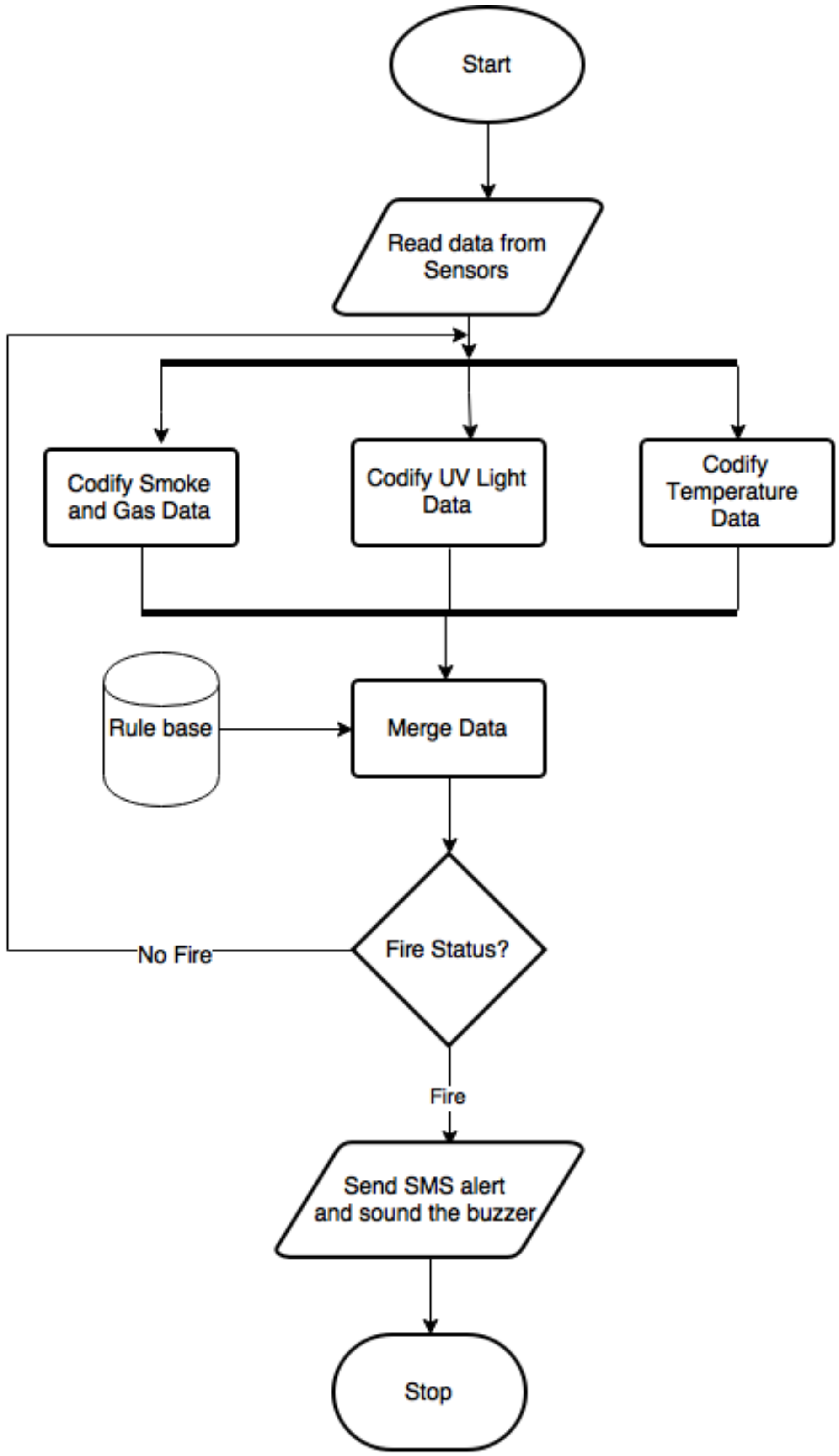


Figure 4.5 System flowchart

Chapter 5 : Implementation and Testing.

5.1 Introduction

This section covers the implementation and testing phase of the fire detection prototype. The section also covers conclusions of the test results and the challenges faced during the implementation process. The various devices, software development platforms as well as test results have been discussed in this chapter. Rapid prototyping methodology discussed in Chapter 3 was fully implemented in the development of the prototype.

5.2 Assembling Components

It was important to first assemble and configure all hardware, software and cloud service components to ease the implementation and testing cycle. Assembling all components allows for adequate planning and resource allocation.

5.2.1 Bill of Materials

A bill of materials (BOM) is a detailed list of items, parts, assemblies and sub-assemblies required for the development of IoT hardware (Smith, 2014). The bill of materials in Table 5.1 below outlines a summary of the hardware components that were used in the development of the prototype and their technical specifications. Specifications such as power supply were important because they directly affected the circuit architecture. Despite there being quite a number of manufacturers in the IoT hardware business, the researcher chose the devices listed in Table 5.1 because they were affordable but at the same time provided sufficient accuracy.

Table 5.1 Bill of materials

Hardware Name	*Technical Specifications*	*Description*
Grove - Light Sensor (P) v1.1	• Power supply: 3.3 - 5V DC • Phototransistor: LS06-S • Connector: 4 pin Buckled • Dimension: 20mm*20mm	The Grove - Light sensor integrates a photo-resistor(light dependent resistor) to detect the intensity of light. The resistance of photo-resistor decreases when the intensity of light increases. This senor was put in place to substitute a flame sensor since it can detect the UV wavelength value of a flame.

