DEVELOPMENT OF A WEB BASED SMART CITY INFRASTRUCTURE FOR REFUSE DISPOSAL MANAGEMENT

By

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DECLARATION

I, Adeyemo Joke Oluwatimilehin declare that this dissertation is a representation of my own work, written and executed by me. Partial or complete submission of this dissertation into any university or institution of higher learning for the award of another degree has never taken place. All information cited from published or unpublished works have been acknowledged.

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DEDICATION

This dissertation is dedicated to the loving memory of my parents. The educational legacy given me has been a foundational source of motivation and encouragement throughout the period of the master’s degree program.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
BoK	Body of Knowledge
CFC	Chlorofluorocarbons
CoTEC	Co-operative Traffic Congestion Detection
DSR	Design Science Research
EDA	Event Driven Architecture
FOSF	First Order Statistical Feature
GND	Ground
GPS	Global Positioning System
GPRS	Global Positioning Radio Service
GSM	Global System for Mobile Communication
HTTP	Hypertext Transport Protocol
IBM	International Business Machines
ICT	Information and Communications Technology
IDE	Integrated Development Environment
IEC	International Electrotechnical Commission
IR	Infra Red
IS	Information Science Research
ITS	Intelligent Transport System
ITU	International Telecommunication Union
IoT	Internet of Things
IOP	Interoperability Open Platform
IPV6	Internet Protocol Version 6
IUAL	Intelligent User Application Layer
IWAL	IoT Web Application Layer
KNN	K-Nearest Neighbour
KP	Knowledge Processors
LED	Light Emitting Diode
LTE	Long Term Evolution
MILP	Mixed Integer Linear Program
MLP	Multi-layered Perceptron
MSE	Mean Square Error

MSW Municipal Solid Waste
NFC Near Field Communication
PaaS Platform as a Service
PDA Personal Based Application
PSU Power Supply Unit
QR Quick Response flash code
RB Refuse Bin
RBFNN Radial Basis Function Neural Network
RDM Refuse Disposal Management
RF Radio Frequency
RFID Radio Frequency Identification
RSSI Received Signal Strength Information
SaaS Software as a Service
SRB Smart Refuse Bin
SC Smart City
SIB Semantic Information Brokers
SSAP Space Access Protocol
SSL Secure Socket Layer
SSPL Signal Sensing and Processing Layer
SVM Support Vector Machines
TCP Transmission Control Protocol
UDP User Datagram Protocol
UHF Uniform High Frequency
UNDP United Nations Environment Programme
UNEP United Nations Environment Programme
UML Unified Modelling Language
VANET Vehicular Ad hoc Network
Vcc Voltage Supply
Vo Voltage Output
VPN Virtual Private Networks
VSN Vehicular Sensor Network
WiFi Wireless Fidelity
WSN Wireless Sensor Network
6LoWPAN Low Power Wireless Personal Area Networks

ABSTRACT

The future of modern cities largely depends on how well they can tackle intrinsic problems that confront them by embracing the next era of digital revolution. A vital element of such revolution is the creation of smart cities and associated technology infrastructures. Smart city is an emerging phenomenon that involves the deployment of information communication technology wares into public or private infrastructure to provide intelligent data gathering and analysis. Key areas that have been considered for smart city initiatives include monitoring of weather, energy consumption, environmental conditions, water usage and host of others. To align with the smart city revolution in the area of environmental cleanliness, this study involves the development of a web based smart city infrastructure for refuse disposal management using the design science research approach.

The Jalali smart city reference architecture provided a template to develop the proposed architecture in this study. The proposed architecture contains four layers, which are signal sensing and processing, network, intelligent user application and Internet of Things (IoT) web application layers. A proof of concept prototype was designed and implemented based on the proposed architecture. The signal sensing and processing layer was implemented to produce a smart refuse bin, which is a bin that contains the Arduino microcontroller board, Wi-Fi transceiver, proximity sensor, gas sensor, temperature sensor and other relevant electronic components. The network layer provides interconnectivity among the layers via the internet. The intelligent user application layer was realized with non browser client application, statistical feature extraction and pattern classifiers. Whereas the IoT web application layer was realised with ThingSpeak, which is an online web application for IoT based projects.

The sensors in the smart refuse bin, generates multivariate dataset that corresponds to the status of refuse in the bin. Training and testing features were extracted from the dataset using first order statistical feature extraction method. Afterward, Multilayer Perceptron Artificial Neural Network (MLP-ANN) and support vector machine were trained and compared experimentally. The MLP-ANN gave the overall best accuracy of 98.0%, and the least mean square error of 0.0036. The ThingSpeak web application connects seamlessly at all times via the internet to receive data from the smart refuse bin. Refuse disposal management agents can therefore query ThingSpeak for refuse status data via the non browser client application. The client application, then uses the trained MLP-ANN to appositely classify such data in order to determine the status of the bin.

CHAPTER ONE

INTRODUCTION

The International Telecommunications Union (ITU) describes a smart city as an innovative city that uses Information Communication Technology (ICT) and other means to improve the quality of life of the citizens (ITU 2014). There have been various initiatives and studies about smart cities by multinational companies and research institutes with the aim of making cities smarter by effective utilization of available resources (Nam and Pardo 2011). Smart city projects primarily rely on capturing and gathering of data from the city infrastructure. Such data include weather information, electrical energy consumption pattern and refuse disposal infrastructure usage to mention just a few (Roscia *et al.* 2013).

Most communities across the globe, including many South African municipalities are experiencing budgetary challenges on refuse disposal (Ohri and Singh 2010). Despite the provision of refuse bin within most municipalities, the fundamental responsibility to maintain a culture of environmental sanitation are left in the hands of individuals. There are also challenges with respect to collection services. Consequently, refuse bins often spill over into accumulation. Since cleanliness is next to godliness, an environmental cleanliness solution is mandatory for a community seeking progress in the well-being of its populace (Muzenda *et al.* 2012).

Given that refuse accumulation usually exists subsequent to recurrent service delay or untimely refuse collection, smart city based solutions can assist in the detection of about 80 percent of refuse accumulation problems (Longhi *et al.* 2012; Patsakis *et al.* 2014; Domingo *et al.* 2013). Collection services can therefore be more effective through an alert recommendation algorithm to readily indicate refuse bin at full status. Thus, a prompt response can help to promote long term sanitation effects.

This dissertation presents the development of a web based smart city infrastructure for refuse disposal management based on Design Science Research (DSR) approach. The requirements of a smart refuse disposal system include system simplicity, cost effectiveness, easy management, flexibility and portability (Arbab *et al.* 2012). Smart refuse disposal systems should also be able to make automatic decisions with respect to the status of the refuse bin with little or no input from humans (Al Mamun *et al.* 2013; Jimenez *et al.* 2013). The developed smart city infrastructure fulfils all these requirements through an appropriate combination of relevant state-of-the art technologies such as embedded electronics, ThingSpeak IoT technology, sensors, and pattern recognition techniques (feature extraction and pattern classification).

1.1 Problem Statement

In recent times, the rapid population explosion in urban areas has been one of the most critical issues affecting the world. Urbanization in the 21st century is expected to further increase by 20 percent in the year 2050. This staggering increase has constituted a growing concern for refuse disposal in many cities worldwide and every year, about 11.2 billion tonnes of solid waste are collected worldwide (UNDP 2012). Refuse decomposition contributes about 5% of global greenhouse gas emissions, which is harmful to the human body (UNEP 2011; Hoonrweg, 2013). Both developed and developing countries generate millions of tonnes of refuse per year from households, businesses and industries. For instance, the average amount of refuse generated per person per day in South Africa is about 0.7 kg (Lincoln 2011). This figure is very close to the situation in the developed countries such as the United Kingdom and Singapore, where the average amount of refuse produced per person per day is around 0.73kg and 0.87kg respectively (Rode and Burdett 2011; Muzenda *et al.* 2012). According to Wang *et al*. (2011), the size of a community and its per capita income is generally proportional to the demand on refuse disposal infrastructure. The current situation in South Africa has also shown that rural communities experience untimely or delayed refuse collection. A problem in service administration that leads to accumulation or overspill of refuse contravenes the objective of the national waste management, which is to promote a clean environment (Fuggle *et al.* 2009). Therefore, in order to contribute towards solving the foregoing problems, this study proposes the development of a web based smart city infrastructure for refuse disposal management.

1.2 Research Rationale

Within the last few years, a government initiative in South Africa made some efforts to identify the challenges of refuse disposal management experienced by municipalities in the country. Four broad obstacles to effective refuse management were identified, which include financial management, equipment management, labour (staff) management and institutional behaviour management (Department of Environmental Affairs, 2013). Although, there are existing refuse bins in place for refuse collection within South African communities, they cannot ‘think’ and detect when refuses are dumped into them nor when they become full. There is therefore the need to intelligently determine the statuses of bins and transmit such information reliably and in a timely manner to relevant refuse disposal agents. The web based smart city infrastructure for refuse disposal management being reported in this dissertation can determine when the refuse is full and promptly notifies municipal officials. Hence, the goal of providing an accurate, reliable, cost effective, convenient, and environmentally friendly solution for refuse disposal management will be attainable.

1.3 Research Question

Based on the problem statement, the following research question is being pursued in this study: **Will the development of a web based infrastructure that incorporates state-of-the-art technologies result in an efficient refuse disposal management**?

