Tinashe Randeni

BSc. Telecommunications

Final Year Project

GSM based Traffic Light fault Reporting System

DECLARATION

I Tinashe Randeni hereby declare that I am the sole author of this dissertation. I authorize the Midlands State University to lend this dissertation to other individuals or institutions for the purpose of academic research.

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APPROVAL

This dissertation entitled "GSM based Traffic Signal Fault Reporting System" by Tinashe Randeni meets the regulations governing the award of Bachelor of Science Honours Degree in Telecommunications by the Midlands State University, and is approved for its contribution to knowledge and literal presentation.

Supervisor: ……………………………………………………………

Date: ……………………………………………………………………

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ABSTRACT

Traffic signal breakdowns are a common problem in the CBD areas of cities and towns. When these breakdowns occur, unsafe road conditions for motorists and pedestrians emerge whereby there is chaos at intersections with each driver trying to proceed without considering other motorists. This leads to traffic jams, delays and collisions. This project aims to address the problem of prolonged traffic signal down time by designing a model traffic signal that uses SMS to automatically and instantly report two of the major faults that occur with traffic signals, that is physical damage and lights failure. For detection of physical damage it uses an accelerometer embedded at a fixed position inside the hollow structure of the pole. It uses the concept that an installed traffic signal will have its pole in a fixed position, and when it is hit by a vehicle in the case of an accident, it moves from the upright position and the accelerometer will detect this motion and registers it to the microcontroller which will then send a signal to the GSM module to send an SMS to the responsible personnel. For detection of light failure it uses a current sensor that is connected to detect the current flowing in the light bulb. When the current is detected to be below a set threshold it registers this to the microcontroller which will then send a signal to the GSM module to send an SMS. For the sake of demonstration of concept, the model was simplified to use one light bulb that has no ON and OFF timings.

LIST OF ACRONYMS AND ABBREVIATIONS

- AC - Alternating current
- API - Application Programming Interface
- ASP - Active Server Pages
- DC - Direct current
- GSM - Global System for Mobile Communications
- GPRS - General Packet Radio System
- GND - Ground
- HTML - HyperText Mark-up Language
- HTTP - HyperText Transfer Protocol
- IMEI - International Mobile Equipment Identity
- IMU - Inertial Measurement Unit
- I/O - Input/Output
- IP - Internet Protocol
- JSON - JavaScript Object Notation
- LED - Light Emitting Diode
- OOP - Object Oriented Programming
- PHP - Hypertext Pre-processor
- PIN - Personal Identification Number
- PLC - Programmable Logic Controller
- PCB - Printed Circuit Board
- Rx - Signal Reception
- SMS - Short Message Service
- SIM - Subscriber Identity Module
- TCP - Transmission Control Protocol
- Tx - Signal Transmission
- TTL - Transistor-Transistor Logic
- URL - Uniform Resource Locator
- USB - Universal Serial Bus
- WSN - Wireless Sensor Network

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CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Definition and Importance of traffic control

A traffic signal is a device that is installed on a road to control the flow of traffic by using three coloured lights which are Red, Amber (Orange or Yellow) and Green [1]. Traffic control is very important in urban settlements such as metropolitan areas, cities and towns. Without them, there would be chaos in the roads of these urban settlements. Road accidents would be commonplace especially at intersections.

1.1.2 History of Traffic Signals: early technologies and modern technologies

Early traffic signals were mechanical and were manually controlled by a police officer. Later on traffic signals that use electromechanically automated timers such as cam and motor systems were invented such that police officers were no longer needed to control the changing of signals. The control of traffic lights made a big turn with the inventions of the computer and semiconductor technology around the 1950s and 1960s. The electronic traffic signal came into being [1]. Most major cities and towns around the world have adopted these electronically controlled traffic signals. These electronic traffic signals can be controlled by a Programmable Logic Controller (PLC) or Microcontroller. Both of these devices are electronic and operate on the principle of the computer. In actual sense they are computer systems embedded into hardware equipment for automating some processes or applications [2]. These electronic devices have numerous advantages over their forerunners:

- They are easily reprogrammable whenever the situation changes.
- They do not suffer the problems of wear and tear experienced by the moving parts in mechanical and electromechanical devices thus system failures are less and long-term efficiency and reliability is increased.
- They can be interfaced with computer systems and other intelligent devices to increase functionality.
- They are less bulky.
- Once a program has been tried and tested, it can be easily transferred to other PLCs or microcontrollers, thus reducing implementation time, minimizing debugging and increasing reliability. [2]

1.1.3 The state of affairs in major City Councils of Zimbabwe (looking at Gweru and Harare)

Two of the major municipalities in Zimbabwe that were considered are Gweru and Harare. These municipalities have confirmed that they face challenges of keeping track of faults in their traffic signals. Gweru City Council faces a serious challenge on a systematic way of maintaining their traffic signals. They face very long periods of time such as going for two weeks without having some faulty traffic lights in the city being repaired. Gweru is smaller as compared to Harare and the traffic volumes are not high such that prolonged downtimes of traffic signals do not result in too much chaos on the roads. As for Harare, the situation is different because it is the capital city of Zimbabwe and it is densely populated. This also means that traffic volume is very high and hence the city cannot afford to have traffic signals going down for prolonged periods. For this reason, the department responsible for roads and traffic within Harare City Council has a good traffic signal support and maintenance department. Their major problem is that of knowing in real time when traffic signals go down or develop faults.

1.2 Motivation of Study

The motivation of this project is derived from challenges being faced in the countries major cities like Harare and Gweru whereby traffic lights at an intersection malfunction or go down and they take several days to be repaired because the responsible departments within the municipalities lack an efficient monitoring system. The motivation is also derived from several signal controlled intersections in the major cities which experience traffic jams and minor road accidents when traffic lights are not working. Therefore the design of such a system can help reduce chaos in city roads and accidents at these signal controlled intersections by alerting the personnel at the control office as soon as the traffic signal develops a fault.

Fig. 1.1 Picture of an accident that happened at a road intersection when traffic signals malfunctioned [3]

1.3 Problem Statement

Road engineering departments of urban councils are facing challenges in keeping track of their city traffic lights as to how can they tell when a system of traffic lights at an intersection has malfunctioned. They do not have real time traffic light monitoring systems that they can use. Currently they deploy personnel who do visual checks for functionality of traffic lights. Sometimes they are informed by the public and traffic police when traffic lights malfunction. There are several problems with this current setup however. With the economic situation that is prevailing in Zimbabwe at the moment, the councils cannot afford to employ enough personnel just to check on the functioning of traffic lights. Another problem is that when the public or traffic police report these malfunctioning traffic lights, it would be several hours or even days after the incident and hence motorists would have long suffered inconveniences such as delays or even road accidents resulting from traffic congestion. The effects are worse during traffic peak hours.

1.4 Research Questions

The study was guided by the following research questions:

- What are the weaknesses of the current system?
- What will be the main components and technologies required to design and build a system that will totally address the observed problems or weaknesses?

- What are the advantages and impacts of the successful implementation of a system that can alert the control office personnel of the failure or fault development of a given set of traffic signals?

1.5 Aim of the Research

To design a prototype system that can send traffic light fault notification messages to a control centre mobile station or computer using a GSM/GPRS module interfaced to the traffic signals' controlling or monitoring computer, which can be a microcontroller or PLC.

1.6 Objectives of the Research

- To have a microcontroller and sensor prototype system that can detect faults by measuring electric signals in the circuits/wirings of the traffic signal.
- To interface a microcontroller with a GSM/GPRS module and to program the system to send notification messages when specified faults occur on traffic signal either by SMS to a mobile station or over the internet using GPRS to a central computer.
- Instant detection of a fault that would have developed on a traffic signal.

1.7 Scope of the project

This project consists of a system that can detect two types of failure for a traffic light which are physical damage and light malfunctions. These types of failures are the major faults that occur to traffic lights as observed when the researcher visited the road and traffic engineering departments of Gweru and Harare city councils. The system can detect the presence or absence and level of electric current flowing in a traffic signal light using a current sensor. Physical damage happens mostly due to car accidents whereby the car swerves out of the road and hit the traffic signal pole. The system can detect physical dame by measuring motion and impact using an accelerometer. LED or bulb malfunction may happen due to long running time or power overload. The system measures the current flowing in the lights of the traffic signal using a current sensor. In each of these cases the responsible sensor and the microcontroller should function to detect the fault. The microcontroller will then generate an alert message that will be sent to the control centre computer or the operator’s mobile phone using HTTP protocol or SMS respectively through the GSM/GPRS module.

1.8 Dissertation layout

The dissertation was organized as follows:

Chapter 1 – The introduction. It covers on the background/history of traffic signals, problem statement, justification, aim and objectives of the project.

Chapter 2 – Literature review and theoretical aspects. It covers on the principles of traffic signals, technologies of interest to the project and related systems, projects or research work done previously by other researchers, scholars or organisations.

Chapter 3 – The methodology. This covers on the information gathering, system analysis and design of the hardware and software components pertaining to the project/research.

Chapter 4 – Testing and results. It is mainly concerned with the illustration and analysis of the results of the research/project such as testing of the developed prototype system for functionality and real world operability.

Chapter 5 – Discussions and conclusion. This chapter covers on the work plan of the project, costs of practical implementation, recommendations and conclusion of the project’s findings.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter covers the theoretical aspects of the project particularly looking at associated technologies to be used such as GSM/GPRS, sensors, C/C++ programming language, Arduino microcontroller board and similar projects that have been carried out in the past.

2.1.1 Types of traffic signals and overview of the working of traffic signals

i) The 3-Aspect Traffic Signal

The 3-aspect traffic signal is a traffic signal with three light sequences Green, Amber and Red. It is used for controllling vehicle traffic. It is the most common road traffic signal [4].