Grove-Temperature Sensor v1.0	• Voltage: 3.3 ~ 5V • Max power rating at 25℃: 300mW • Zero power resistance: 10 KΩ • Operating temperature range: -40 ~ +125 ℃	The Grove Temperature Sensor uses a Thermistor to detect the ambient temperature. The resistance of a thermistor will increase when the ambient temperature decreases. It's this characteristic that was used to calculate the ambient temperature. The accuracy iof the sensor is ±1.5ºC.
MQ 2 gas sensor	• Concentration: 300-10000ppm • Voltage: 5V	The Grove - Gas Sensor(MQ2) module is useful for gas leakage detection (home and industry). It is suitable for detecting H2, LPG, CH4, CO, Alcohol, Smoke or Propane. Due to its high sensitivity and fast response time, measurement can be taken as soon as possible.
Arduino Uno	• Operating Voltage: 5V • Input voltage(Recommended): 7-12V. • Digital I/O pins: 14	A cheap and easily programmable micro controller. It was was picked for this research because of its compatibility with most sensors.
SIM900 GSM module	• Operating Temperature: 30 °C to +80 °C • Supply voltage: 3.5V – 4.5V	The frequency of operation of the module is 850/900/1800/1900MHz and which can be used not only to access the Internet, but also for oral communication (provided that it is connected to a microphone and a small loud speaker) and for SMSs. This device was picked mainly because of its low power consumption.

Buzzer	• Operating Voltage: 3 - 24V • Rate Voltage: 12V DC	Standard Piezo buzzer.
Bread board MB102 (Solderless type)	• Dimension: 165mm x 55mm x 10mm. • Wire size: Suitabe for 29-20 AWG wires	The bread board serves as a connection point for the electrical devices such as the sensors, capacitors and resistors. It enables the creation of the circuit and provides pins that can also be used for data transfer.
Jumper Cables	• Red, blue, black and yellow color codes.	An assortment of female-female, male-male and female- to male jumper cables were purchased for the wiring.

5.2.2 IoT Cloud Services

IBM Bluemix is a cloud platform as a service developed by IBM. It provides support to several programming languages and services for building, running, deploying and managing applications on the cloud. Bluemix in this research was used as a data capture and visualization tools. This platform was selected for the implementation of the prototype because robustness when it comes to IoT cloud services. The service is however only free for 30 days after which a developer is required to pay for the service. The free trial version however provides enough privileges to develop and test an entire IoT project.

Setting up the platform entailed accessing the IBM Bluemix website and registering the information. The setup window is illustrated on Appendix. Refer to Appendix C which illustrates the entire catalog of services available on Bluemix for IoT. However not all services were used from the catalog. The service labeled Internet of Things Platform was the only service used.

5.2.3 Setting up the Software Development Environment

To begin development and integration of the prototype, the development environment was setup. The Arduino IDE (Integrated Development Environment) is the main development tool was used. The IDE is available on the official Arduino website (https://www.arduino.cc) for Windows, MacOS and Linux operating systems. Arduino delivers an open-source and easy-to-use programming environment for writing instructions and uploading them to the Arduino board.

Arduino language uses a C/C++ compiler. All standard C and C++ constructs supported by avr-g++ work in Arduino. The implementation in this research was done on a MacOs platform. This is because the operating system provides stability and high speed performance during compilation as well as reliability.

The next step was to install the MQTT library as shown in Appendix C. The MQTT protocol was to enable publishing of data to the cloud once the prototype was ready as well send SMS notifications. To do the following steps were followed:

i. The MQTT Library was downloaded from GitHub.
ii. The Library was then added to the Arduino IDE by opening the IDE and clicking on the "Sketch" menu followed by Include Library > Manage Libraries as illustrated in Figure 5.1. The library manager then opened and a list of libraries that are already installed or ready for installation were displayed.
iii. The MQTT Library was finally located from the download location and installed.

5.3 Developing and Testing Hardware Units

As stated in chapter 4, rapid prototyping methodology was used in prototype development. Each sensor unit was assembled and tested before the entire prototype was assembled. It was important to ensure that each sensor was functioning independently and was able to record data from the environment.

5.3.1 MQ 2 Sensor and Buzzer Unit

To develop and test this unit, the following materials from the bill of materials was used:

i. Arduino Uno with USB cable
ii. Breadboard
iii. MQ-2 Gas sensor module
iv. Jumper cables.

The first step was to ensure that the breadboard is powered. The breadboard has a '+' power rail marked by a red stripe and a '-'power rail marked by a blue stripe. A male to male jumper cable was connected from the 5V pin on the Arduino board to a port along the '+' power rail(any port can be used along the rail). Another male to male jumper cable was connected from the GND (Ground Port) on the Arduino Uno to the '-' power rail in order to have a complete circuit. A final male to male jumper cable was connected from Analog Port A0 on the Arduino Uno microcontroller to a port on the terminal strips to provide the data signal connection used to send sensor values from the sensor to the Uno. Appendix D illustrates the complete circuit. Appendix E shows readings captured during testing of the sensor. The readings on the serial monitor showed that the sensor functioned properly.

5.3.2 Grove light sensor unit

The grove light sensor is used to measure the intensity of light and in this case was used to measure a surge in light intensity which could characterized the presence of a flame. The following materials from the bill of material were used to test and validate the unit.

i. Arduino Uno with USB cable
ii. Breadboard.
iii. Grove Light Sensor V1.1
iv. Jumper Cables

The first activity in construction of this module was creating a complete circuit using the breadboard and Arduino uno which was the power source. Communication between the light sensor and the Arduino Uno was then established by connecting the signal cable from the light sensor to the Arduino Uno A0 Serial port. The Arduino IDE was launched and the microcontroller was connected to a laptop using a USB cable. The small piece of code on Appendix K was typed into the sketch window, verified and uploaded to the Arduino board. Finally, the serial monitor was launched to see if the light sensor was sensitive to light and gave an output as shown on Appendix F.