1.4 Research Aim and Objectives

The overarching aim of this research study based on the research question is to develop a web based smart city infrastructure for refuse disposal management. The set of objectives that guided this study are as follows:

a. To provide a framework for enhanced refuse disposal management
b. To provide timely and accurate information on the status of refuse bins to the relevant refuse disposal management agents.
c. To enhance the ease with which full refuse bins are located by refuse collection agents.
d. To inject cost effectiveness into refuse disposal management.
e. To provide flexibility and ubiquity in the monitoring of refuse disposal activities by supervisors and administrators.

1.5 Research Methodology

Design Science Research (DSR) approach was adopted for this study. The DSR has its roots in engineering and the sciences (Simon 1996). It is fundamentally a problem-solving paradigm. It seeks to create innovations that define the ideas, practices, technical capabilities and products through which the analysis, design, implementation, management and use of information systems can be effectively and efficiently accomplished (Denning 1997). Over the years, DSR has been engaged in fields like computer science, software engineering and information systems (Tsichritzis, 1998). Chapter three of this dissertation provides a comprehensive description of DSR and its application for the development of the web based smart city infrastructure for refuse disposal management in this study.

1.6 Research Scope

This research drew inspiration from an awareness that prompt disposal of refuses is a basic requirement for sustainable environmental cleanliness within communities (Solomon, 2009; Bani *et al.* 2009; United Nations Environment Programme, 2012). With the challenges being faced by citizens with respect to refuse accumulation, there is a need to critically study refuse disposal management as a way to foster cleaner environments. The scope of the present research covers the use of smart city technological paradigms for effective refuse disposal management.

1.7 Contributions

The main contributions of this study are as follows:

a. Development of a smart city architecture for refuse disposal management. The architecture improves on the existing architectures in the literature by incorporating pattern classifier for efficient implementation of a refuse disposal management. The pattern classifier provides intelligent and accurate decision on the status of any refuse bin at different locations.

b. Development of a proof of concept prototype based on the smart city Jalili reference architecture. The prototype provides a reliable model for practitioners to develop and deploy systems for refuse disposal management. It also provides a basis for formulation of the research agenda and stimulation of research direction for refuse disposal management.

c. This dissertation and other publications from the study add to the Body of Knowledge (BoK) on the use of ICT for refuse disposal management.

1.8 Synopsis

This dissertation consists of five chapters. The first chapter presents a brief introduction of the study. It also described the problem statement, research rationale, research question, research aim and objectives, research methodology, research scope and contribution. Furthermore, this chapter presents the outline of the dissertation as well as the research output. Chapter two presents a broad overview of smart city concepts such as definitions, components, architectures as well as a thorough description of refuse disposal management strategies. It also presents a comprehensive review of existing literature on the use of smart city technology to solve diverse problems. Chapter three describes the application of the DSR approach to realise the aim and objectives of this research study. Chapter four presents the prototype implementation and evaluation results while Chapter five, which is the final chapter of the dissertation presents the discussion, recommendations for future works and the concluding remarks.

1.9 Research Output

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CHAPTER TWO

LITERATURE OVERVIEW

This chapter presents a review of relevant literature to the study at hand. Published works were sourced from research knowledge bases such as IEEE Xplore, ScienceDirect and Web of Science. The chapter begins with definitions of smart city, in relation to the different goals that can be achieved to improve the quality of life of citizens and also the essential issues smart city can possibly address within a city. The chapter further looks into the evolution of smart city through the various developmental processes. Furthermore, smart city services made available to the numerous end users are discussed while emphasizing on the different reference architectures that provide these services. The last part of this review focuses on implemented and deployed projects that are based on smart city technological concept.

2.1 Definitions and Goal of Smart City

The term smart city means different things to different set of people and it is used in different contexts. In fact, the term is yet to be strictly defined by practitioners and academicians (Chourabi *et al*. 2012). Thus, the researcher deems it necessary to capture a wide range of the existing definitions in the literature so as not to quell some of the integral components of the technology.

One of the definitions given by Bakici *et al.* (2013) is that smart city is a city that uses Information and Communication Technology (ICT) with the intent to improve the quality of life of its citizens and provide sustainable development. Citizens quality of life is improved through the integration of ICT into existing city services such as health care, refuse management, air quality assessment, noise monitoring, traffic congestion, city energy consumption, smart parking and smart lighting (Zanella *et al.* 2014). Furthermore, IBM defined smart city as a city that utilizes ICT to detect, analyse and incorporate vital information into executable services within cities (Su *et al.* 2011). Solanas *et al* (2014) defined smart city as a city that utilises ICT to enhance the performance and quality of urban infrastructure, thereby reducing costs and resource consumption. This is achieved by means of the technologies deployed on such urban infrastructures to make them more functional. These infrastructures are able to harness relevant information through acquisition and analysis of data for ensuring the usefulness in service delivery to the citizens within the smart cities. Toppeta (2010) defined smart city as a city that combines ICT and Web 2.0

technologies with other organizations, design and planning efforts to disintegrate and hasten bureaucratic processes. The author further opines that this will help in the identification of new innovative solutions to complex city service management. A smart city is defined as any city that utilizes novel ICT such as the Internet of Things (IoT), cloud computing and geographical information system to ease the planning, construction, and management of city services (Wenge *et al.* 2014, Geisler 2015).

It is apparent from the definitions above that ICT plays a fundamental role in ensuring that a city accommodates and makes sufficient provision for the modern day needs of its citizens (Chourabi *et al.* 2012). However, there are other definitions of the term smart city that lay emphasis on the schemes through which modern cities can adjust to the needs of the citizens. For example, Hollands (2008) defines a smart city as a city that supervises and centralises conditions of all of its critical infrastructure, including roads, bridges, tunnels, rails, subways, airports, seaports, communications, water, power and even refuse disposal management. Moreover, according to Bowerman *et al.* (2000) a smart city is said to be achieved when a city's resources are optimized, planned for preventive maintenance activities and properly monitored to secure the citizen. Washburn (2010) defines a smart city as a city that utilizes technologies to create infrastructural components and services, which makes it more intelligent, interconnected and efficient. These services include city administration, education, healthcare, public safety, real estate, transportation and utilities. Harrison *et al.* (2010) defined smart city as an instrumented and interconnected urban labelling phenomena in which sensors, actuators and other similar data acquisition systems are deployed into the streets of a community to make it intelligent. "Instrumented" refers to the capability of capturing and integrating real-time data through the use of sensors, meters, appliances, personal devices, and other similar sensors. Albino *et al.* (2011) further explained that "interconnected" means the integration of these data into a computing platform that allows the communication of such information among the various city services. Whereas, "Intelligent" refers to the inclusion of complex analytics, modelling, optimization and visualization services to make better operational decisions (Albino *et al.* 2011). Recently, smart grid, smart meter and smart bin have been used to intelligently notify household users when human servicing is required as either input or output (Harrison *et al.* 2010; Chourabi *et al.* 2012).

Based on the foregoing definitions of smart city, it can be inferred that the overarching goal of a smart city is to improve the quality of life of the citizens through the interplay of various entities (Batty *et al.* 2012). Therefore, to achieve this goal, it is necessary to put in place enabling elements such as state-of-the-art ICT amenities in conjunction with other relevant technological infrastructure, public policy and citizen engagement. This will ultimately foster productivity, economic growth, innovation, social mobility and inclusiveness for citizens (Kominos *et al.* 2013; Taylor and Schejter, 2013; Bakici *et al*. 2013; Hernandez-Munoz *et al.* 2011).

2.2 Evolutionary Phases of the Smart City Concept

According to Dutton (1987) and Inoguchi (1999), the concept of smart cities started as far back as the late eighties into the early nineties. During this period, cities recognized as smart were those that heavily relied on the application of wired communications network for capturing data from the city infrastructures (Dutton, 1987; Inoguchi *et al.* 1999; Satterthwaite 1999; Eger 1997; Wei 1997). The undue exposure of wired networks to human vandalism and climatic factors was an inherent disadvantage during this era.

As time progressed, the wired approach was no longer considered as smart due to technological advancement. For instance, at the onset of the twentieth century, smart city became smarter. The key elements in the literature involved the use of faster and ubiquitous ICT infrastructure like fibre optic channels, Wi-Fi networks, wireless hotspots, kiosks and service-oriented information systems (Al-Hader and Rodzi 2009; Al-Hader *et al.* 2009; Al-Hader 2009; Anthopoulos and Fitsilis 2010). Hence, contemporary technologies took over the scene as the drawbacks of the early technologies were adequately improved upon. Through wireless networking, data capturing became faster and more secured. This ultimately guaranteed effective service delivery to the citizens via the city infrastructure.

Anthopoulos and Fitsilis (2013) further presented another evolutionary phase of smart city between 1989 and 2011 as shown in Fig. 2.1. During this period, the recurrent terms in the literature for describing smart city projects were based on the specialised services being offered by different cities to their citizens. These terms include knowledge bases (1989-1994), broadband cities (1994-1999), digital cities (1994-2011), web cities (1996-2011), smart cities (1999-2011), wireless cities (2002-2004), ubiquitous cities and eco-cities (2008-2011).