Fig. 2.1 The Three-aspect Traffic signal [4]

ii) The 2-Aspect Traffic Signal

A 2-aspect traffic light is a traffic light with two signals; usually it has the Green pedestrian and Red pedestrian. It is used for controlling pedestrians whether to stop or go at road intersections [4].

Fig. 2.2 The Two-aspect Traffic signal

iii) The 4-Aspect Traffic Signal

A 4-aspect traffic light is a traffic light with four light signals usually Green, Amber, Red and a Green Arrow for filtering some traffic during peak hours [4].

Fig. 2.3 The Four-aspect Traffic Signal

iv) The 1-Aspect Traffic Signal

A Single-aspect traffic light has one light signal [4].

Fig. 2.4 The single-aspect Traffic Signal [4]

v) Light bulb traffic signals and LED array traffic signals

Traffic signal can be made from light bulbs. If the traffic signal set uses bulbs, they are chosen to be 60 or 100 watt bulbs screwed to lamp holders with a silvery surrounding reflective surface. The meaning of the signal is then determined by the colour of the glass cover placed over the light bulb.

Fig. 2.5 Light bulb traffic signal

For traffic signal sets that use LEDs, an array of coloured light LEDs is placed on a black metal plate with a PCB back joined to it. The meaning of the signal is then determined by the colour of the light radiated by the LEDs when they are powered.

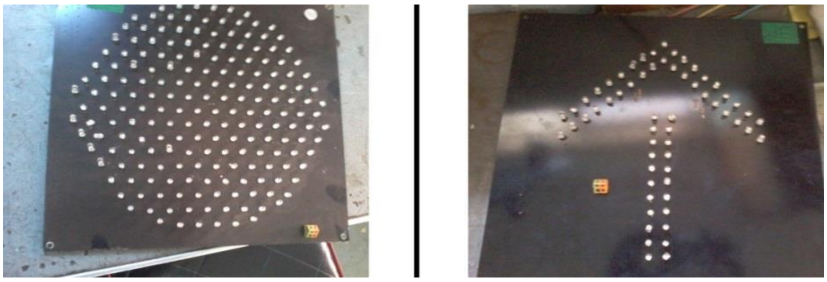

Fig. 2.6 LED array traffic signals

vi) Traffic Flow Charts and Control Programmes

All of these traffic lights work by illuminating an appropriate colour signal for a given period of time and in a specific sequence. The timings of these traffic signals are programmed into the controllers. Prior to programming of the controllers an activity called traffic counting is done whereby each intersection and its connected roads are observed over different times of the day to study the traffic statistics. The results of these traffic surveys are traffic flow charts which determine how the controller will be programmed.

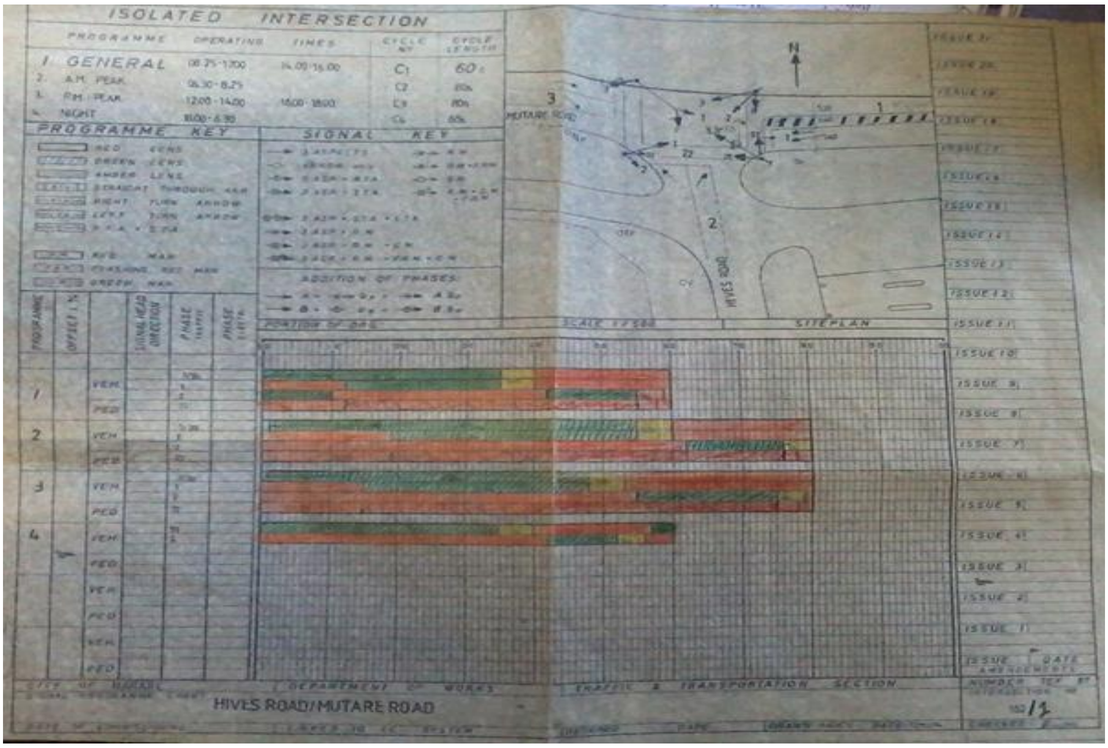

Fig. 2.7 Sample traffic flow chart of Hive Street and Mutare Road intersection [4]

The table below shows the information derived from the above traffic flow chart and it has been simplified to a three-aspect traffic signal that caters for vehicles only; for simplicity's sake.

Table 2.2 Operating times of different traffic control programmes

Programme	**Operating Times**	**Cycle Length t/sec**
A.M. Peak	06:30 – 08:25	80
General	08:25 – 12:00; 14:00 – 16:00	60
P.M. Peak	12:00 – 14:00; 16:00 – 18:00	80
Night	18:00 – 06:30	60

2.2 Related work

2.2.1 Cable theft monitoring system using GSM

GSM Commander is a GSM Telemetry Controller that is designed to effectively manage any unattended or remote site from a cellphone or a computer interface. The GSM Commander provides a 2-way communication via SMS, GPRS and voice call. GSM Commander can be used to monitor copper cable installations to detect if any vandalism or theft is happening. It can monitor copper cables installed for use as three-phase power lines, transformer cables, irrigation control cable, pivot cables, borehole pump cable and telecommunications cables [5].

i) Summary

Telecommunications companies still use copper as a medium for communications. Copper wire cables are also use in electrical equipment installations. Over the years copper cable theft has been a serious problem. The GSM Commander system is installed to monitor a copper cable section and send an SMS when any part of that section is cut. The responsible person can take immediate action after receiving the notification message. GSM Commander will be powered from a small solar panel. The battery on the solar panel is also monitored by the GSM Commander.

ii) Operational capabilities and features

- The GSM commander system operates by loop detection; if a cable is cut the loop will be broken hence triggering the alarm system.
- It has a logic controller with built-in GSM/GPRS functions
- It can send an SMS to multiple recipients when there is a cable cut
- It can also do a voice call or GPRS (internet)
- It has expandable hardware plugins
- Up to 32 opto-isolated digital inputs and up to 32 relay outputs
- 1 analogue input
- 10 – 24vDC power input with
- 1 backup battery input
- 2 temperature inputs
- Interface ports such as Serial port and audio port
- Dual SIM for redundancy
- External antenna jack

iii) Additional products of the GSM Commander system:

- BaseLogger software is developed to manage from 1 to 127 GSM Commander field devices, using SMS communication. It is a very cost effective system for basic site control and critical events reporting.
- Central Command software is developed for real time site management using GPRS communication. It has a web based user interface with unlimited GSM/GPRS Commander field device connections. A subscription based service for real time site control, critical events management and advanced reporting.
- PLC Commander: Another version of the GSM Commander, called the PLC Commander, is available. This unit is all the PLC-type functionality and easy-to-use configuration software, without a GSM module [5].

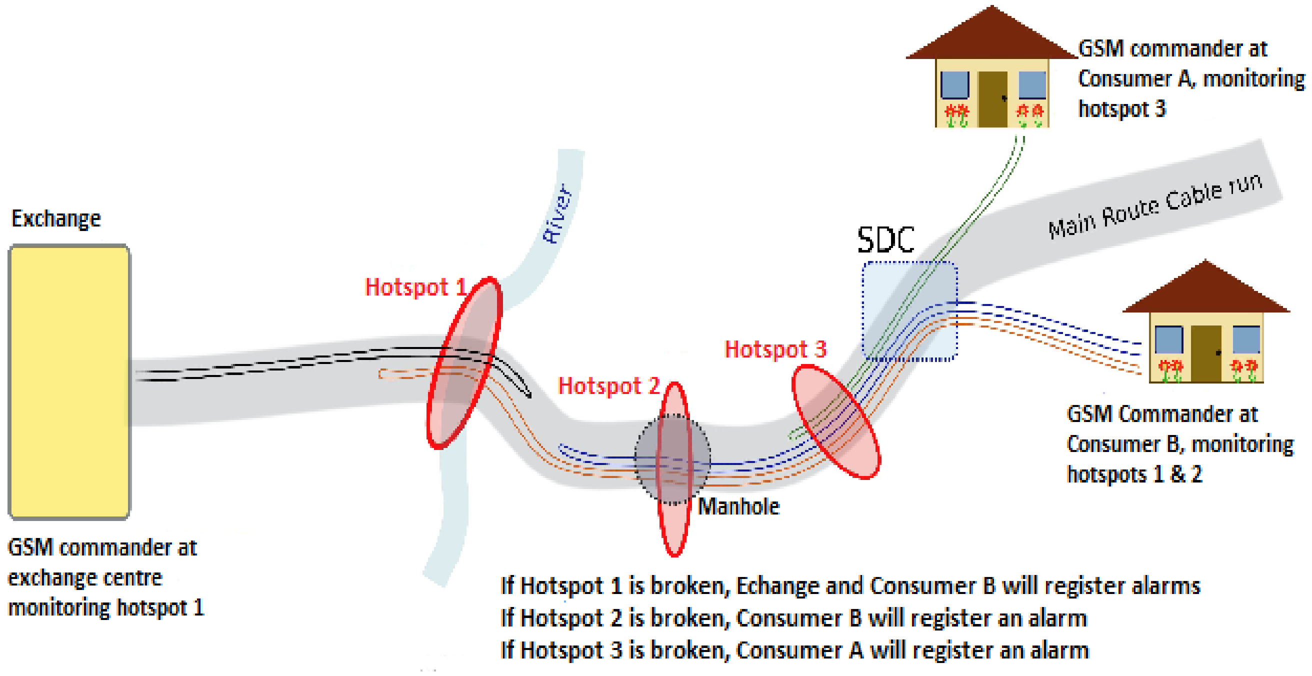

Fig. 2.8 Telecom copper cable monitoring setup using GSM Commander [5]