The Serial monitor showed values as illustrated in Appendix E. A flame from a lighter was then introduced close to the light sensor and an instant surge in readings was detected and noted.

5.3.3 Grove Temperature Sensor Unit

The temperature unit was perhaps the most important unit in the system because heat is the easiest parameter to work with and measure accurately as compared to smoke. To test and implement this, the grove temperature sensor, the Arduino board and breadboard were connected just like in previous circuits. A simple function was then written to convert the voltage from the sensor to temperature based on the formula provided on the Grove sensor datasheet.

Temp in Celsius = *[(Vout in mV) - 500] / 10*

5.3.4 Communication and location Unit (GSM and GPS)

The unit mentioned above was put in place to support both the SMS notification service and data transfer from the sensor units to the Bluemix server. A Safaricom sim card loaded with airtime and data bundles was used to enable connect. A text notification was the preferred choice for communication to increase the chances that the fire alert notification reached the home owner. Using an application such as an Android App that would require internet to be enabled on the end user's mobile phone would mean if the internet services were not enabled then the notifications would not be received. Appendix G is a screenshot generated for the fire department in the format:

["*String text alert* " (**Latitude**, **Longitude**)]

Once the fire personnel receive the text alert, the GPS coordinates are entered into a third party application. The preferred application used during the implementation was google maps which is available free of charge. Appendix H Illustrates the extraction of the actual fire location from the GPS coordinates. The pin on the map represents the exact location

5.4 Complete Hardware and Software Integration

Complete hardware integration was final step in development of the prototype. All the prototype units were merged into a single synchronous device. For the device to function it needed to be powered. Various methods of powering IoT devices exist the most common ones being the use of batteries (rechargeable and un-rechargeable) and direct connection to power sockets. The prototype however was powered using a laptop through a USB cable connected to the Arduino Uno for prototyping purposes.

The hardware however does not function independently. The Arduino IDE development platform that was setup was used to program the hardware to achieve its objective which is fire detection. Appendix I and J show a the initial circuit diagram and the integrated prototype consisting of all the units.

5.4.1 Creating Fire Detection Rules

Three final states that were defined for determine the presence of a fire outbreak. The three states are:

i. LPG leakage
ii. Fire
iii. No Fire

Table 5.2 below shows instances of the 4 attributes (parameters) used for rule definition and there instances.

Table 5.2 Attribute definitions

Attribute	Instance
Temperature	Normal: 0 – 35 Degrees Celsius Abnormal: 40 degrees Celsius to 150 degrees Celsius
Smoke	High: 301ppm – 1000ppm Low: 0 – 300ppm
LPG gas concentration	High: 600ppm and above Low: 0-300ppm Medium: 400 – 600ppm
Light Intensity	Normal: 0 – 499cd Too Bright: 500 – 900cd

The following were some of the rules that were used to determine a positive detection of fire i.e the "Fire" state. The rules were defined as functions in the Arduino IDE.

i. **IF** Smoke is present **AND** Temperature is Abnormal **AND** LPG gas is High **AND** Light intensity is Too Bright **THEN** FIRE

ii. **IF** Smoke is Present **AND** Temperature is Abnormal **AND** Light intensity is Too Bright **THEN** Fire

iii. **IF** Smoke is Present **AND** Temperature is Abnormal T**HEN** Fire

iv. **IF** LPG gas concentration is High **AND** Smoke is Present **AND** Temperature is Abnormal **THEN** Fire

v. **IF** LPG gas concentration is Medium **AND** Smoke is Present **AND** Temperature is Abnormal **THEN** Fire

vi. **IF** LPG gas concentration is High **AND** Temperature is Abnormal **AND** Light intensity is Too Bright **THEN** Fire

vii. IF **LPG** gas concentration is high **AND** Temperature is Abnormal **THEN** Fire

5.6 Testing

Each sensor unit was tested individually as illustrated earlier in this chapter (Unit testing). The tests conducted were intended to ensure the accuracy of each sensor before incorporation into the main prototype. The final prototype system was tested to ensure that it was accurate in fire detection implying that it was free from false alarms.

5.6.1 LPG module testing

The LPG leakage detection module in the prototype was tested for functionality. A cigarette lighter was used to produce the combustible gas. The test results are as illustrated below:

Table 5.3 Functionality testing for LPG module

Test Name: LPG module test **Type of Test: Functionality.**		
Sensor Threshold: 400ppm		
LPG Sensor Value in ppm (Parts-per-million)	**Action**	**Remark**
0 ppm	No Text Alert Sent	This is the expected action.
365ppm	Text Alert Sent	This is the expected action.
490ppm	Text Alert Sent	This is the expected action.

Three tests were carried out on the smoke sensor. All the three tests were passed representing a 100% percent functionality.

5.6.2 Integration testing (System Testing)

This was the testing done on the integrated prototype to verify combined functionality of the entire system. For the test to be carried out, a lighter and a piece of paper were used. The lighter was used to produce the flame and heat while the piece of paper was ignited and put out to produce smoke. The text that combined both the LPG and Flame was not carried out because of the risks involved (Unwanted ignition).