For instance, Copenhagen knowledge bases (1989-1994) was set up to provide citizens with community portal and information services. Seoul in South Korea (1994-1999) was described as a broadband city because it offered broadband services to its inhabitants and local enterprises (Anthopoulos and Tsoukalas 2006; Anthopoulous and Vakali, 2012; Chourabi *et al.* 2012). The evolution of digital cities came to the fore when Austin in U.S.A

(1994-2011) started offering various e-services to the citizens in the environmental, tourism and transportation sectors. Kyoto in Japan was described as a web city because it provided web prototype experimental services to its citizens during the period 1996-2011. Dubai was described as a Smart city (1999-2011) due to the existence and continued integration of cutting edge ICT solutions into different sectors for the benefit of the citizens. In codicil, Kista and Stockholm (2002-2004) were described as wireless cities because they offered e-services in mobile and ICT development for the citizens. Both eco-cities and ubiquitous cities terms emerged during the same period. Masdar in United Arab Emirate (2008-2011) was described as an eco-city because it offered heating and cooling plants in public housing projects. Whereas Osaka in Japan (2008-2011) was named a ubiquitous city because diverse technologies that engendered ubiquity were integrated into the daily life of the citizens.

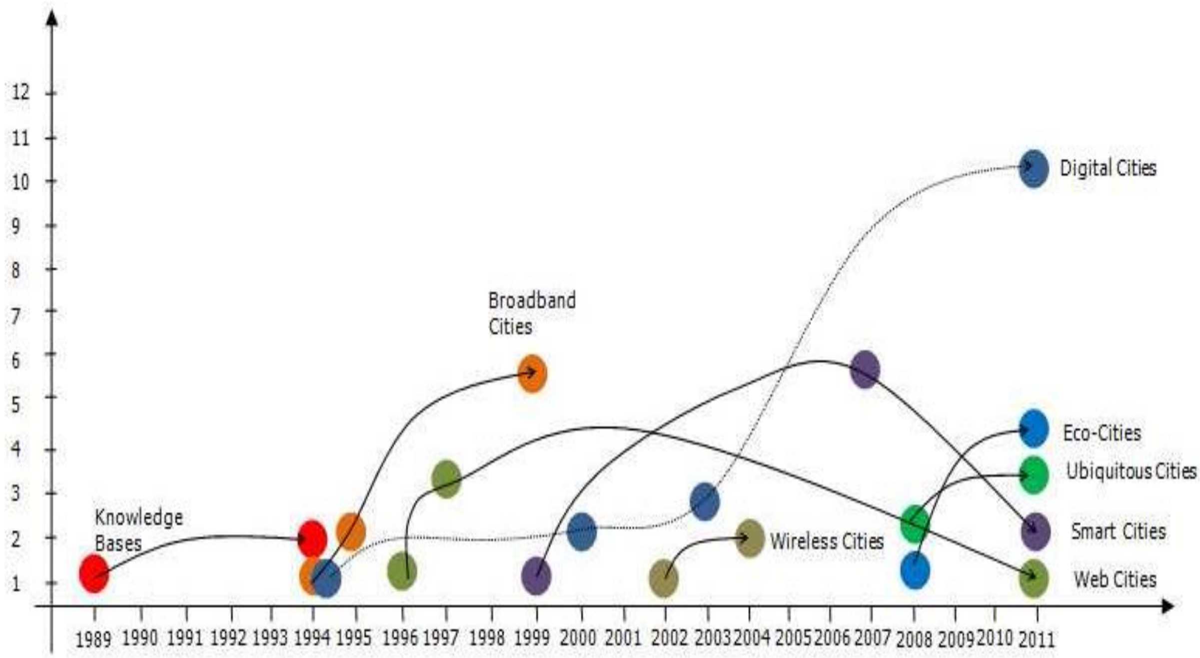

Figure 2.1: Evolutionary phases of smart city (1989-2011) (Anthopoulos and Fitsilis 2013)

Zygiaris (2013) argued that smart city has become a generalized term to describe ICT based innovations for sustainability and growth within communities. The term has gained so much publicity that nowadays, it has become a suitable term to describe any city that provides one or more of the aforementioned services via ICT and associated technologies.

2.3 Smart City Components and Services

Based on the neoclassical theory of urban growth, six different components of smart city have been outlined in the literature. These components are 1) smart mobility, 2) smart environment, 3) smart living, 4) smart economy, 5) smart people, and 6) smart governance (Giffinger et al. 2007). Figure 2.2 shows the diagrammatic illustration of the components. Al Hader (2009) argues that it is necessary to design useful applications and services based on these components to engender overall development, urbanization, industrialization and sustainability of cities (Giffinger *et al*. 2007). A review of studies in which applications and services were developed based on these components are presented as follows.

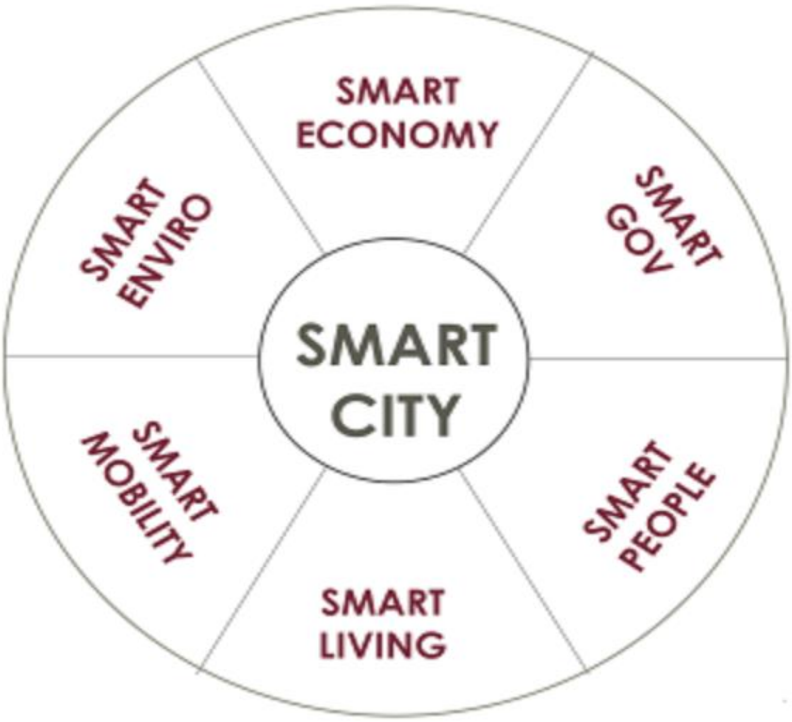

Figure 2:2: Components of smart city (Giffinger *et al.* 2007)

a) Smart Mobility

Smart or intelligent transportation systems involve the inclusion of smartness into mobility through the amalgamation of ICT and transportation infrastructure. Traditional road networks have mostly been built with little or no active management of how it is used and maintained. According to Budde (2014), investing in intelligent transport infrastructure can allow road managers to be more aware of how the network is being used and how it can be used more efficiently.

Smart mobility also includes vehicles, which can communicate with each other and take action to improve safety and efficient operations. There are several advanced technologies that are being installed in vehicles to make them smarter. This includes adaptive cruise control, GPS based dynamic navigation systems and powering of vehicles through wireless and grid technology (Budde 2014).

Smart parking, which is an aspect of smart mobility has attracted the attention of a number of researchers. Pala and Inanc (2007) in their study proffered solutions to the problems that are often encountered in parking of vehicles. The hardware aspect of the work was based on RFID technology for barrier and check-in/checkout control while the software aspect handled transaction reporting and operational management tasks. Chinrungrueng *et al.* (2007) implemented a payment system based on Wireless Sensor Network (WSN) for electronic parking services. Wang and He (2011) designed a smart parking system based on sensor network, Wi-Fi and the internet for location of vacant spaces where vehicles can easily park during rush hours. Other smart parking applications and services in the literature include the use of genetic algorithm (Fazelpour *et al.* 2013), optimal resource allocation and reservations (Geng and Cassandras, 2011) and mixed integer linear program (Geng and Cassandras, 2012).