2.2.2 Fire detection and monitoring using Wireless Sensor Network (WSN) technology

Sensors which use the ZigBee communication protocol to communicate information to a sensor proxy are deployed within an environment of interest such as a fire prone area. The sensors are of various types so that they enable the system to detect various parameters. In the case of automatic fire detection and monitoring, it would be gas sensors for detecting Carbon dioxide (CO_2) level, Carbon monoxide (CO) level, Oxygen (O_2) level, thermocouple for detecting temperature, moisture sensor for humidity and a camera for capturing photographic imagery. The sensor proxy is part of a Local Alerting Control Unit that communicates to a computing subsystem that is used for remote monitoring by personnel [6].

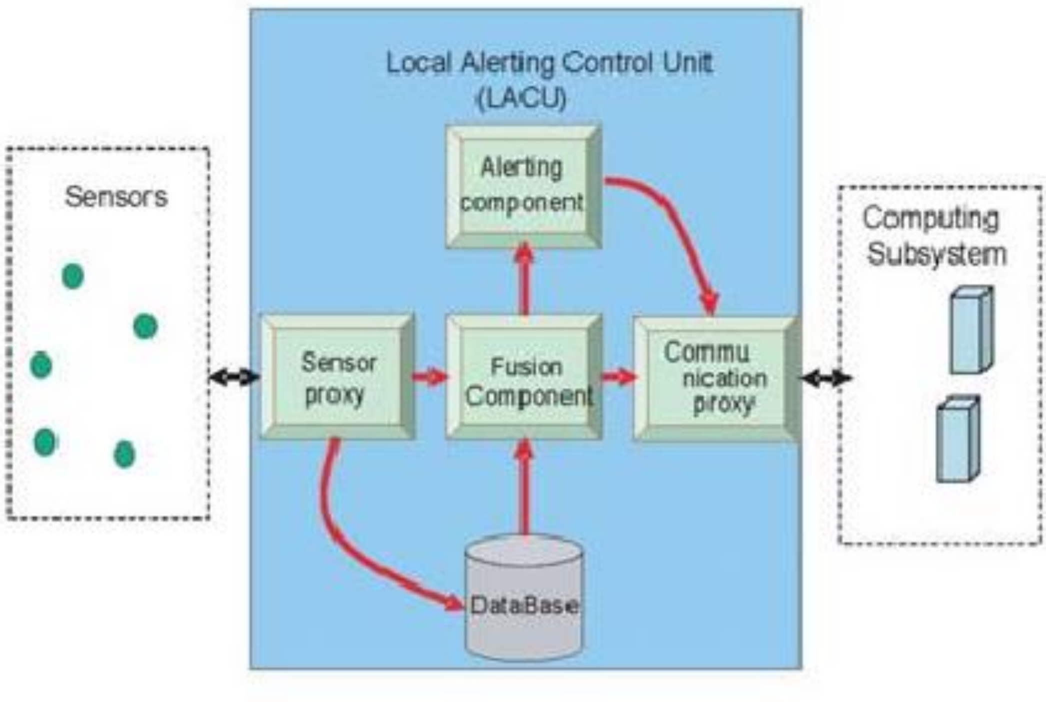

Fig. 2.9 System Architecture for a Fire Detection and Monitoring system [6]

2.2.3 Monitoring System for Traffic Lights

This system can detect two types of failure, power failure and bulb/LED failure (a particular light not working i.e. red light only or green light only). Upon receiving the power failure signal, an SMS will be send to the responsible parties for further action. For LED types of traffic light the system has the capability to detect deterioration in function. If less than 50% of the LEDs for any traffic signal are not working the system will notify the contractor and other related parties to perform preventive action. The malfunction of LEDs can be detected by measuring real current versus the nominal current for that particular signal. The degrees of traffic light failure are divided into three parts which is the total power failure, total LED failure and partial failure. The microcontroller analyses the degree of the failure and sends the signal to a GSM module. The GSM module will then send the details of failure including location and types of failure [2].

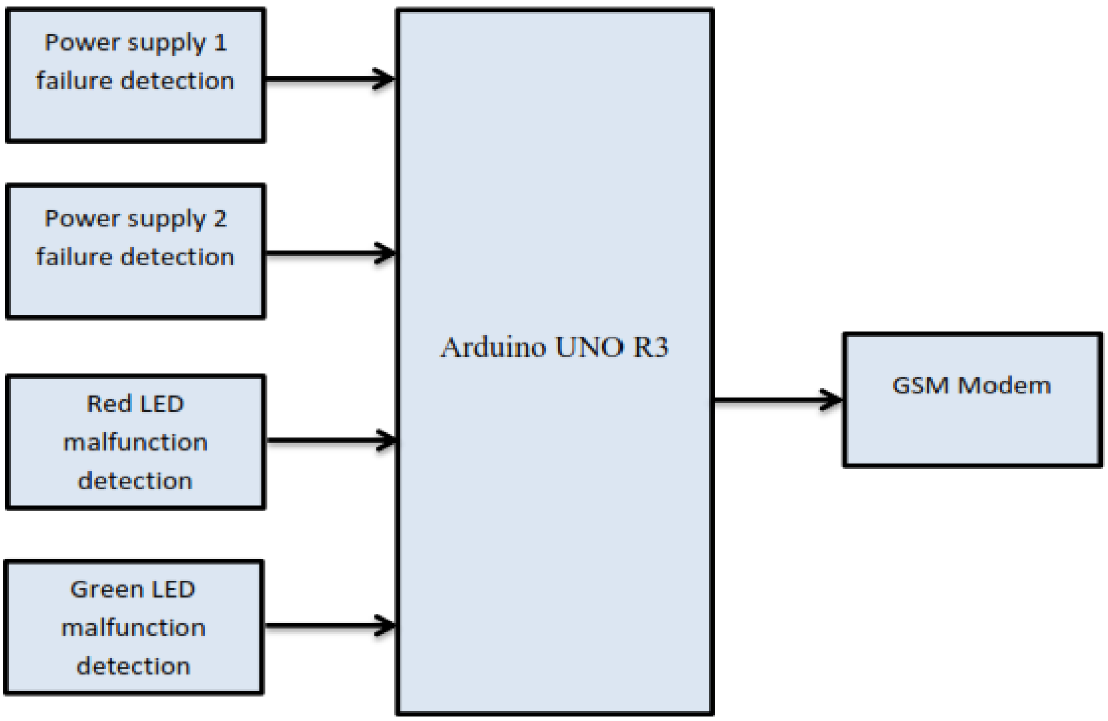

Fig 2.10 Monitoring System for Traffic Lights Block diagram [2]

2.3 Definitions of various devices, technologies and their specifications

The following are devices, concepts and technologies that the project hinges on.

2.3.1 Sensors

A sensor is a device that detects or measures a physical property and records, indicates, or otherwise responds to it [7]. The sensors used in the system are the accelerometer and current sensor.

i) Accelerometer

An accelerometer is a device that senses acceleration [7]. It is a type of IMU (Inertial Measurement Unit). In essence an accelerometer measures force not acceleration. It just happens that acceleration causes an inertial force that is captured by the force detection mechanism of the accelerometer. A gyroscope is another type of IMU sensor. It is a device that senses inclination or tilt or rotational motion. Thus it essentially measures rotation by an object. A magnetometer is also another type of IMU sensor. It senses inertia by comparing the magnetic field of its particular location to the magnetic field of the Earth as a whole [7]. IMU sensors are usually available as a combination of two or three of these sensor types. A device that is a combination of all the three IMU sensors was found for the project. It is called a GY85 IMU sensor. In order to use a particular function, there is need to have the particular device driver library installed and referenced when writing code to use it. For this project the accelerometer function was deemed sufficient to detect physical damage to traffic signals whereby traffic signal poles are hit by cars in case of accidents. The traffic signal pole is setup in a vertical position and after being hit by a car it usually drifts from the vertical position depending on the force of impact and so the IMU sensor can detect that inertial force and inclination hence enabling the system to detect if a traffic signal pole has been hit.

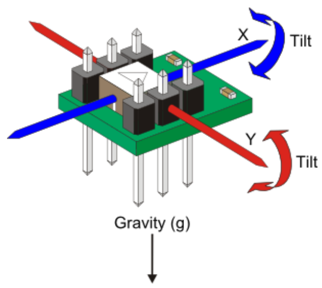

Fig. 2.11 IMU sensor: function illustrative diagram

Fig. 2.12 IMU sensor: GY-85 model

ii) Current sensor

A current sensor is a device that detects and converts current to an easily measured output voltage, which is proportional to the current through the measured path [7]. The current sensor was identified as an ideal sensor to use for detecting the functionality of lights of a traffic signal. The model used for the project is the ACS 712 with 5A current rating.