Table 5.4 Integration test results

LPG(ppm)	**Smoke(ppm)**	**Temperature(°C)**	**Light Intensity(Cd)**	**Fire Status**	**Expected Result**
Low: 225	Low:100	27.4	397	No Fire	No Fire
	High: 326	41.0 (Abnormal)	445 (Normal)	Fire	Fire
	Low: 180	49.2 (Abnormal)	503(Too bright)	Fire	Fire
	High: 406	45.0	398(Normal)	Fire	Fire
Medium	Low: 142	23.0	700(Too bright)	Fire	No Fire
-	High: 440	41.0	445	Fire	Fire

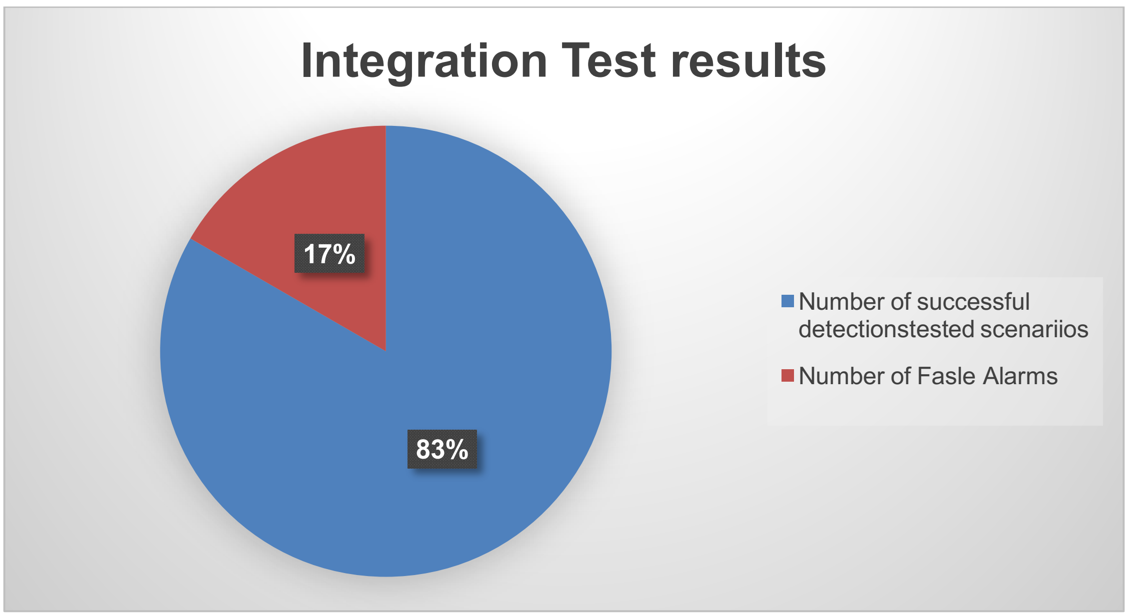


Figure 5.1 Summarized integration results

As clearly depicted on figure 5.10, there was an 83% success rate when the prototype was tested. The use of a small number of taste cases was responsible for the large error margin. The 83% success rate is still however a major improvement from smoke detectors which as outlined earlier have registered false alarms rates of up to 95% in a duration of one year

5.6.3 Testing Against Known False Alarm Triggers.

The prototype was tested against some of the main triggers of false alarms in smoke and thermal based fire detectors in a home setting. The known main triggers are chemical odors, steam, burning food, dust and humidity (Vintech Systems, 2011).

Table 5.5 Requirement testing

Type of Test: Requirement Testing	
Trigger	**Result**
Humidity (Tested at 70% Humidity)	No false alarm
Cigarette	No false alarm
Steam	No false alarm

Three of the triggers were used to test the prototype. Table 5.5 summarizes the test results where by the fire detection device did not trigger a false alarm representing a 100% success rate (3/3).

5.6.4 Performance Testing.

Performance testing was carried out to asses the notification service (Text alert) based on a speed metric. It was important for the prototype to send timely text SMSs to the relevant parties once a fire was detected. This test was carried out using a stopwatch to investigate and record the amount of time taken between fire detection and the arrival of the alert to a mobile phone. 3 tests were done and the results are as tabulated below.

Table 5.6 Performance Testing

Alert Name	**Time before text arrived**
Alert 1	45 seconds
Alert 2	1 min and 20 seconds
Alert 3	1 min 4 Seconds
Average Time(In Seconds)	63 seconds

The average time before the text notification was received by the end user was about 63 seconds. This is still within the incipient period of a fire which is ranges from 0 to 5minutes as outlined by the researcher in chapter 2. The variations in time were due to network connectivity issues since the GSM module relies on a mobile service provider platform.

5.6.5 User Acceptability Testing

Unlike all the other forms of testing carried out above, this test was carried out in conjunction with potential users of the system to determine whether it fits their needs for fire detection. The user acceptance questionnaire on Appendix L was used to test for acceptability. The results of the test are as tabulated in Table 5.7.

Table 5.7 User Acceptability Testing

Type of Test: ***User Acceptability*** **Number of Respondents:10**	
Issues Raised	*Performance*: 2 *User Friendliness*: 1
Overall Score (Based on Likert Scale) :	4 (Very Good)

Most users while using the system acknowledge that it can be instrumental in the timely detection on fire but insisted that the development on a mobile application to aid in device management would make the system even better.

5.7 Challenges in Implementation.

The major challenge faced during implementation was the unavailability of some of the sensors required for the prototype in the Kenyan market. This lead to modifications to the prototype to suit what was available. Notably, a flame sensor and UV light sensor were unavailable because they are rarely used by IoT researchers in the country. Secondly, due to the number of sensors used, a lot of power was drawn by the sensors as well the communication unit of the system. This led to unforeseen fluctuations in the readings read by the sensors.

5.8 Summary.

To summarize, there are keys functionalities/techniques that were implemented to ensure the the prototype was used to achieve its main objectives which was to reduce false alarm rates and its sub-objectives which were affordability and making fire detectors “smart”. They are as follows:

i. Using Smoke, Temperature and Light Intensity as parameters to detect fire.
ii. Incorporating a potential cause of fire (LPG gas) into the system.
iii. Combining both rate of rise in the temperature unit and a fixed temperature threshold as techniques to detect changes in room temperature.
iv. Using GSM instead of Wi-Fi for sending text notifications.