Smart traffic congestion monitoring has also been widely studied and reported in the literature. Tsubota *et al.* (2011) and Zanella *et al*. (2014) posited that traffic congestion on the road within cities can be ameliorated via remote monitoring with sensors, GPS and Bluetooth technologies. Researches on Vehicular Sensor Networks (VSN) and Vehicular Ad hoc Networks (VANET) have also provided a new solution for realizing traffic congestion monitoring. Through VSN and VANET, vehicles that are equipped with sensing devices move around in the city to track cases of traffic congestion. The information acquired by such vehicles is of great values to both the authorities and citizens. On the part of the authorities, law enforcement officers can be seamlessly notified of locations with heavy traffic congestions for immediate action. Whereas on the part of the citizens, such information can be used to strategize appropriate route to their desired destinations (Lee *et al.* 2009; Choi *et al.* 2013; Li *et al.* 2013; Taylor 2002; Zanella *et al.* 2014; Li *et al*. 2009; Bauza and Gozalvez 2012; Terroso-Sáenz *et al.* 2012).

b) Smart Environment

Cook and Das (2005) defined a smart environment as one that is able to acquire and apply knowledge about an environment and adapt such knowledge to improve the experience of the inhabitants of the environment. Within the past few years, technological advancement coupled with the emergence of the smart city concept has fast tracked the realization of the dream of smart environments. Remarkably, there are variations in individual's expectations from their environments. These may include safety, low environmental maintenance cost, automation of tasks and optimization of utility such as energy, water as well as communication bandwidth (Cook and Das 2005; Das and Cook 2009; Rashidi *et al.* 2011; Hussain *et al.* 2009). Key areas that have attracted research efforts to engender smart environments are air quality monitoring (Zanella *et al.* 2014; Al-Ali *et al.* 2013; Cuff *et al.* 2008; Dohler *et al.* 2011; Vilajosana *et al.* 2013; Bhattacharya *et al.* 2012), noise monitoring (Filipponi *et al.* 2010; Maisonneuve *et al.* 2009; Zanella *et al.* 2014; Kanjo 2009; Renterghem *et al.* 2010), city energy consumption (Zanella *et al.* 2014; Feng *et al.* 2012), smart lighting (International Energy Agency, 2006; Castro *et al.* 2013; Zanella *et al.* 2014; Adetiba *et al.* 2011; Ajisafe 2007; Fahdil 2010; Kanma *et al.* 2003; Martirano 2011; Bhardwaj *et al.* 2010; Sevincer *et al.* 2013), structural health of building (Zanella *et al.* 2014; Lynch and Loh 2006; Zanella *et al.* 2014; Lynch and Kenneth 2006; Jang *et al.* 2010) and refuse management (Chowdhury and Chowdhury 2007; Domingo *et al.* 2013; Longhi *et al.* 2012; Bashir *et al.* 2013; Glouche *et al.* 2013; Nuortio *et al.* 2006). Based on the relevance to the study at hand, research studies on smart refuse management will be elaborated more in subsection 2.4.3

c) Smart Living

Advances in ICT have brought about a lot of changes in the way people live and work. Bai and Huang (2012) conducted a research on the design and implementation of a cyber system for building smart living spaces. An intelligent control box, which integrates lighting, air conditioning, access control, video surveillance and alarm systems was used as a multiple control platform. This led to a drastic decrease in the difficulties of controlling device within the living space and create the scenario of smart living.

Senior citizens often have special needs in their daily lives due to disabilities such as dementia (Zheng and Pulli 2007; Lavanya *et al.* 2006; Lau *et al.* 2002). They also have special behavioural patterns, which often makes the design of suitable systems for their use a challenging endeavour (Zheng and Pulli 2007; Lavanya *et al.* 2006; Lau *et al.* 2002).

Therefore, smart living services have been developed by researchers based on mobile devices to make life easier for the senior citizens (Parra *et al.* 2012).

d) Smart People

Smart people live in a humane city that provides diverse opportunities for them to exploit their potential and lead creative lives. Winters (2010) opined that a smart city is a centre of higher education and better-educated individuals. Similarly, Glaeser and Berry (2006) argue that a smart city is one that is full of skilled workforces. The knowledge worker, high tech, and knowledge-sensitive industries migrate into communities that contains a high number of smart people (Eger 2000). Along with the inflow of smart people, new culture driven by them often lead to further development within the smart city. Švob-Đokiæ (2007) lauded the outcome of creative cultures that are stimulated by smart people, which extends beyond diversity and innovations in economic performance and social tolerance. In an academic context, smart people are known to be of fast comprehension and assimilation especially when using ICT technologies to study (Schiefele *et al.* 1992; Krapp 1999).

e) Smart Governance

Governance encapsulates collaboration, cooperation, partnership, citizen engagement, and participation (Coe et. al. 2001). One common characteristic of successful cities is the collaboration among different functional sectors such as government, business, academics, non-profit and voluntary organizations (Anderson and Tregoning 1998; Ingram *et al.* 2009; Lindskog 2004; Paskalewa 2009; Eger 2010). According to Johnston and Hanssen (2003), to achieve smart governance, infrastructures must be developed for accountability, responsiveness and transparency. This infrastructure helps collaboration, data exchange, service integration and communication (Odendaal 2003; Mooij 2003). Smart government should share concepts, visions, goals, priorities and strategic plans with the public and stakeholders in a seamless manner (Dirks and Keeling 2009; Eger and Maggipinto 2010; Odendaal 2003; Anthopoulos and Fitsilis 2010). Scholl and Scholl (2014) argued that pervasive information along with the underlying technologies are the essentials for developing models of smart governance. This will foster smart, open, and agile governmental institutions as well as stakeholder participation at all levels of the governing process.

f) Smart Economy

Smart economy is the intersection between the economy and smart cities. The essential attributes of a smart economy include innovation, entrepreneurship, trademarks, productivity, flexibility as well as integration into the national and global market. The competitive ability of a city as an economic engine is ultimately one of the vital gauges used in measuring its growth (Giffinger *et al.* 2008).

2.4 Refuse Disposal Management

Refuse is often described as a by-product of human activities considered useless and to be disposed. In addition, refuse can be described as unwanted materials which can be reused as a resource for industrial production and energy generation (UNEP 2011; Fuggle and Rabie 2009;O'leary *et al.* 2002). It may comprise of both organic and inorganic materials and are often heterogeneous in nature. A large percentage of refuse in the environment is generally produced in urban areas (Kulkarni and Ramachandra 2009).

Refuse Management is a complex term that describes a process which involves many technologies and disciplines. Refuse management processes have to be economical and aesthetically acceptable. In addition, they must also be conducted within the boundaries of relevant social and legal guidelines so as to protect the environment and public health" (O'leary *et al.* 2002). Refuse management therefore involves the following processes: generation, storage, collection, transportation, processing, and disposal. The collection and disposal of refuse, especially those generated in urban areas, have become a relatively difficult problem to solve. The problem is even more critical in developing countries, where critical resources (financial and human) are generally rare. The public service sector (municipalities, departments) in many of these countries are unable to render services effectively to their citizens, hence, illegal dumping of domestic and industrial refuse is a common practice in those cities. Because low priority is given to refuse management, very limited funds are provided to the refuse management departments by the respective governments. This problem is even more severe at the local government level (UNEP 2005).

Improper refuse management generally leads to substantial negative impacts as described below (World Bank 1999):

a) Ozone Depletion

The ozone layer is important because it prevents too many harmful ultraviolet rays from reaching the earth. The continuous existence of life on the earth is possible only because of the presence of the ozone layer around the earth. Refuse disposal methods such as incineration and landfill sites contributes to ozone depletion as refuse are gotten rid of through burning. The main cause of the ozone hole was found to be gases that contained chlorofluorocarbons, halons and freons, which are found commonly in aerosol cans and released by many electronic appliances (Wise *et al.* 2009).

b) Health Hazards

Incineration elevates the release of dioxins, gaseous emission from lead and other metals to the atmosphere. Consequently, health conditions such as skin cancer and cataracts are common among operators within the incineration facilities. Diseases are also spread by insects and rodents that are attracted by garbage heaps. Air, soil and water pollution caused by refuses are also responsible for various forms of diseases (NRC 1999; Hopke *et al.* 2000; Snary 2002).

c) Adverse Environmental Conditions

In municipal refuse incinerators, the bottom ash is approximately 10% by volume and approximately 20 to 35% by weight. This can contaminate the environment when not properly managed (Zafar *et al.* 2010).

Overview of current refuse disposal management strategies being used to address the listed menaces are hereby presented under three categories, namely, manual refuse disposal management, modern refuse disposal management and smart refuse disposal management.

2.4.1 Manual Refuse Disposal Management

These are traditional means of refuse disposal. Those commonly used around the world are door to door collection, incineration and landfill sites.

a) Door to Door Collection

Door-to-door refuse collection is a form of the waste collection method whereby waste is collected by removing the waste container for individual household and returning it after disposing the refuse into a collection vehicle. It can also be done by a house owner placing his or her waste containers on the sidewalk, ready for collection by the collection crew, and retrieving them after collection. Door to door refuse collection is usually done by the municipality or department in charge of solid waste and in some cases, it is also done by private waste management service providers (Teerioja *et al.* 2012).

b) Incineration

Incineration can be defined as a waste management process involving the combustion of solid waste materials (Knox 2005). It is also known as "thermal treatment", which is the process of converting waste materials into ashes and gas. The ash is mostly formed by the inorganic components of the solid waste, usually in the form of solid lumps. According to Dalager (2006), the use of incinerators for solid waste management can reduce the solid component of the original refuse by more than 80%.

c) Landfill Sites

Refuses have traditionally been sent to landfill sites (rubbish dumps), where it is buried in a scientifically chosen, designed, engineered and managed location. Here, it is spread, compacted and covered with sand and builder's rubble, which prevents the waste from blowing around and spreading diseases as well as attracting unwanted animals and insects. After the waste has been buried and tightly packed to lock out all oxygen, it can lie there for hundreds of years while it decays very slowly. When landfill sites are full, they need to be closed and rehabilitated that is restored to a useful, environmentally sound condition). Although a costly process, it helps to contain health and environmental pollution, (Smart Living Handbook 2011; Webster 2014; Colon 2012).