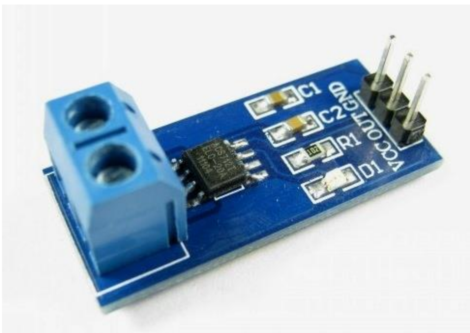

Fig. 2.13 Current Sensor model ACS 712

2.3.2 Light Emitting Diode (LED)

It is an optoelectronic device which generates light from the electron-hole recombination mechanism. LEDs of different colours were used in the project, namely Green, Amber and Red the colours used by road traffic signals. The color of the light from an LED is determined by the energy gap between conduction and valence band of the semiconductor used, which determines the energy that the photon generated by the recombination mechanism has. Being a diode, it's characterized by a threshold voltage (of about 1.8 to 5 V depending on the colour), below which the current is nearly zero, and beyond which the current increases in an exponential fashion. In a first approximation, the voltage is considered almost constant and equal to the threshold. Most LEDs require a current limiting, for which usually a series resistor is used [7].

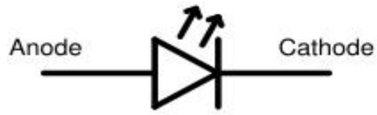

Fig. 2.14 Schematic Symbol of the LED

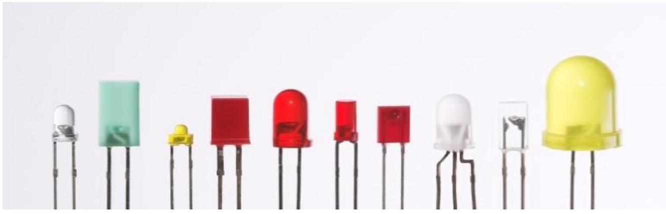

Fig. 2.15 Physical structure of the LED

2.3.3 Light Bulb

A light bulb is an electric lamp consisting of a translucent glass housing that contains a wire filament usually made from tungsten that emits light when heated by electricity [7]. They are available in different sizes and power ratings. For this project, the prototype model was designed to use either an LED or a small light bulb as the traffic signal light.

2.3.4 Communication device: GSM/GPRS module

A GSM/GPRS module is used to establish communication between a computer and a GSM-GPRS system [19]. Global System for Mobile communication (GSM) is an architecture used for mobile communication [10]. Global Packet Radio Service (GPRS) is an extension of GSM that enables mobile internet data transmission [7]. The GSM/GPRS module consists of a GSM/GPRS modem assembled together with other circuitry such as power supply and communication interfaces for connectivity to computing devices like microcontrollers, PLCs and desktop computers. It requires a SIM (Subscriber Identity Module) card just like mobile phones to activate communication with the network. It also has the IMEI (International Mobile Equipment Identity) number similar to mobile phones for their identification [8]. The model that has been identified for use in this project is the SimCom SIM900. Its specifications and structure are as shown below.

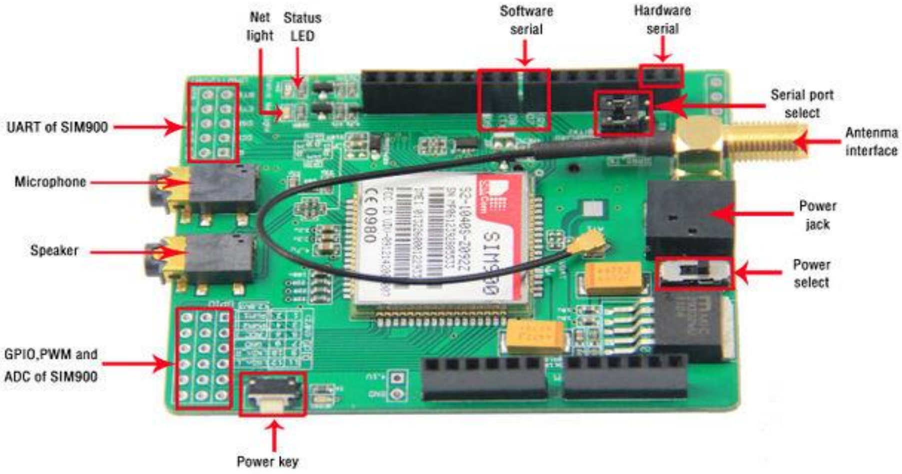

Fig. 2.16 SIM900 GSM/GPRS Module

i) Specifications of the SimCom SIM900 GSM/GPRS Module

- Quad-Band 850 / 900/ 1800 / 1900 MHz
- GPRS multi-slot class 10/8
- GPRS mobile station class B
- Compliant to GSM phase 2/2+
- Class 4 (2 W (AT) 850 / 900 MHz)
- Class 1 (1 W (AT) 1800 / 1900MHz)
- Control via AT commands - Standard Commands: GSM 07.07 & 07.05 | Enhanced Commands: SIMCOM AT Commands.
- Read, add, search phonebook entries of the SIM.
- Make, Receive, or reject a voice call
- Short Message Service – for sending and receiving of small amounts of data over the network (ASCII or raw hexadecimal).
- Embedded TCP/UDP stack - allows you to upload data to a web server.
- RTC supported.
- Selectable serial port.
- Speaker and Headphone jacks
- Low power consumption: 1.5mA (sleep mode)
- Industrial Temperature Range: -40°C to +85 °C

ii) AT-Commands

AT commands are instructions used to control a modem. AT is an abbreviation of Attention. Every command line starts with "AT" or "at" as the prefix. This prefix informs the modem about the start of a command line. It is not part of the AT command name. For example, D is the actual AT command name in ATD, and +CMGS is the actual AT command name in AT+CMGS [9]. The MODEM needs AT commands, for interacting with the computer, which are communicated through serial communication. These commands are sent by the computer. The MODEM sends back a result after it receives a command. Different AT commands supported by the MODEM can be sent by the computer to interact with the GSM and GPRS cellular network.

iii) SIM Card and PIN Code

In addition to the GSM/GPRS module, a SIM (Subscriber Identity Module) card is needed. The SIM card enables the GSM/GPRS module to communicate over a mobile cellular network of a particular communications service provider. By default SIM cards usually come with a four-digit PIN (Personal Identification Number) code for security purposes. This code must be noted and specified in the firmware source code of the microcontroller as it is necessary for the SIM card to work. Another option will be to disable the PIN request and have the SIM card operate with no PIN code.

2.3.5 Notification System

Two methods of notification could be used, SMS and Web server-client system.

i) Short Message Services (SMS) Notification System

SMS is a mobile cellular service that allows sending of short text messages with a maximum of 140 or 160 characters including spaces. Communication of the traffic light fault notification system and the monitoring person can be achieved by use of SMS, whereby a text message is sent to the mobile phone of that person whenever a fault is detected.

ii) Web server and Web client Notification System

HTTP is a communication protocol that uses the Transmission Control Protocol (TCP) to transfer hypertext requests and information between web servers and web browsers (clients) [10]. The hypertext requests are the web pages. The fault notification system can be programmed to act as a web server whereby it generates webpages that contain the fault messages and serve them over the internet. The web client will be the browser of the monitoring workstation at the traffic signal monitoring office that has a connection to the internet. The packet data communication feature provided by the GPRS architecture will be used to carry this HTTP data traffic. To enable this functionality the code developed for the microcontroller should have a reference TCP port number and a URL (web address/uniform resource locator) that will be used by the web client to listen for HTTP data traffic. As for the computer at the office, additional programming is needed. A web service is created that allows interfacing of the client web browser and the fault notification system web server. An API (Application Programming Interface) is an interface between one software program and another [20]. A specific API could be developed for this system that enables interfacing of the web client on the workstation and the web server software running on the microcontroller. Programming and/or scripting languages like Java, JSON, ASP, PHP and Python etc. can be used to develop this API and integrate it with the Arduino C/C++ code.

2.3.4 Control Unit: Arduino Uno R3 board

Arduino is an open-source electronics prototyping platform [16]. In order to prototype an electronic control system there is need for a microcontroller and the Arduino IDE compiler installed on a desktop computer. The Arduino Uno is a single computing board based on the ATMEL ATmega328 microcontroller. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, an on-board resonator, a reset button, and holes for mounting pin headers for associated modules [11].