Chapter 6 : Conclusions and Recommendations

6.1 Conclusion

There were numerous challenges identified relating to fire detection and response. The main challenge identified under fire detection were high false alarm rates by detection devices others being unaffordability of some of the devices and lack of sufficient awareness on the importance of installing these devices. The high false alarms especially by smoke sensors and heat/ thermal sensors stood out as the major challenge.

The researcher's main agenda was to investigate the problem and subsequently develop a solution that solved the false alarm problem while considering the cost of the final product. To achieve this, the researcher laid his emphasis on using more than one percept from the environment during a fire outbreak. The researcher investigated extensively and identified three main percepts that formed or were emitted during a fire. They were smoke, heat and a flame.

The researcher went further and looked into literature (secondary data) for instance fire reports and identified a common and a potential cause of fire at residential level and this was LPG gas leakages. The research incorporated this aspect into the prototype to aid in increasing accuracy in fire detection devices. Based on both the secondary and primary data collected, a multi-sensor fire detection was implemented and tested accordingly giving an 83% percent success rate and 17% false alarm rate based on 6 test cases of which only one failed.

Stakeholders in fire department services should adopt the technique proposed in this research for fire detection as a stepping stone towards a faster response time to fire incidents. This will go a long way in saving lives and property. Data collected from the detection device also provide an opportunity for better reporting and data analysis which could help in the process of improving fire detection services especially in Kenya where there is insufficient recording and publishing of information relating to fire.

6.2 Contribution to research

The researcher in chapter one pointed out that the Kenya Red Cross an international humanitarian organization echoed the sentiments of several parties involved in fire disaster management that there is urgent need to innovate accurate and timely fire detection solutions. The multi-sensor fire detection system has provided a solution that can significantly reduce false alarms rates and provide timely alerts incase of fire accidents at domestic(residential) level. The researcher has contributed a feasible solution to two growing fields in computing which are The Internet of things and real-time data capture and analysis by incorporating them into the field fire detection.

6.3 Recommendation

The following are recommendation based on the research results that were analyzed by the researcher and challenges faced during implementation:

i. A Mobile based application can be developed to aid the home user to manage the device for instance check if its up and running.
ii. The device can be extened to enable it use rechargeable batteries as a power source.
iii. A web application based on the Google maps API for navigation by the fire department once an alert is sent can be developed.
iv. The use of a flame sensor instead of light sensor would make the device more accurate

6.4 Future Works.

Apart from false alarms, fire detection devices face other challenges. Upgrading the device to suit industry stands so that it can be adopted for fire detection at industry level as well as in commercial buildings. Integration of fire intervention methods based on Robotics e.g a fire-fighting bot that communicates with the detection device after a fire is detected as a first line of defense before fire-fighting service men arrive is a positive step towards full automation of fire detection and mitigation services. Finally the most important expansion that researcher suggests for the expansion of the system is the integration of image processing for flame detection(which has been done) into the the multi sensor fire detection prototype to further enhance its accuracy.

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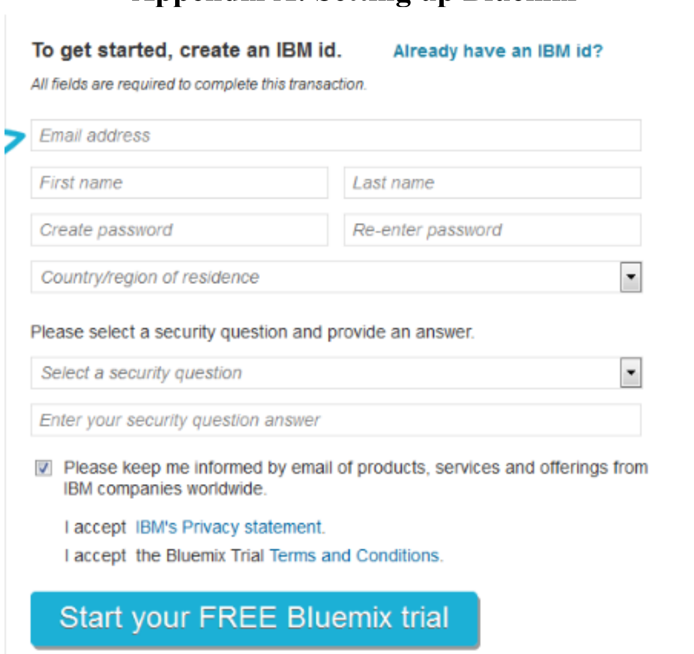
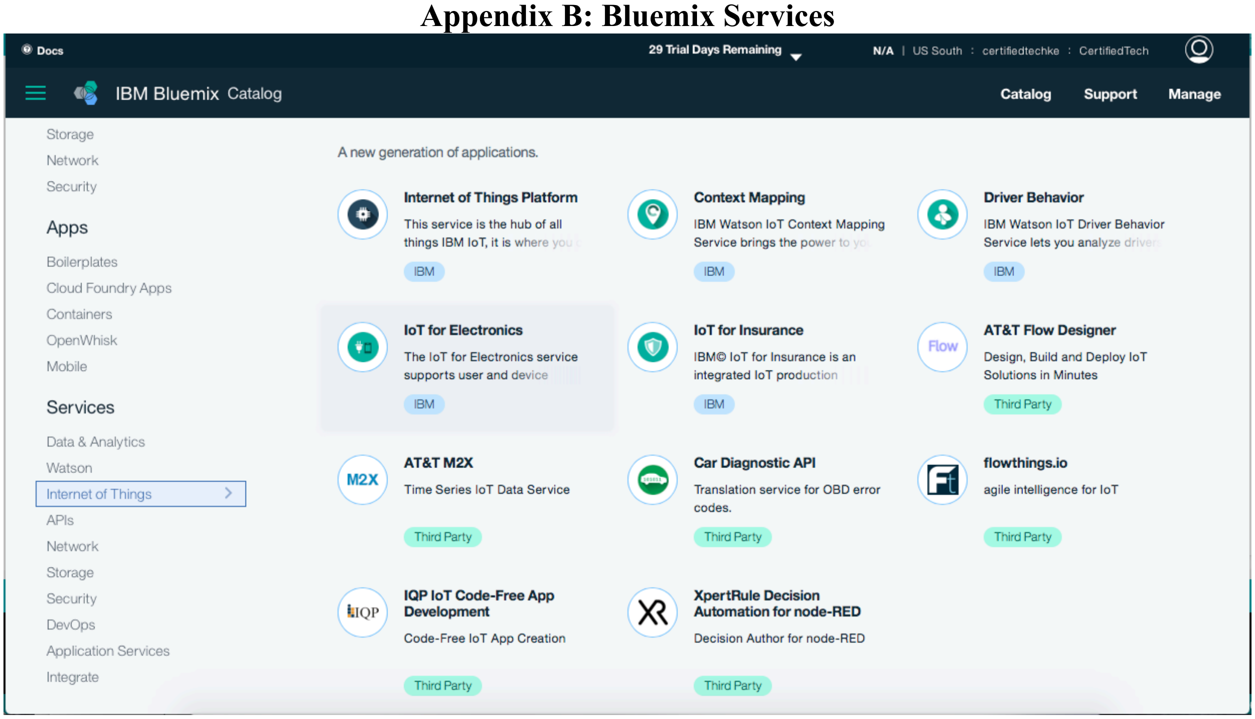
Appendices