2.4.2 Modern Refuse Disposal Management

The modern means of refuse disposal that are commonly used around the world include pneumatic refuse collection and recycling.

a) Pneumatic Refuse Collection System

Pneumatic refuse collection is the transportation of refuse at high speed through pneumatic tubes to a collection station where it is compacted and sealed in containers. When the container is full, it is transported away and emptied. The system helps to facilitate separation and recycling of waste (Teerioja *et al.*2012).

b) Recycling

Recycling can be defined as the process of converting solid waste into reusable and useful material in order to prevent waste of potentially useful materials, reduce the consumption of raw materials, reduce the usage of energy, reduce air, land, and water pollution. It is a very important component of modern waste reduction initiatives and the third component of the

"Reduce, Reuse and Recycle" also known as the 3Rs waste hierarchy (Lyons and Bufford 2006).

2.4.3 Smart Refuse Disposal Management

Refuse management is obviously a concern in modern cities because of service cost and storage problem that are associated with disposing refuse in landfills. Published works of researchers have indicated different ways technology have been applied in an attempt to achieve smart refuse disposal management.

Arbab *et al.* (2012) utilized the sensor model to develop a novel and ubiquitous "smart" concept to avoid reconstructing an existing refuse disposal infrastructure. Other researchers have also reported the integration of global system for mobile communications (GSM) with a multivariate sensor algorithm to measure a prerequisite parameter for bin state to minimize energy use (Komninos 2013; Al Mamun *et al.* 2013).

In addition, wireless sensor networks have been applied by several authors to develop smart refuse disposal management systems. For instance, real time activity monitoring system for waste bins was developed by Chowdhury and Chowdhury (2007). The system is based on a multi-tiered platform of wireless sensor and RFID technology. The authors utilised knowledge driven database to filter sample datasets and an extensible graphical user interface for user friendliness. Bashir *et al.* (2013) designed a vehicular smart transport using Infra-Red sensor, radio frequency encoder along with decoder base station nodes for smart bin monitoring. The system ensures that refuse collection service agents are accountable through data entry for bin status and location. Longhi *et al.* (2012) proposed a method to determine smart bin position via a wireless sensor unique received signal strength information (RSSI). According to the authors, the work was aimed at improving the accuracy in bin activity monitoring by means of a public open sensor innovation. Glouche *et al.* (2013) proposed a new approach by using RFID on smart bin. The refuse items were configured as self-describing objects as a quick option for easy recycling.

Moreover, pattern recognition algorithms have also been recently employed to realise smart refuse disposal management. Abbasi *et al.* (2013) developed a method for forecasting Municipal Solid Waste (MSW) generation. The researchers combined the Support Vector Machine (SVM) classifier and Partial Least Square (PLS) for feature selection to determine quantity of MSW that are generated on a weekly basis in Tehran, Iran. Comparing SVM and PLS-SVM models, the authors reported that PLS-SVM gave superior performance to the SVM model with respect to predictive ability and computational time. Livani *et al.* (2013)

developed a prediction method in which the weighted K-means clustering algorithm was utilized for clustering refuse dataset of 63,000 records. Afterwards, linear regression model was used to build the prediction models from each of the clusters. They submitted that the combination of the two methods gave better performance than using each of the methods individually. Additionally, the authors produced a hybrid of the prediction model to develop a decision support system for refuse collection and recycling services.

Overall, Nuortio *et al.* (2006) and Zanella *et al.* (2014) are of the opinion that through the use of smart bin that can detect load level and allow collector truck route optimization, cost reduction and improved quality of the refuse management service can be achieved.

2.5 Smart City Reference Architecture

Given the smart city components and services discussed in subsection 2.3, many architectures have been designed to model these services and underpin the development of end-user applications. Five existing smart city reference architectures, are reviewed in this section to lay the foundation for the proposed system architecture to be presented in Chapter 3.

a) Filipponi Smart City Full Architecture

The reference smart city architecture proposed by Filipponi *et al.* (2010) is an offshoot of the ARTEMIS SOFIA project. The architecture was developed to create a semantic interoperability platform based on embedded systems and a selected set of vertical applications to form smart environments. Two smart spaces known as Semantic Information Brokers (SIB) and Knowledge Processors (KP) were created and managed to ensure the delivery of the architectural service. SIB provides a service interface for KP agents, whereas KP accesses the information within the smart space by connecting SIB. Thus, KP reacts appropriately and timely to changes within the smart space while avoiding unnecessary communication (Filipponi *et al.* 2010; Toninelli *et al.* 2009). The shortcoming of the architecture is the fixed sectional services.

b) Context-Aware Smart City Architecture

Khan and Kiani (2012) proposed a context-aware smart city architecture that comprises of a cloud environment and integrated intelligence for urban management services. One of their design principles was to present context-aware component at many layers of the architecture to properly co-ordinate the flow of essential information. According to the author, the proposed architecture consists primarily of five horizontal and vertical layers. The horizontal layers are platform integration, thematic layer, data acquisition and analysis, service composition and application service layers.

The platform integration layers portray an internet infrastructure based on a cloud environment for cross platform data accessibility. Data acquisition and analysis layer was designed to gain access to differently sourced environmental data. It ensures that quality data are acquired and identified for necessary data cleaning and harmonization. A context aware filter is introduced to perform quality checks of unrelated data and thereby promote data harmony. Thematic layer sorts out produced data into application specific thematic classes and does data or service updates for further use. The service composition layer is required to plan workflows, data sources and component linking for necessary analysis to be executed in this layer. Application service layer uses findings from service composition layer in the form of simulations to perform contextual analysis for decision making.

The vertical layers of the architecture include management and integration layer, as well as a security layer. The management and integration layer aims to manage the different changes and to reduce management overhead. The security layer performs authentication, authorization and auditing of data used by legitimate users. With this layer, personalized profile of the end user within the cloud environment are secured.

The smart city components, which are recipient of the services provided at both the horizontal and vertical layers are at the top-level of the architecture. They are generally named as Software as a Service layer (SaaS) while the platform layer of the architecture is referred to as Platform as a Service layer (PaaS) following the cloud computing technical paradigms. Despite the attractive features of this architecture, the major downside is its complexity.

c) Big Data Smart City Architecture

The focus of the reference architecture proposed by Bellini *et al.* (2014) is majorly on big data processing. The architecture combines the integration of park sensors, weather sensor and traffic sensors bring about a smart environment for big data processing. The process scheduler manages the data ingestion process by allocating processes to several parallel but distributed servers. These processes are updated on a regular basis through regular retrieval and frequent checks allowed by the scheduler. Ingested data are transcoded and improved so that they can be mapped into the system ontology accordingly. Therefore, the architectural service solution allows ingesting and harvesting a wide range of public and private data, coming in as static, semi-static and real time data (Bellini *et al.* 2014; Ngomo and Auer 2011; Bellini *et al*. 2013). This architecture is highly specialised and the complexity of processing big data may hinder its effectiveness.

d) Padova Smart City Architecture

Zanella *et al.* (2014) developed another smart city reference architecture which provides the basis for the development and deployment of an experimental wireless sensor network testbed with more than 300 nodes at the University of Padova. A combination of different protocols and technologies within the architecture include Internet Protocol version 4 (IPv4), Secure Socket Layer (SSL), Hypertext Transfer Protocol (HTTP), Constrained Application Protocol (CoAP), User Datagram Protocol (UDP), IPv6 over Low power Wireless Personal Area Networks (6LoWPAN), 802.15.4 and Transmission Control Protocol (TCP) (Zanella et al. 2014).

Padova smart city target application was to collect environmental data and monitor the public street lighting. The wireless nodes were equipped with different kinds of sensors that are located strategically on street light poles and connected to the internet through a gateway unit. Examples of environmental parameters that are collected via the implementation that was built on the architecture include carbon dioxide level, air temperature and humidity, vibrations and noise. There was also an accurate technique to check the correct operations of the public lighting system. This architecture specifically targeted smart lighting, which is an aspect of smart environment within a smart city. Thus, such over specialisation may hinder its adaptation to another context.

e) Jalali Generic Architecture for Smart City

Jalali *et al*. (2015) developed a generic reference architecture for the design of smart cities and its services as shown in Fig 2.3. The architecture was developed based on the non-availability of holistic data collection and analysis at the community level in previous architectures. The Jalali architecture can benefit several models aimed at developing different smart city applications for urban planning and sustainable communities.

The architecture is subdivided into three layers, namely sensing layer, network layer as well as control and services layer. The sensing layer collects data from heterogeneous sensors using sensing resources such as the Wireless Sensor Network (WSN), Radio Frequency Identification (RFID) and crowdsourcing. On the other hand, the network layer provides a means of communicating data from sensing layer to control layer and vice versa. In the architecture, internet is a major communication component that adapts IP technology for data routing (Jalali *et al.* 2015). However, user can also connect to the available services through 3G or LTE mobile telecommunication devices which are part of the network layer. The control and services layer provide a communication channel between community and individual services through a web interface. These control services at individual and community level comprises of database management, knowledge discovery and service management (Jalali *et al.* 2015). This architecture (Jalali *et al.* 2015) has the advantage of generalization for different areas of smart city applications and services. However the diversities of modules within the different layers of the architecture may impose some implementation challenges. Therefore, this current study amends the Jalali architecture for smart refuse disposal management. The details of the proposed architecture in the current study are presented in Chapter 3.