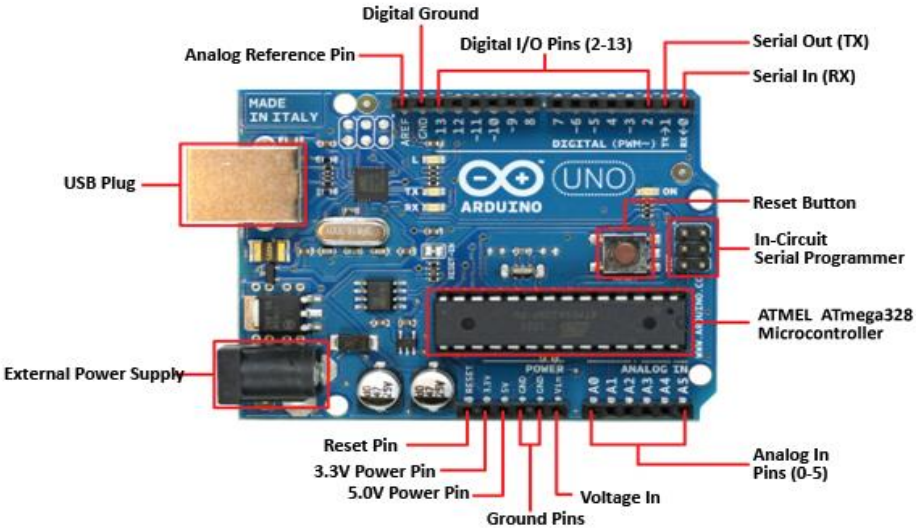

Fig. 2.17 Structure of the Arduino UNO R3 board

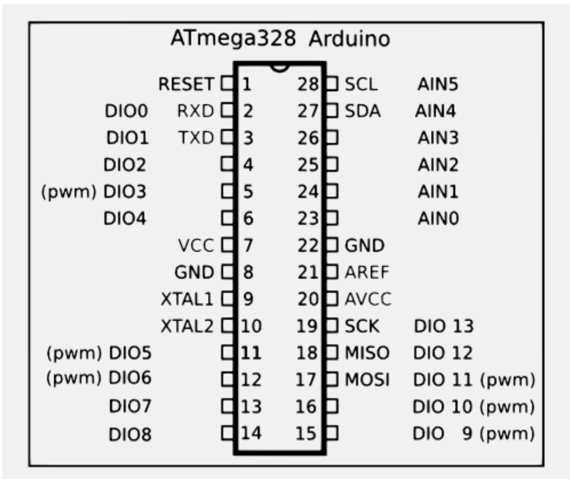

Fig. 2.18 Atmel ATmega328 microcontroller structure

2.3.5 Microcontroller programming tool: Arduino IDE

The Arduino IDE (Integrated Development Environment) is the software development platform for the microcontroller hardware [11]. It is the programming tool which has a C/C++ code editor and compiler. It is used to develop the program code that is written to the Arduino board and to determine its functions and how it controls the other devices connected to it [11]. The Arduino IDE program is installed on a desktop computer and written code is verified for errors, compiled then uploaded to the microcontroller using an interface such as USB or RS232 port depending on model version.

2.3.6 The C/C++ Programming Language

C/C++ is a high level computer programming language developed by Bell Laboratories. It was originally developed as C, a general-purpose and imperative language that supports structured programming. Later on C++ was developed as an extension to the C language with OOP (object-oriented programming) features. C++ compiler and editor programs are compatible with C hence the programming language being referred to as C/C++ more often in present times [12]. C/C++ is well suited for developing high level code for controlling machinery because by design it provides constructs that map efficiently to typical machine instructions, and therefore it is well suited for use in applications that had formerly been coded in assembly language such as embedded systems [12]. Other advantages of using C/C++ are that it improves software-development productivity. It is an OOP hence it is modular and provides separation of duties in object-based program development. It can be updated in case of improvements and bug fixes, without a need to make large-scale changes. Lower cost of development: the reuse of software also lowers the cost of development. OOP languages come with libraries of objects and header files for code developed during other projects that are reusable in future projects. Higher-quality software: Faster development of software and lower cost of development allows more time and resources to be used in the verification of the software [12].

2.3.7 PLC (Programmable Logic Controller)

A PLC is a computer-type device purpose-built to perform logic functions to control industrial equipment as previously accomplished by electromechanical relays, mechanical timers and counter sequence controllers [13]. In real world situations, traffic signal systems use PLCs as control units.

2.3.8 Comparison of a PLC to a Microcontroller

PLC and microcontroller are basically the same. They are computer based controllers with processing power, memory and input/output interfaces and they are re-programmable. A PLC actually has more microcontrollers as its central processing unit and has more memory capacity. The main difference is that the PLC is a dedicated controller designed for industrial usage, thus it is more robust. It contains the various types of I/Os (Inputs and Outputs) that suitably match with the industrial instrumentation and plant control interfaces. It is programmed using the Ladder Logic language with hand-held programming units. It can also be programmed using the standard programming interface whereby the PLC programming software is installed on a desktop computer. The overall system is modular, i.e. a user can add modules to increase the PLC’s Inputs and Outputs. However the microcontroller provides the TTL logic outputs that can be programmed in assembly language or a C/C++. All the same, when the control programming is interpreted and compiled in either a PLC or a microcontroller it ends up as machine code. The microcontroller is available as a single chip solution for smaller applications that use low power levels thus it does not suffice in the automation and control of huge applications that use high power levels such as industrial plants [2]. However it is well suited for use in prototyping small electronic control systems hence its use in this project.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter discusses the systematic research methods, system analysis and design used for this project. These include the information gathering techniques used and the design formulation, system schematics design and implementation. As originally proposed, the aim of this project was to design and implement a traffic signal system that can be monitored for fault occurrence due to accident damage and lights failure. The monitoring system consists of a Current Sensor (ACS712), Gyro-accelerometer-magnetometer (GY85 IMU sensor), GSM/GPRS module (Sim900), and a microcontroller board (Arduino Uno R3).

3.2 Research Design

A research design is a detailed outline of how an investigation will take place. As for this project, the research design involved the following:

- Identification of research areas and establishment of the research problem
- Information gathering
- System requirements analysis and specification
- System design
- Implementation and Component Testing (Prototype building)

3.3 Identification of research areas and establishment of the research problem

The areas of research identified for this project were the cities of Harare and Gweru. The researcher chose these cities because of convenience of frequent travelling between the two cities and to reduce travelling costs that could be incurred in of visiting other major cities such as Bulawayo and Mutare. These cities are two of Zimbabwe's major cities, with Harare being the capital city and also the largest city in the country in terms of population, road traffic volumes and geographical area. Therefore findings from these cities can fairly be considered to represent the other cities within the country. The major problem discovered from the operation of traffic lights within these cities is that of quickly determining when a traffic signal at a particular location developed a problem so that maintenance personnel can be deployed quickly to the site to attend to the fault. City of Gweru was said to have no field surveillance personnel who check on the functionality of traffic lights due to lack of financial backing to employ such personnel. As for city of Harare, they task assistant technicians from the traffic lights maintenance when they are not busy, to do patrols in the CBD area. They also rely on being informed of traffic signal failures by the public and traffic police. Another finding was that most of the faults they attend to were due to lights failure and physical damage when traffic signal poles get hit by vehicles in case of road accidents that occur at intersections.

3.4 Information gathering techniques used

The researcher employed a number of techniques in order to collect the data. He utilized various techniques and tools in this process.

3.4.1 Field visits to traffic signal sites

Site visits were done to visually monitor the traffic signals operating at various intersections.

3.4.2 Participatory method

The researcher took part in the work of maintaining traffic lights. A short internship was arranged at Harare City Council's Traffic Lights Section within the Road Engineering and Public Works Department.

3.4.3 Interviews and consultations

Relevant staff members at the city councils of Gweru and Harare as well as other professionals and academics with knowledge of the relevant fields were interviewed to gather some of the information required.

3.4.4 Photographing

Some images of physical objects were captured as photographs using a camera. Some of the pictures used as illustrations for traffic signals and charts were photographs taken at the Harare City Council Traffic Lights Maintenance Workshop.

3.4.5 Hard copy literature

The researcher acquired some of the information from hard copy literature such as manuals, technical data sheets, text books and magazines. For example, in-house manuals at the Harare City Council Traffic Lights Maintenance Workshop were a source of some of the information especially on PLCs and traffic flow charts.

3.4.6 Online material

The researcher also used various materials from the internet such as demonstration videos, device libraries, device data sheets, past research papers and pictures.

3.5 System Requirements Analysis and Specification

The system requirements for the prototype mainly include the hardware components and the associated software.

3.5.1 Hardware

- Arduino Uno R3 computing board (Atmel ATmega 328p microcontroller)
- GSM/GPRS Shield for Arduino (SimCom SIM 900) with SIM card
- Gyro-accelerometer-magnetometer (GY-85 IMU sensor)
- Current Sensor (ACS712-5A)
- Connecting wires
- Model Traffic signal pole (accessorized metal cylinder)
- 2 by 9V cells (power source)
- 6V, 0.5A Light Bulb
- Wooden boards
- Breadboard

3.5.2 Software

- Windows 7 (development computer's operating system)
- Arduino IDE (C/C++ editor and compiler for Arduino boards hardware)
- Device libraries
- Source code

3.5.3 Other tools and accessories

- Soldering gun and solder wire
- Screw drivers
- USB cable
- Insulation tape

3.6 Design

This includes the technical planning, drafting of technical drawings and producing of schematic layouts of how the different hardware components and software programs will be connected together and manipulated to implement a functional system [18]. In this project a plan was laid out to design a model traffic signal pole; to design the system circuitry connections comprising of the electronic hardware components as well as a design of how the system's program (firmware) will work using a flow chart.