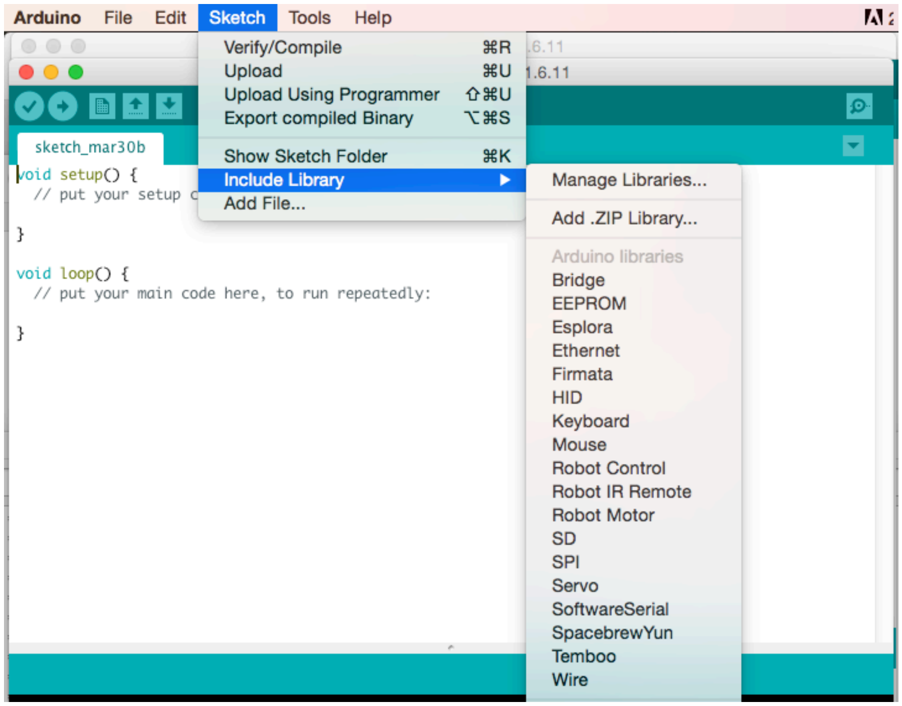
Appendix A: Setting up Bluemix



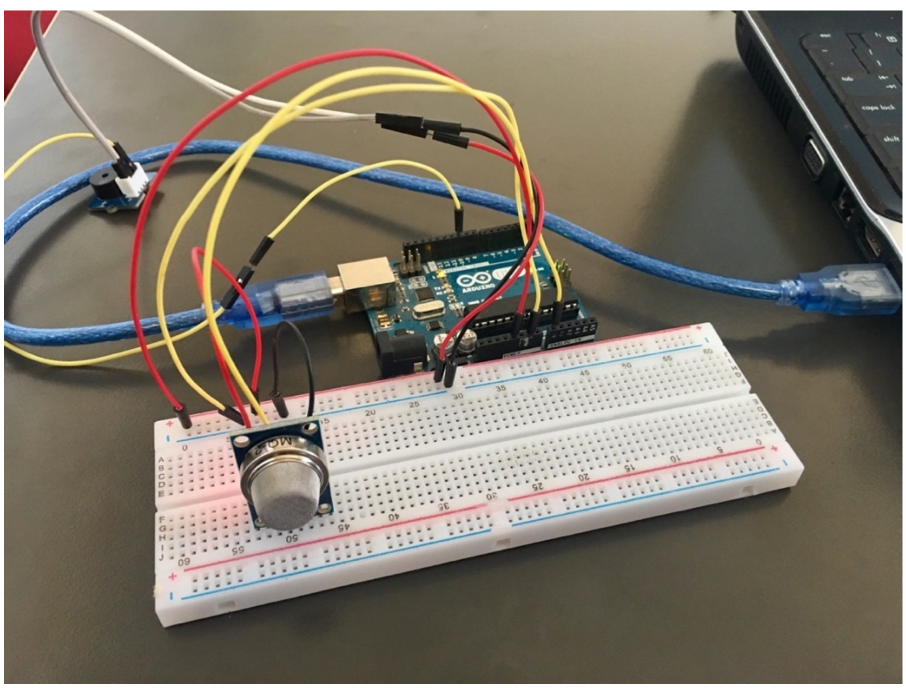
Appendix B: Bluemix Services



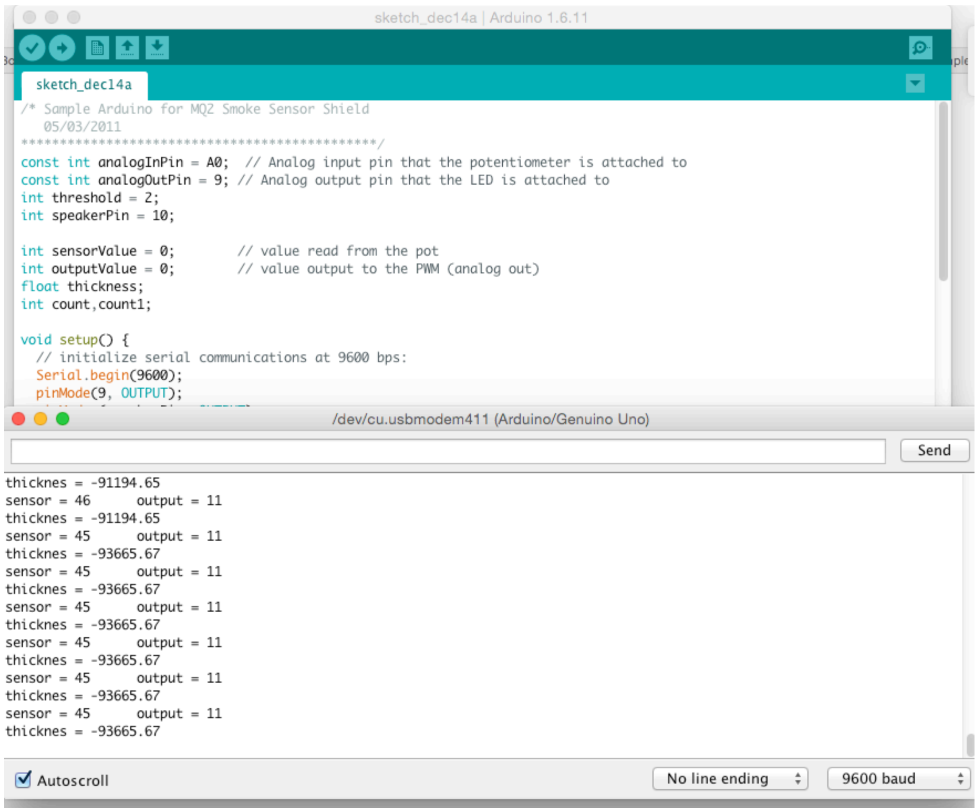