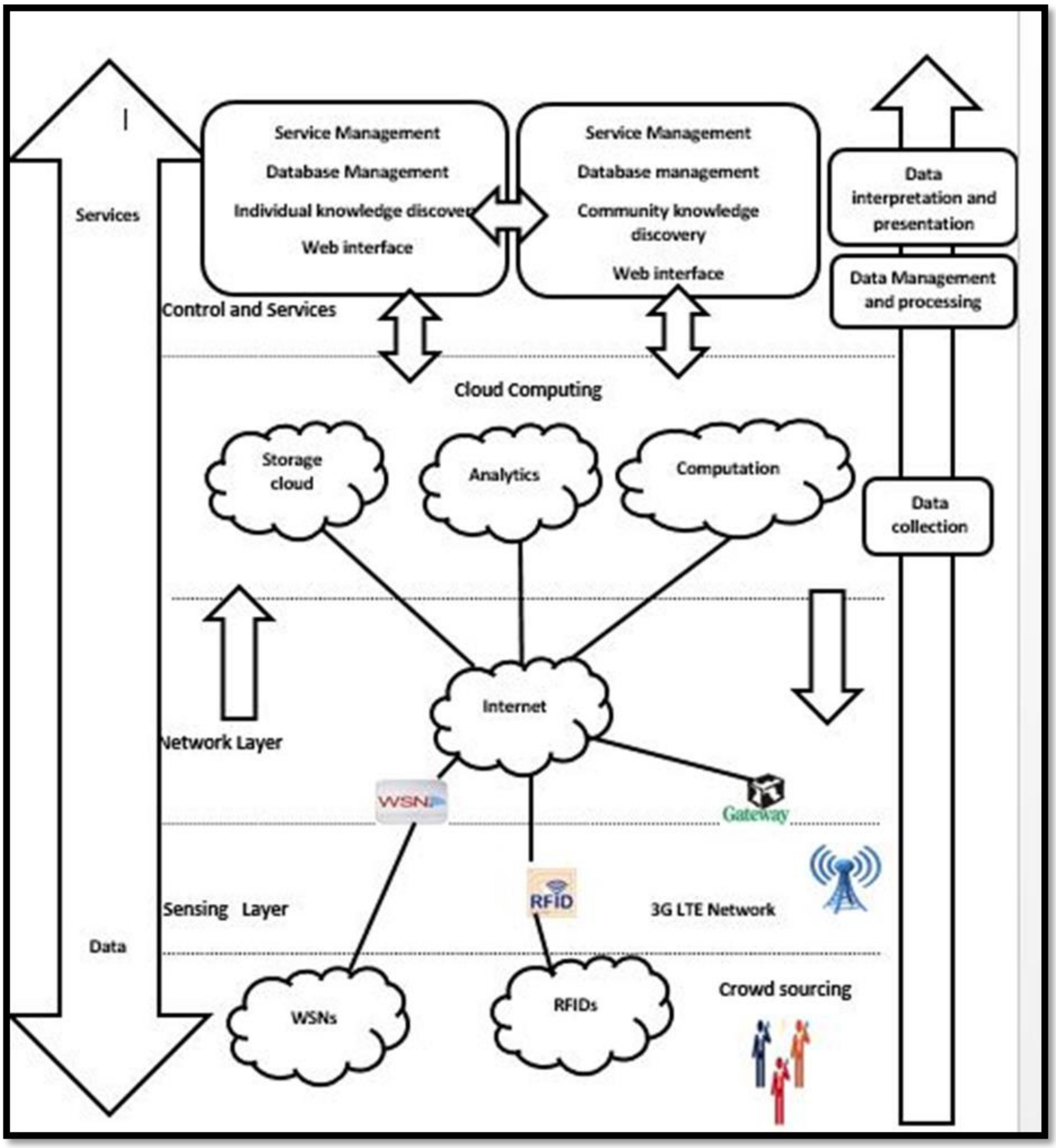

Figure 2.3: Jalali generic architecture for smart cities (Jalali *et al.* 2015)

2.6 Existing Smart City Implementations and Deployments

Numerous smart city implementations that resulted in full deployment are already in existence in different parts of the world, however, only a few of them are discussed in this section. Filipponi *et al.* (2010) developed the SOFIA project and implemented Interoperability Open Platform (IOP) in an attempt to monitor the public areas in the city so as to enhance security and detection of emergency cases and abnormal situations. The implementation used an Event Driven Architecture (EDA) to permit wireless sensors to observe unusual events, thereby promoting a smart space and environment. Moreover, Hasan *et al.* (2012) also implemented an EDA to promote heterogeneity and semantic matching of events. The authors used a sensor based matcher to structurally represent Wikipedia and Freebase event. The application promotes educationally related functions for smart people. Carretero (2012) developed a smart city implementation named Adapcity, which is a self-adaptive system that offers heterogeneous devices and the ability to react effectively to environmental changes. Hence, the operations of Adapcity were geared towards promoting a smart environment. Smart Santander was developed and deployed by Sanchez *et al.* (2011) at Santander, North of Spain. Smart Santander is a facility for interconnecting sensors for environmental monitoring and traffic management within the city. The SmartEye by Pozza *et al.* (2012) was an experimental deployment to manage energy consumption within a smart city.

Just recently, Samaras *et al.* (2013) developed and deployed an educational mobile application for smart people called SEN2SOC. The application interacts with social networks through natural language generation and sensors. Information received from the sensors are converted to messages that can be easily understood by humans, which consequently lead to the improvement of citizens' and visitors' experiences.

2.7 Conclusion

This chapter presented an overview of the mart city concept, components of smart city, smart city services, smart city reference architectures, implementations and deployed smart city projects among many others. Even though the smart city architecture by Jalali *et al.* (2015) provides some clear advantages over others, there are some gaps with respect to ease of implementation and the way the decision support mechanism is represented.

An overview of existing studies in which smart city technology was employed for refuse disposal management was also presented. Despite the various efforts in developing smart systems for refuse disposal management, some of the existing systems are largely faced with myriad challenges engendered by the size of data that is available for decision making. It is also noteworthy that most reputed works only utilized pattern recognition models for prediction instead of bin status classification or recognition.

This research work, therefore endeavours to fill some of the gaps in the literature by modifying and adapting Jalali *et al.* (2015) smart city architecture for refuse disposal management. The modification largely involves compactness and the use of pattern classifiers for bin status decision making. The development of a proof of concept prototype based on the proposed architecture provided a basis for evaluating the architecture in this study.

CHAPTER THREE

STUDY METHODOLOGY

This chapter presents the use of design science research (DSR) approach to develop the architecture and design the proof of concept prototype of the web based smart city infrastructure for refuse disposal management. A brief fundamentals of DSR and the adaptation of its different guidelines to this research study is firstly presented so as to lay a foundation for the rest of the chapter.

3.1 Design Science Research

There are two research approaches that are commonly employed in the information systems discipline. These are the behavioural and design science research approaches (Hevner *et al.* 2004). Behavioural science has its roots in the social and information sciences. It involves either systematic analysis or controlled experiments using human or animal subjects (Tokar *et al.* 2010). Models are designed based on how human subject can respond to specific stimuli and make corresponding adjustments based on basic assumptions, as a result, new models can be created or reflection on existing knowledge can occur (Tokar 2010; Kaptein *et al.* 2010; Mays *et al.* 2010).

On the other hand, DSR has its roots in engineering and the applied sciences (Simon 1996). It involves the creation and evaluation of Information Technology (IT) artefacts intended to solve identified organizational and societal problems. Such IT artefacts include constructs, models, algorithms, practices, implemented and prototype systems (March and Smith 1995; Nunamaker *et al.* 1991, Batra *et al.* 1990). The mathematical basis for design allows many types of quantitative evaluations of the IT artefact, including optimization proofs and analytical simulation (Nunamaker *et al.* 1991; Klein and Meyers 1999). Through the use of DSR, computer scientists and engineers have developed new computer architectures, programming languages, new algorithms, compilers and other types of systems (Livari 2006). Given the foregoing description of behavioural and design science research approaches, the later (i.e. DSR) is more appropriate to realise the aim and objectives of this study.

Hevner *et al.* (2004) outlined seven guidelines for DSR based on the principle that knowledge and understanding are created in the construction and application of artefacts. Thus, the guidelines (Hevner *et al.* 2004) provide a methodological template to achieve the aim and objectives of the current study (Klose *et al.* 2007). Each of the seven guidelines and its adaptation to the present work are described in the following sub-sections.

3.1.1 Guideline 1 - Design as an Artefact

DSR involves the creation of an innovative and purposeful IT artefact aimed at solving problems within an organisation or the larger society. Nunamaker *et al.* (1991) also proposed a multi-methodological approach to IS research which includes theory building, observation, system development and experimentation. The tasks that are involved in the different stages of the approach proposed by Nunamaker *et al.*, (1991) are illustrated in Fig. 3.1. Apparently, theory building, system development and experimental aspects of the approach are essential processes in artefact development. Furthermore, requirements analysis and design specification are also necessary steps for an artefact to be developed (Peffers *et al.* 2007). The present study aligns with the first DSR guideline by developing an architecture of a web based smart city infrastructure for refuse disposal management. The architecture was prototyped through the design and development of appropriate hardware and software. Hence, the architecture as well as the hardware and software units of the prototype are the artefacts that were developed in this study.