3.6.1 Conceptual design of the traffic signal pole

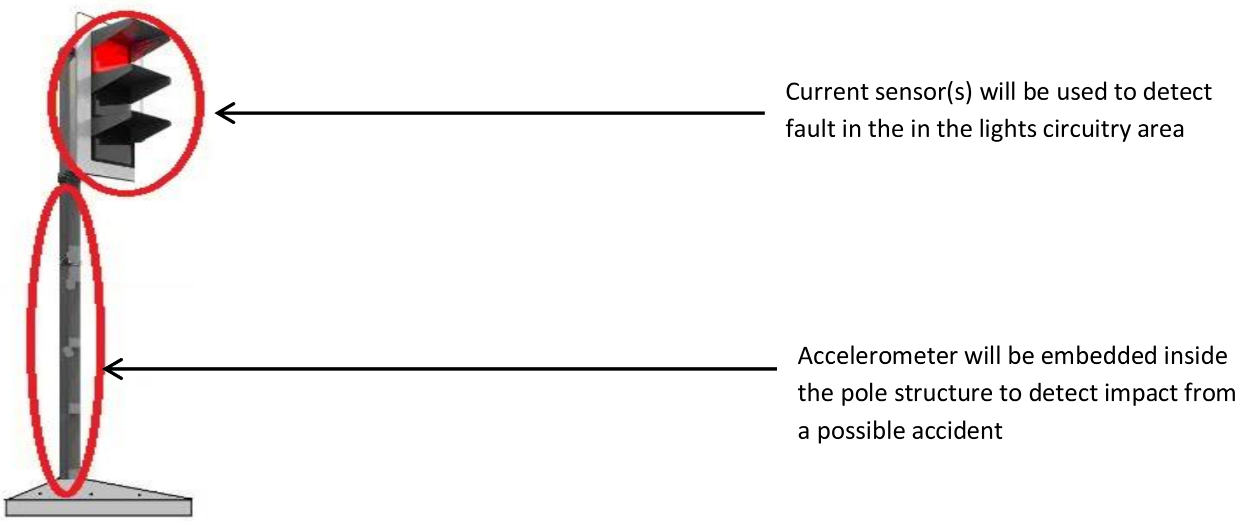

Fig. 3.1 Conceptual traffic signal pole design

3.6.2 Model traffic signal pole design

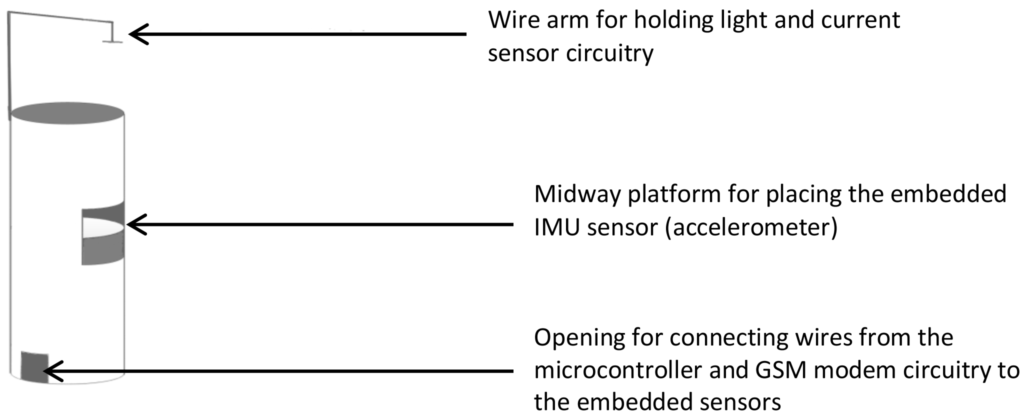

Fig. 3.2 Model traffic signal pole design

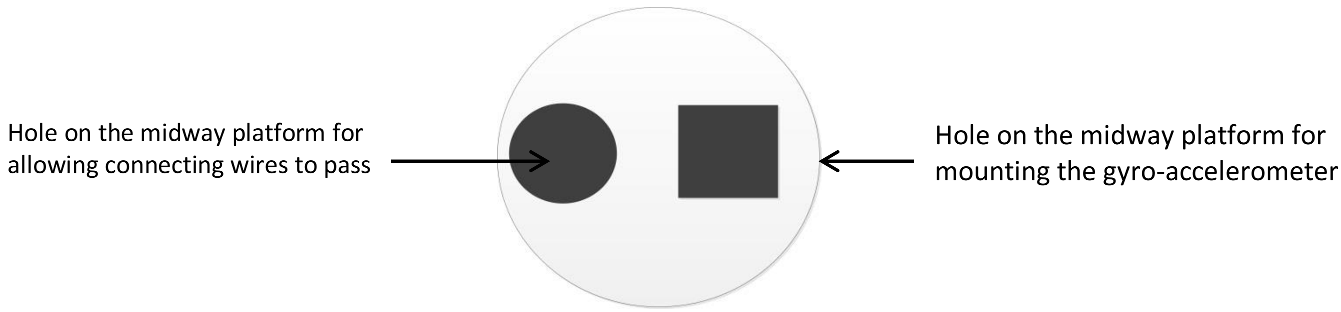

Fig. 3.3 Top-view cross-section of the model pole – midway platform design

These designs shown in the above diagrams were used in machining a structure that is shown in the picture below. The wire arm suspending from the top is for holding a wooden board where the light bulb is fixed.

Fig. 3.4 Actual traffic pole model that was made in a mechanical workshop

3.6.4 System program design

This is the logical design of the system. The C/C++ code to be written for execution by the microcontroller as firmware is depended on the logic depicted in this system flow chart.

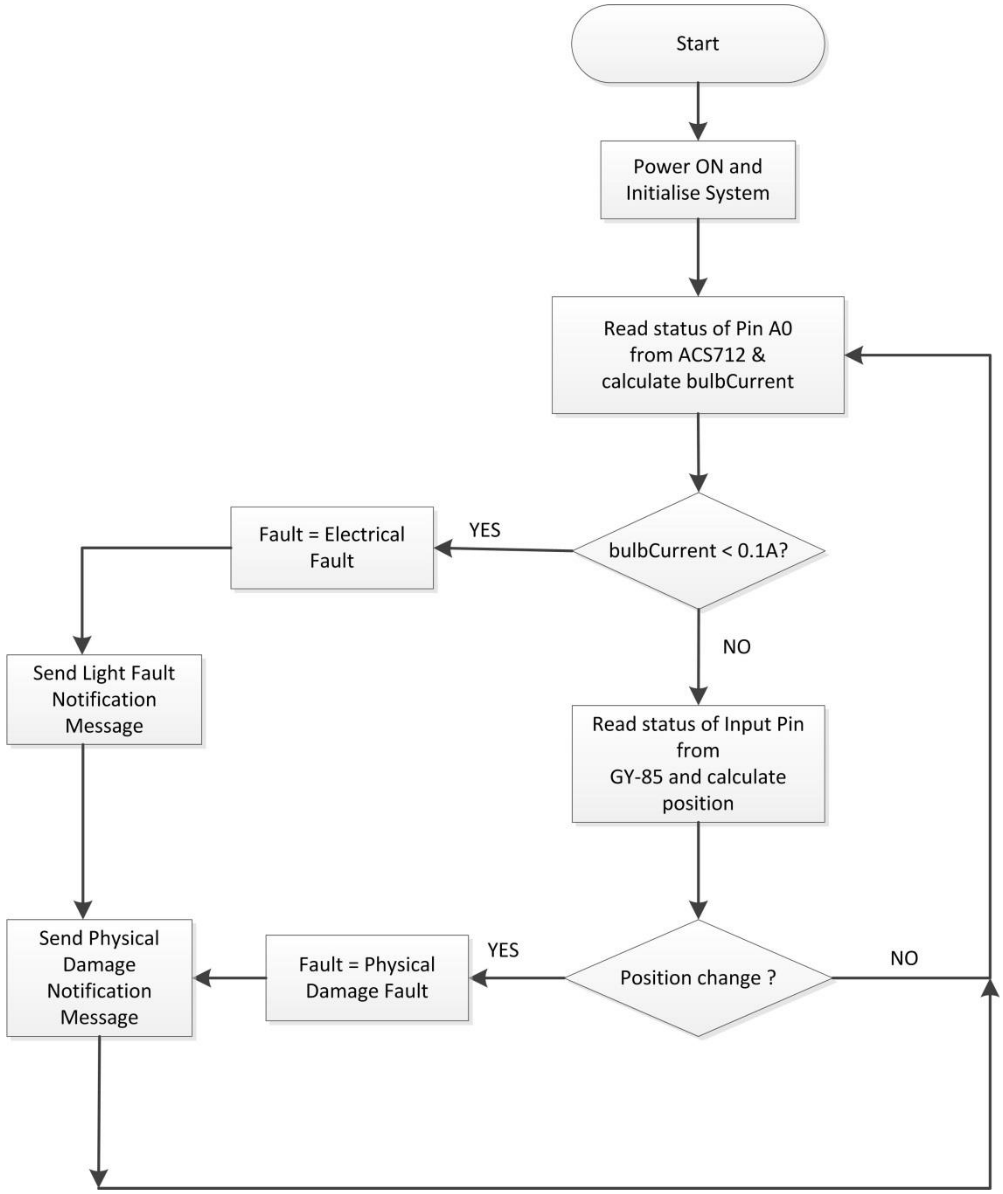

Fig. 3.5 System program flow chart

3.7 Implementation and Component Testing (Prototype building)

Implementation is the stage where the conceptual system is actually materialized. The system is put together beginning in parts. In this project, each of the three major components - GSM/GPRS module, ACS712 Current sensor and GY85 IMU sensor was initially connected with the microcontroller without any other device in the circuit. As for the 9-Volt cells it was tested with the bulb and its output voltage was measured with a multimeter. The light bulb was tested for continuity with a multimeter and it was also connected to the cell to confirm if turned on. After the individual components were tested separately, they could be used to build the whole system stage by stage.

3.7.1 Interfacing the Arduino Uno Board and the Sim900 GSM/GPRS module

The Arduino UNO microcontroller board and the GSM/GPRS module were interfaced together by plugging the connector pins of the GSM/GPRS into the corresponding connector holes on the Arduino Uno microcontroller board.

Fig. 3.6 Sim900 GSM/GPRS module mounted onto the Arduino Uno board using the pins and pin holes [#]

A test SMS was sent from the GSM/GPRS module using a serial monitor command from a desktop computer as the trigger event and it was successful.