Appendix C: Adding MQTT library to Arduino



Appendix D: MQ2 Sensor Unit



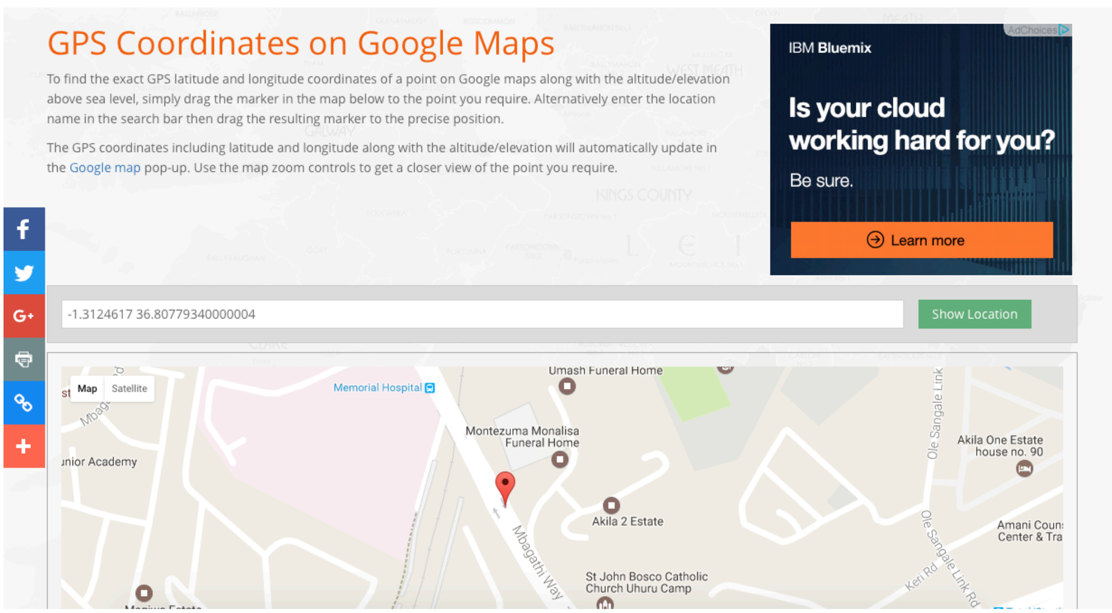
Appendix E: Serial Monitor readings from MQ2 sensor