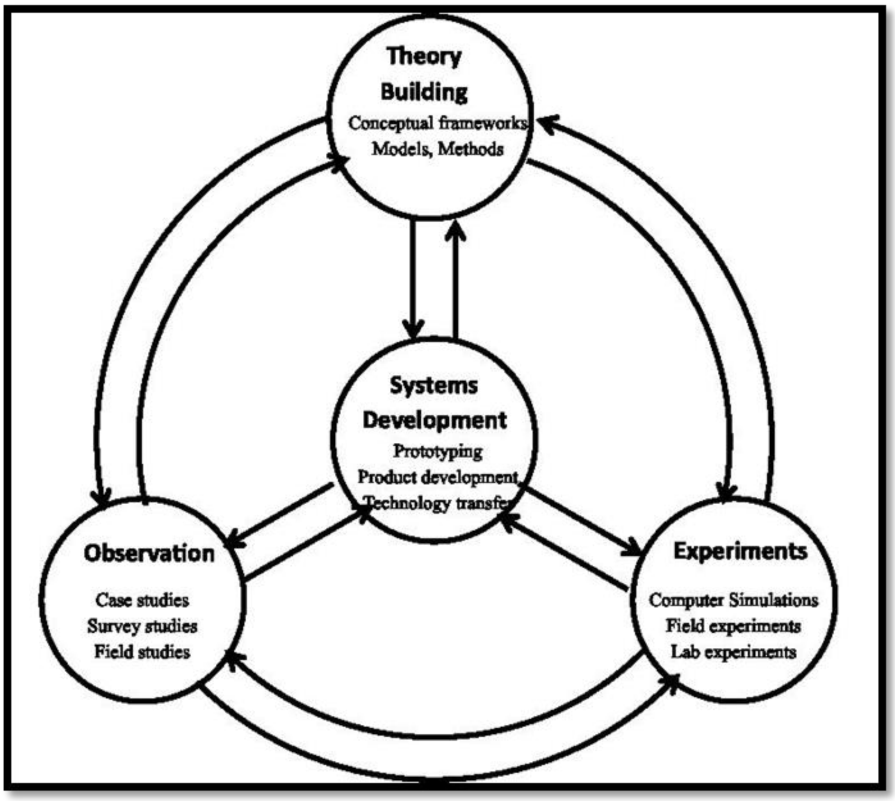

Figure 3.1: A multi-methodological approach to IS research
(Nunamaker *et al.* 1991)

3.1.2 Guideline 2 - Problem Relevance

Another goal of DSR is to ensure that developed artefact provides technology-based solutions to important and relevant business or societal problems. Good DSR often identifies and represents problems in an actual application environment (Hevner 2007). The solutions to such problems are drawn from the existing body of knowledge and efforts are made at solving the problems in a creative way (Vaishnavi *et al.* 2004). In line with this DSR guideline, the delay in collection of accumulated refuses within communities is being addressed in this study. Refuse not disposed only create an obnoxious look and unwholesome smell in the environment, but often lead to serious health hazards. Refuses that are left to decompose result in the growth of a number of pathogenic bacteria, fungi, viruses and generate harmful gases that pollute the air. Flies, insects and rodents also live on accumulated refuses and consequently carry germs of various diseases to human habitations. Furthermore, accumulated refuses are washed off to water bodies when it rains, thereby causing water pollution. Epidemics associated with water contaminated with pathogens have devastated human populations and even more recently, cholera has been a common occurrence. Some of the direct health impacts of the mismanagement of refuse are especially pronounced in developing countries (Giusti 2009). The developed prototype, which is one of the artefacts in the present study, if deployed, will provide a platform for relevant municipal officers to probe the status of smart refuse bin located within communities. This helps to determine when refuses are ready/unready for collection and thereby eliminate the delay in refuse disposal.

3.1.3 Guideline 3 - Design Evaluation

Design evaluation involves the creation of design alternatives against requirements until a satisfactory design is achieved. The evaluation of the artefacts typically uses methodologies that are available in the knowledge base of scientific theories and engineering methods. In order to select evaluation methods, there must be an appropriate match between such methods and the designed artefact. Existing DSR evaluation methods include observation (case study or field study), analysis (static/architectural/dynamic analysis or optimization), experiments (controlled experiment or simulation), testing (functional or structural testing) and description (informed arguments or scenarios). It is an established fact that the efficiency and efficacy of a designed artefact can be appositely demonstrated through well selected evaluation methods (Hevner *et al.* 2004). The study at hand adopted a blend of evaluation methods from electrical engineering, software engineering and machine learning, knowledge bases based on the appropriateness to the different aspects of the work. This agrees with the recommendation by

Karmokar *et al.* (2013) that multiple methods should be employed to evaluate a system. For instance, the hardware components of the prototype developed based on the proposed architecture were tested to establish their alignment with the expected electrical and functional characteristics as documented in the data sheets of the manufacturers. Unit testing was performed for the software aspect of the prototype. In addition, experiments were performed and machine learning based evaluation metrics such as accuracy and mean square error were engaged to select suitable pattern classifier for the prototype.

3.1.4 Guideline 4 - Research Contributions

DSR provides an adequate answer to the ultimate research assessment question - “what are the new and interesting contributions?” (Hevner *et al.* 2004). It has been stated that DSR must provide verifiable and unambiguous contribution in the areas of *artefacts, foundations* and *methodologies* (Hevner *et al.* 2004). The dimension of *artefacts* of DSR has been described in Section 3.1. *Foundations* imply the knowledge base of the field in which the research is being conducted while *methodologies* entail the creative development and use of new evaluation methods and metrics (Klose *et al.* 2007). Zimmerman *et al.* (2007) also opined that research contributions should be novel integrations of theory, technology, user need and context rather than a refinement of an existing product. In this dissertation, the proposed architecture of web based smart city infrastructure for refuse disposal management is a modification of the generic architecture of smart cities by Jalali *et al.* (2015). The architecture in the present study is very compact and incorporates pattern classification methods as well as Internet of Things (IoT) technology. This enables data gathering from smart refuse bins to an IoT web application and intelligent classification of the refuse bin status.

The proposed architecture is an artefact contribution that is made by the current study. This is because the architecture provides a modest extension to existing smart city architectures in the literature. The prototyped smart refuse bin and intelligent web based client application (based on the architecture) are also modest artefacts contributions. They represent the hardware and software infrastructure for refuse disposal management being developed in this study. Once they are fully deployed (this is beyond the scope of the current study), they will introduce some innovations to refuse disposal management practices.

3.1.5 Guideline 5 - Research Rigour

DSR requires that the researcher applies rigorous methods in the construction and evaluation of the designed artefacts. Rigour usually derives from the effective use of theoretical foundations and methodologies from the scientific as well as the engineering knowledge base within the field of research (Hevner *et al.* 2004). In an attempt to achieve the rigour requirement of DSR, other essential attributes such as applicability, generalizability and relevance of the designed artefact must also not be downplayed (Applegate 1999). The architecture presented in this dissertation was evolved based on the discovery of the gaps in existing smart city architectures after a rigorous and meticulous search of the literature. The constructed prototype based on the architecture is made up of both hardware and software. To make an apt selection from the huge repertoire of electronic hardware components in the market, a detailed study of their electrical and mechanical characteristics was undertaken. All the software in this study was developed in the MATLAB R2015a programming environment. MATLAB is a highly versatile software that is widely used both in the academia and industry for algorithmic programming, simulations, visualisation and prototyping (Keutzer *et al.* 2000; Žlajpah 2008; Marchand *et al.* 2005). ThingSpeak IoT web application (García *et al.* 2014) was selected based on its surpassing features over similar IoT web applications in the literature. The evaluation aspect of the designed artefacts in this study also aligns with the rigour requirement of DSR.

3.1.6 Guideline 6 - Design as a Search Process

DSR is intrinsically an iterative process, which essentially involves a search to discover an effective solution to a problem. It simplifies problems by explicitly decomposing them into sub problems. As the sub problems are refined and made more realistic iteratively, the designed artefact becomes more relevant and valuable (Hevner *et al.* 2004). Simon (1996) and Hevner *et al.* (2004) have also considered design process as a generate-and-test-cycle involving the generation of design options and testing of the options against specific requirements. In line with this DSR guideline, the developed architecture in this study, contains three major layers with appropriate interfaces for intercommunication of signals. The hardware and software units of the prototype were also developed through independent and iterative construction, implementation, experimentation, refinement and testing.

3.1.7 Guideline 7 - Communication of Research

DSR requires that the designed artefacts be presented to both practitioners and researchers. This enables practitioners to take advantage of the benefits offered by the artefact and researchers to build an increasing knowledge base for further extension and evaluation (Hevner *et al.* 2004). The researcher currently has a published article on the architecture developed in this study and its preliminary prototype in a conference proceeding. Ultimately, this dissertation, which contains the technical report of the architecture and prototype development will be a valuable addition to the ICT body of knowledge. Smart refuse bin and refuse disposal management software are feasible products that practitioners could leverage on based on the architecture and prototype in this study.