3.7.2 Interfacing the ACS712 Current Sensor and the Arduino Uno board

Table 3.1 ACS712 Current sensor to Arduino Uno board pin connections

ACS712 Pin	Arduino UNO Pin hole	Jumper/wire colour
Vcc	5V	Red
OUT	A0	Yellow
GND	GND	Black

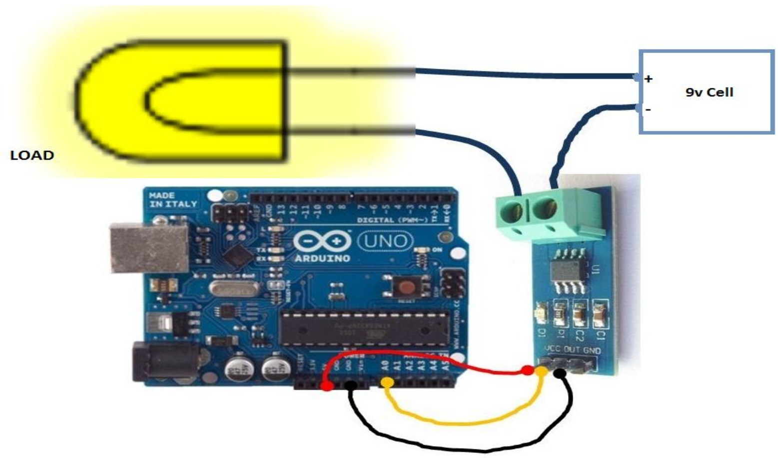

Fig. 3.7 Illustration of interfacing of ACS712 current sensor to Arduino Uno together with power cell and light bulb

Initially the currents sensor was connected to the microcontroller on its own without the bulb and cell to determine its voltage reading when there is no current and the output was send to the serial monitor of a desktop computer for viewing. Theoretically it is supposed to be 2.5V. It was determined that the current sensor gave readings in digital raw data with a range of 0 to 1023. So a formula was needed to change the digital raw data to current values in Amperes. The data sheet of the ACS712-5A current sensor was used to check the sensitivity (conversion factor) and it was determined to be 185mV/A. The formula was determined to be:

$$\left(\frac{510-currentSensorRawData}{1023}\right)*\left(\frac{5}{0.185}\right) \text{Amps} \quad \text{…………… ………… (1)}$$

And it was simplified to: $\left(\frac{510-currentSensorRawData}{1023}\right)*27.03 \text{ Amps}$ ………………………. (2)

This formula was used in the C/C++ code to determine the values of the analog current detected by the ACS712-5A current sensor. The current sensor was then connected with the light bulb to determine its average current of the light bulb when functioning normally as expected. The light bulb used was nominally rated at 0.5A but an actual average reading had to be determined to avoid errors in the system design. It was determined that it normally functioned at a current of 0.33A. So the trigger condition for light bulb failure in the model traffic signal was set to be at any reading below 0.1A. Prior to using the bulb in the circuit, an LED was used. The LED had the problem of registering a very low current that was not very much different from 0A. So given the relatively low sensitivity of the current sensor that was used, the LED was rejected because it could not be used for building this prototype system.

3.7.3 GY85 inertial sensor with the Arduino Uno board

Table 3.2 GY85 IMU sensor to Arduino Uno board pin connections

GY85 Sensor Pin	Arduino UNO Pin hole	Jumper/wire colour
3.3V	3.3V	Orange
GND	GND	Black
SCL	A5	Green
SDA	A4	Blue

The GY85 sensor was determined to be a 3 in 1 Inertial Measurement Unit (IMU). It can function as an Accelerometer, Gyroscope and Magnetometer. The Accelerometer function of the GY85 IMU was utilized for this project. The reason is that its driver library and header file (ADXL354) were easy to work with by not giving errors during program compile time. The accelerometer also gave raw digital data readings for the 3D plane i.e. X, Y, Z. It was difficult to find a position that was considered a stable one, so the GY85 IMU sensor was embedded inside the model traffic signal pole with the jumper wires already soldered into its connector holes. Whatever position it took as it settled inside, it did not matter. Some code was written in such a way that the GY-85 would trigger sending of a message if a deviation in any plane by a set threshold was detected.

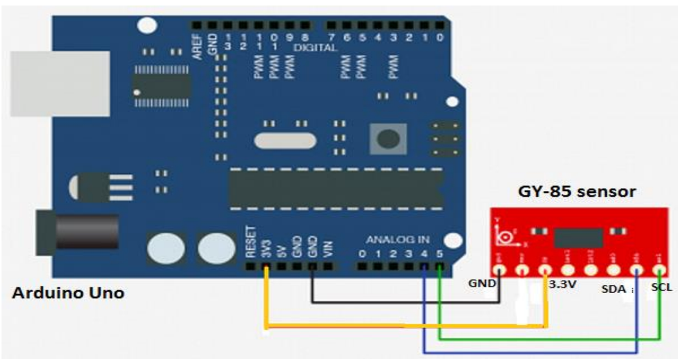

Fig. 3.8 Illustration of interfacing of GY85 IMU sensor to the Arduino Uno board

3.7.4 Coding

During the coding phase, an appropriate programming language, development software and a computer are used to program the system. For this project, Arduino C/C++ was used. The code of the whole system was built by integrating the separate programs written during the stage of testing the individual components with the microcontroller and a few modifications were done.

The system code was written following the logic depicted in the system program flow chart that was drafted during the design stage. As the norm in programming, bugs do crop up. Some functions that were initially coded failed to give desired results and different approaches had to be used. Some coding even yielded errors during program compile time, due to syntax errors and violations of the programming language rules. In such cases, error finding and debugging was done to check for these errors and correct them. As for the code functionality, the SMS messaging system was implemented because of its simplicity and it takes less time to program. The functionality of web messaging was complex and it was going to take longer to implement the system.

CHAPTER 4: SYSTEM TESTING & RESULTS

4.1 Introduction

This chapter presents the findings of the research project and test results from the prototype system designed and its relevance to solving the real world problem.

4.2 Functional Test Results

Functionality testing is system testing that is performed to verify that a system performs and functions correctly according to design specifications.

4.2.1 SMS Notification when a traffic light malfunctions

The results observed from the prototype system were as per expectations. The system sends an SMS to the targeted mobile station if the current flowing in the bulb is detected to be too low or if the current is not present at all, hence indicating that the light has a fault. To simulate a traffic light failure, a wire connecting the light to one of the cell terminals is removed. This results in the sending of an SMS being generated to the targeted recipient.

4.2.2 SMS notification when motion of the traffic pole structure is detected

The system sends an SMS to the targeted mobile station if motion of the traffic pole structure is detected. The model traffic signal pole can be tilted to incline from the normal vertical position to trigger sending of an SMS. This action simulates a real world situation whereby a traffic pole is hit by a vehicle in a road accident.

4.2.3 Functionality Test Results Presentation

The sensors, microcontroller, GSM/GPRS, bulb and model traffic pole were integrated to form a model system that yielded some test results. The prototype system test results are discussed in the following sections.

i) Light failure test results presentation

The picture below shows the light bulb switched off to simulate failure.

Fig. 4.1 Manually switched off light bulb (Light failure simulation)

The picture below shows the SMS that was sent to the target mobile phone as a notification of the light failure.

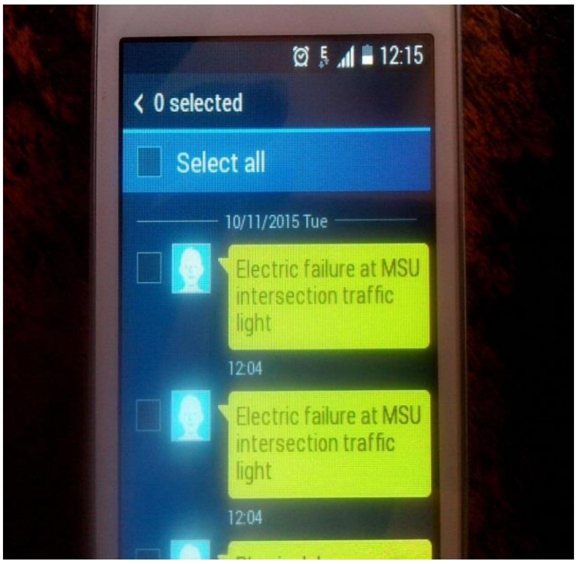

Fig. 4.2 Received SMS notifying the responsible officer of the light failure at the traffic signal

ii) Impact and motion detection test results presentation

The picture below shows the model traffic pole in tilt position to simulate impact and motion of the structure when it is hit by a vehicle in an accident.

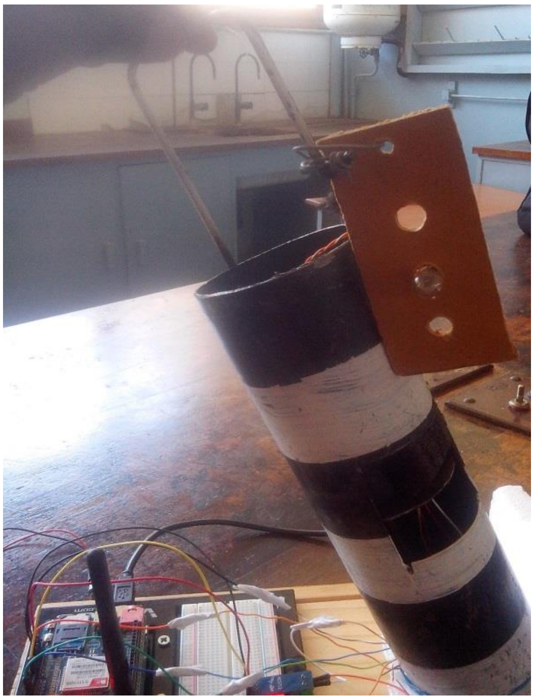

Fig. 4.3 Tilted traffic pole (Motion and Impact simulation).