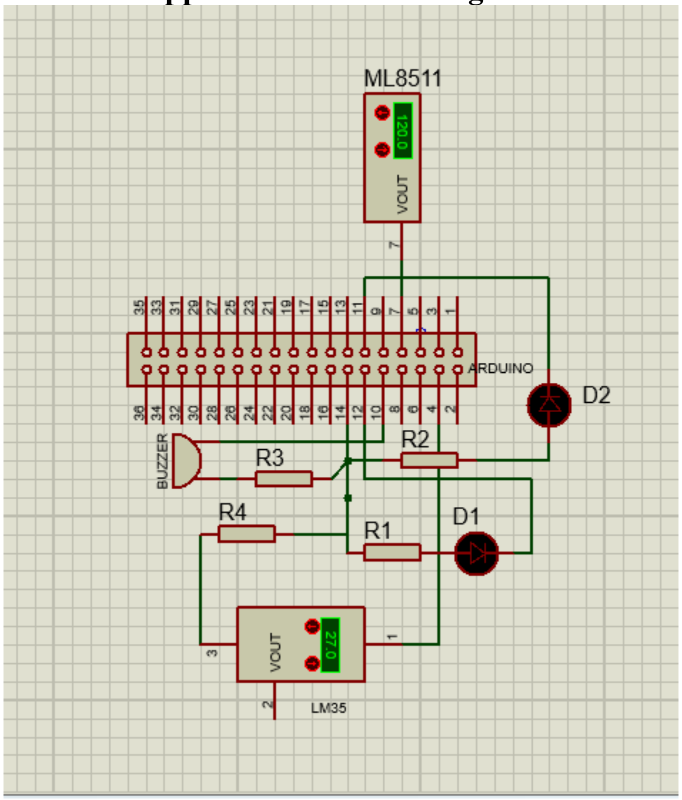
Appendix F: Serial monitor readings for Grove light sensor

Appendix G: Fire Department Text Notification with GPS Coordinates

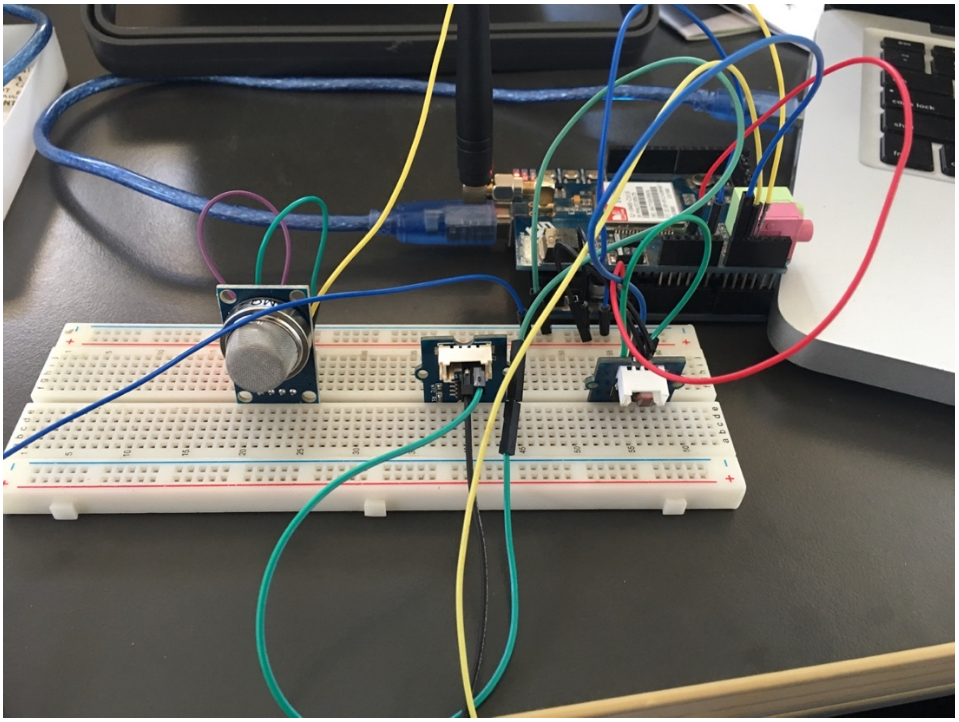
Appendix H: Extraction of physical location from GPS coordinates by the fire department



Appendix I: Circuit Diagram



Appendix J: The integrated prototype



Appendix K: Code for tesing the light sensor

```
int light;
void setup() {
//Setup Code:
Serial.begin(9600);
pinMode(A0,INPUT);

}

void loop() {
//main code:
light=analogRead(A0);
Serial.println("Light = " + String(light));
delay(600);


}
```

Appendix L: User Acceptability Questionnaire

User Acceptance Testing Questionnaire for the Multi-Sensor Fire Detection System

1. **Name(Optional)**

2. **What is your gender?**
   - Male
   - Female

3. **In the scale of 1-5, Please tick the best option for the following questions (5 = Excellent, 4 = Very Good, 3 = Good, 2 = Poor, 1 = Very Poor)**

   How do you rate the the functionality of the system in terms of performance?

Very Poor	Poor	Average	Good	Excellent

   How do you rate the system in terms of user friendliness?

Very Poor	Poor	Average	Good	Excellent

4. **Do you understand the concept of the system?**
   - Yes
   - No

   If No, which part do you not understand?

5. **Do you agree that the fire detection prototype can help in faster detection of fire outbreaks, can reduce loss of property and save lives?**
   - Yes
   - No

6. **Did you encounter any difficulty while using the prototype?**
   - Yes
   - No

   If yes, state the the aspect that was difficult?

Appendix M: Turnitin Report

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ORIGINALITY REPORT

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3	www.scribd.com Internet Source	2%
4	Sowah, Robert, Abdul R. Ofoli, Selase Krakani, and Seth Fiawoo. "Hardware module design of a real-time multi-sensor fire detection and notification system using fuzzy logic", 2014 IEEE Industry Application Society Annual Meeting, 2014. Publication	1%
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