The picture below shows the SMS that was sent to the target mobile phone as a notification of physical damage to the traffic signal.

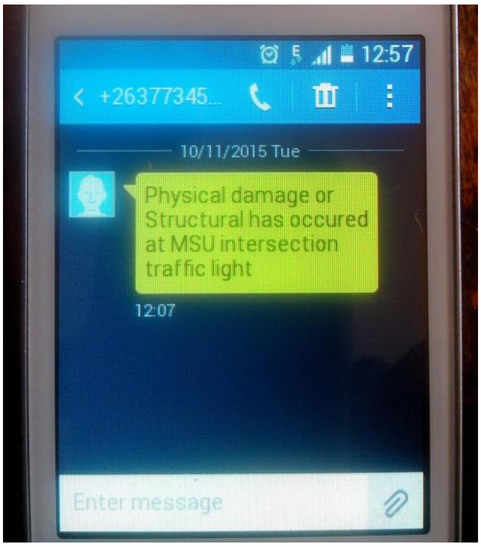

Fig. 4.3 Received SMS on target mobile phone notifying the responsible person of physical damage to the traffic signal.

CHAPTER 5: DISCUSSION & CONCLUSION

5.1 Introduction

This chapter discusses the findings of the research project and gives recommendations on system improvements, then conclusion.

5.2 Real world operability analysis

A model is an abstract of a real system and therefore in this project the traffic signal model was designed in a simplified manner. The traffic signal model was designed with a single light instead of the standard three lights to simplify it and cut costs of the model's implementation. Also in a real world situation the traffic signal will be turning ON and OFF depending on control signals from the controller. This was not implemented in the model as this was not the subject area of the research. Rather the subject area was that of fault monitoring and notification/reporting and so the model was designed to have a single light bulb that turns on perpetually as long as it has power supply and not faulty. Moreover the model's results demonstrate that the research concept is possible and can be implemented in the real world to solve the concerned problem albeit with some modifications to suit the design of a real traffic signal. If the system is to be implemented in a real world situation, the quantity requirements would be 1 GSM/GPRS module, 4 accelerometers and 12 current sensors. All the other components used in the prototype such as the pole, microcontroller and connecting wires are already there. Real world traffic lights use PLCs as the controllers and they are modular. So for each set of traffic signals the GSM/GPRS module can be plugged in to one of the free modular interface ports. The city councils can then engage mobile cellular service operators to supply them with SIM cards and bulk SMSs for enabling communication. The accelerometers can be easily embedded into the hollow structures of the traffic signal poles. The current sensors can also be easily connected to the lights. To enable system functionality, the necessary additional programming of the PLC will need to be carried out.

5.2 Recommendations

The prototype system does not cater for all faults that occur with traffic signals. In order for the system to be implantable and operable in a practical situation it needs to cater for all possible problems that occur even though they may not be frequently occurring faults. One of these rare faults is that of signal conflict whereby the lights can be all Green or all Red for all roads of the intersection. Real world traffic signals have a fail-safe mode that automatically activates and enables the Amber lights to start switching ON and OFF. The system can be improved by programming it to detect fail-safe mode and send a notification message. The system can also be improved by use of GPRS (internet) and HTTP as the messaging platform whereby a traffic signal can be monitored from a desktop computer using a web client. Another important recommendation is that the prototype system needs to be implemented as an additional function to a traffic signal PLC.

5.3 Summary and Conclusions

As fault monitoring and reporting is a problem for city councils' traffic signal maintenance departments, the designed system can be a viable solution. This project's design prototype server to prove that such a system can be implemented because the set objectives were achieved. However the system can have some challenges such as the problem of power cuts. This one can be addressed by use of solar power backup batteries for traffic signals.

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APPENDICES

Appendix A: Source Code

```
//This is C/C++source code for Arduino Uno microcontroller board for
//BSc. Telecommunications Engineering final year project by Tinashe Randeni
//GSM based fault monitoring/reporting system for Traffic Lights

//inclusion of Header files for referenced libraries during run-time ( or
//dependencies definition)
#include <SPI.h>
#include <Wire.h>
#include <ADXL345.h>
#include <SoftwareSerial.h>

SoftwareSerial Sim900Serial(2, 3); //Code to create a virtual serial port:
                                   //Pin2 is Rx Pin and Pin3 is the Tx pin
ADXL345 adxl;     //line of code to variable adxl, which is an instance of the
                  //ADXL345 library

//setup code, to run once.
void setup() {

//Code to start the serial link to the computer monitor. To be used in case
//of troubleshooting.
Serial.begin(9600);

//Code to setup the GSM/GPRS modem baud rates and initialise it.
Sim900Serial.begin(115200);
delay(500);
Sim900Serial.println("AT+IPR=19200");
delay(500);
Sim900Serial.begin(19200);
delay(1000);

//This block of Code serves to setup and calibrate the Accelerometer
adxl.powerOn();

//set activity/ inactivity thresholds (0-255)
adxl.setActivityThreshold(75); //62.5mg per increment
adxl.setInactivityThreshold(75); //62.5mg per increment
adxl.setTimeInactivity(10); // how many seconds of no activity is inactive?

//look of activity movement on this axes: 1 == on; 0 == off
adxl.setActivityX(1);
adxl.setActivityY(1);
adxl.setActivityZ(1);

//look of inactivity movement on this axes - 1 == on; 0 == off
adxl.setInactivityX(1);
adxl.setInactivityY(1);
adxl.setInactivityZ(1);

//look of tap movement on this axes - 1 == on; 0 == off
adxl.setTapDetectionOnX(0);
adxl.setTapDetectionOnY(0);
adxl.setTapDetectionOnZ(1);

//set values for what is a tap, and what is a double tap (0-255)
adxl.setTapThreshold(50); //62.5mg per increment
adxl.setTapDuration(15); //625μs per increment
adxl.setDoubleTapLatency(80); //1.25ms per increment
```

```
adxl.setDoubleTapWindow(200); //1.25ms per increment

//set values for what is considered freefall (0-255)
adxl.setFreeFallThreshold(7); //(5 - 9) recommended - 62.5mg per increment
adxl.setFreeFallDuration(45); //(20 - 70) recommended - 5ms per increment

//setting all interupts to take place on int pin 1
//I had issues with int pin 2, was unable to reset it
adxl.setInterruptMapping( ADXL345_INT_SINGLE_TAP_BIT,  ADXL345_INT1_PIN );
adxl.setInterruptMapping( ADXL345_INT_DOUBLE_TAP_BIT,  ADXL345_INT1_PIN );
adxl.setInterruptMapping( ADXL345_INT_FREE_FALL_BIT,  ADXL345_INT1_PIN );
adxl.setInterruptMapping( ADXL345_INT_ACTIVITY_BIT,   ADXL345_INT1_PIN );
adxl.setInterruptMapping( ADXL345_INT_INACTIVITY_BIT,  ADXL345_INT1_PIN );

//register interrupt actions - 1 == on; 0 == off
adxl.setInterrupt( ADXL345_INT_SINGLE_TAP_BIT, 1);
adxl.setInterrupt( ADXL345_INT_DOUBLE_TAP_BIT, 1);
adxl.setInterrupt( ADXL345_INT_FREE_FALL_BIT, 1);
adxl.setInterrupt( ADXL345_INT_ACTIVITY_BIT,  1);
adxl.setInterrupt( ADXL345_INT_INACTIVITY_BIT, 1);
}

// main code, to run repeatedly.
void loop() {

int currentSensorValue = analogRead(A0);  //Read analog value from OUT pin
                                          //from ACS712 connected to A0.
Serial.println(currentSensorValue);
double bulbCurrent = ((510 - currentSensorValue)*27.03/1023);  //defining
                                                               //current in light bulb
Serial.println(bulbCurrent);

int x,y,z;
adxl.readAccel(&x, &y, &z); //read the accelerometer values and store them in
                            //variables x,y,z

 // Output x,y,z values in serial monitor on computer. "Commented out"
 //Serial.print(x);
 //Serial.print(y);
 //Serial.println(z);

  delay(500);

// Code to test for fault in light and send notification SMS
if (bulbCurrent < 0.1)     //if the bulb is connected an average current of
                           //0.33A is read.
{
Serial.println("Electric failure of light at MSU intersection Traffic Light,
Notification SMS has been sent.");
Sim900Serial.println("AT+CMGF=1\r");     //Code to send the SMS in text mode
delay(500);
Sim900Serial.println("AT+CMGS = \"+263717717216\""); //The target phone
delay(500);
Sim900Serial.println("Electrical failure of light at MSU intersection Traffic
Light.");   //the content of the message
delay(500);
Sim900Serial.println((char)26);  //the ASCII code of ctrl+z is 26
delay(500);
Sim900Serial.println();
delay(5000);
}
delay(100);
// Code to test for fault due to physical damage to the pole structure and
//send notification SMS
```

```
//So the aim is to read interrupts source and look for triggered actions
byte interrupts = adxl.getInterruptSource();
if (adxl.triggered(interrupts, ADXL345_ACTIVITY))
{
 Serial.println("Physical damage has occurred at MSU intersection Traffic
Light, Notification SMS has been sent.");  //serial monitor message
Sim900Serial.println("AT+CMGF=1\r");     //Code to send the SMS in text mode
delay(500);
Sim900Serial.println("AT+CMGS = \"+263717717216\""); //The target phone no. r
delay(500);
Sim900Serial.println("Physical damage has occurred at MSU intersection
Traffic Light.");   //the content of the message
delay(500);
Sim900Serial.println((char)26);  //the ASCII code of ctrl+z is 26
delay(500);
Sim900Serial.println();
delay(5000);
}
}
```