3.2 Development of the Proposed Architecture and Design of the Prototype

As reported in Section 2.5, several authors have proposed different multi-tier/multi-layer smart city architectures (Filipponi *et al.* 2010; Khan *et al.* 2012; Bellini *et al.* 2014; Zanella *et al.* 2014; Jalali *et al.* 2015). The various smart city architectures in the literature contains Radio Frequency (RF) components and sensors, liaison networks as well as service-oriented information systems as the first, second and third layers respectively. However, the topologies of most of the architectures are very cumbersome, which may impose some difficulties for practitioners that desire to implement them. Another vital gap in some of the earlier architectures is in the service–oriented information system layer, in which intelligent data processing is majorly represented as a prediction problem. These gaps provide the motivation to develop an architecture of a web based smart city infrastructure for refuse disposal management in this study, thereby fulfilling the DSR guideline 1 (that is designed as an artefact). The proposed architecture (shown in Fig. 3.2) emulates some aspects of Jalali *et al.* (2015) generic smart city reference architecture which was reviewed in Section 2.5. In similarity with Jalali *et al.* (2015) generic architecture, the proposed architecture contains signal sensing and network layers as well as IoT web technological paradigm for cloud computing. This gives the advantage of ubiquitous monitoring of refuse disposal activities through a state-of-the-art approach. The proposed architecture is however more compact and incorporates pattern classification techniques for bin status decision making. The compactness provides ease of implementation of the architecture while pattern classification techniques provide better decision by processing multivariate dataset extracted from the internal state of the refuse bin.

Following the DSR guideline 6 (that is research as a search process), the proposed architecture contains four layers which are the Signal Sensing and Processing Layer (SSPL), Intelligent User Application Layer (IUAL), IoT Web Application Layer (IWAL) and the Network Layer (NL). The NL provides wide area wireless communication channel for the other three layers using the Internet technology. However, each of the other three layers (SSPL, IUAL and IWAL) offers a template for the design of the functional hardware and software units of the proof of concept prototype in this study. Therefore, the subsequent sections contain the descriptions of the proposed architecture as well as the report of the hardware/software designs for the SSPL, IUAL and IWAL.

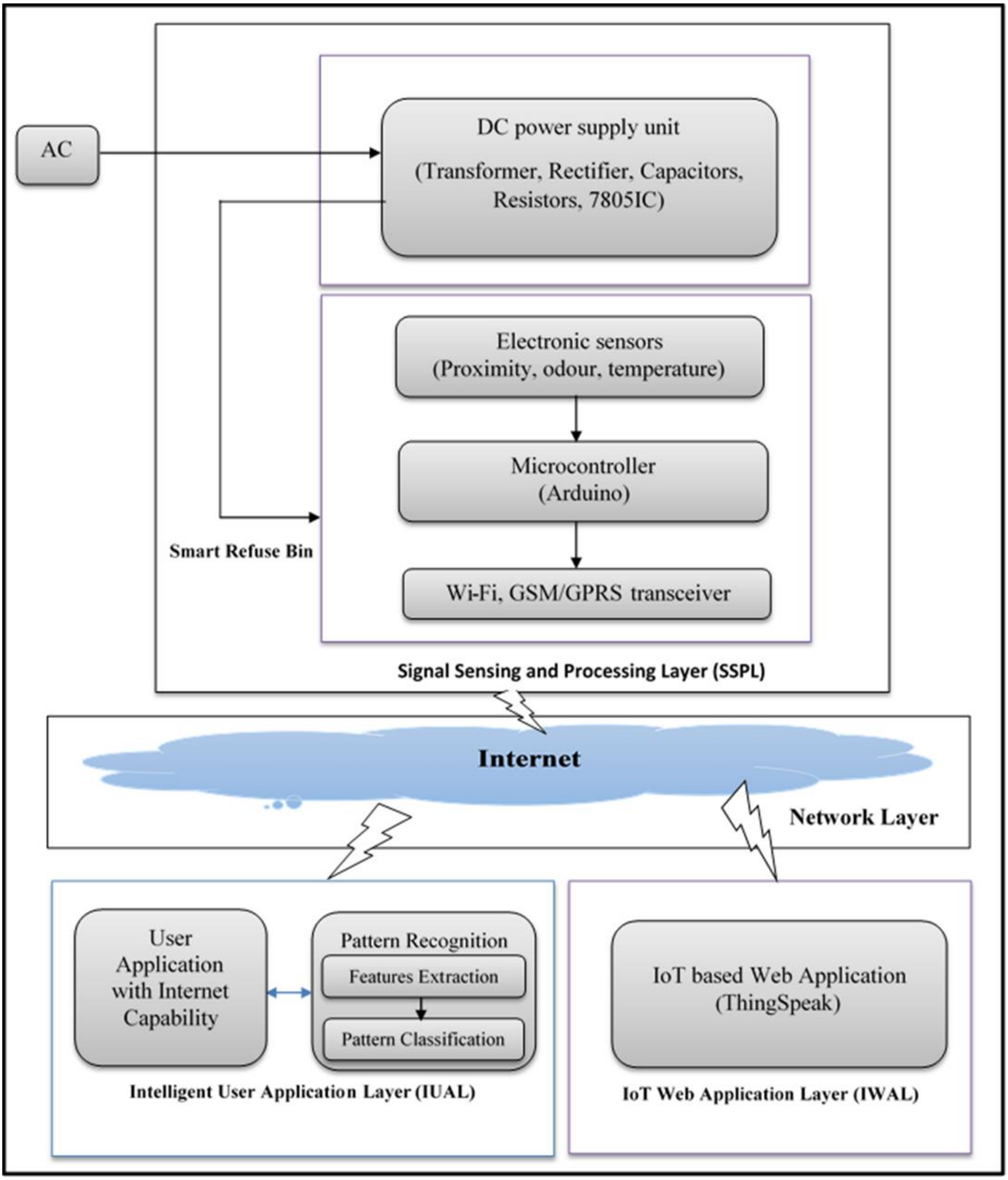

Figure 3.2: The proposed system architecture

3.3 Signal Sensing and Processing Layer

As shown in Fig. 3.2, the SSPL is made up of the Refuse Bin (RB), DC Power Supply Unit (PSU), electronic sensors, Wireless Fidelity (Wi-Fi) or GSM (Global System for Mobile) / GPRS (General Packet Radio Service) transceiver and the microcontroller development board that runs an embedded software. The RB is calibrated into five different levels as shown in Fig. 3.3. Level1, level2, level3, level4 and level5 represent empty, quarter-full, half-full, three-quarter-full and full statuses respectively. The PSU contains rectification circuits to convert Alternating Current (AC) from the main supply to Direct Current (DC), which powers the SSPL. The electronic sensors capture raw information from the RB and transduce them into electronic signals. Such signals include:

i) The distance from the lid to the level of refuse in the RB using proximity sensor.
ii) The gaseous emission from the decomposing refuse to use odour sensor.
iii) The temperature of refuse in the RB using temperature sensor.

The microcontroller in the SSPL is a device which contains components such as processor, memory interface controllers, timers, interrupt controller and General Purpose Input/Output (GPIO) pins. The electronic sensors in the SSPL are connected to the appropriate GPIO pins on the microcontroller to collect the acquired signals and transmit them over the internet via Wi-Fi or GSM/GPRS transceiver. The author finds it convenient to report the design of the resulting hardware and/or software from each layer of the architecture immediately after the description of the layer.

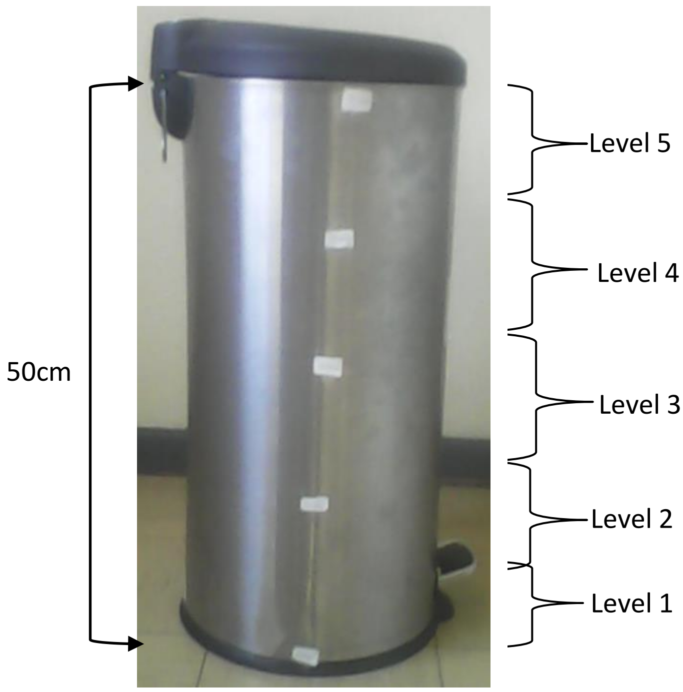

Figure 3.3: The refuse bin

3.3.1 SSPL Hardware Circuit Design

The integration of the different electronic hardware components in the SSPL is a requirement for the layer to be able to perform the function of data sensing and transmission. This is because there must be a complete circuit for an electronic module to work. A circuit is a connection of conducting materials that goes in a circle from one terminal of a PSU through the interconnected components and then back to the other terminal of the PSU. The circuit diagram represents the path between two or more points along which an electrical current can be carried, the standard way of illustrating an electronic circuit is to order how the circuit works. Fig. 3.3 shows the hardware circuit diagram of the SSPL. The electrical configuration of each section of the circuit diagram is described below.

3.3.1.1 Power Supply Unit

The PSU section of the circuit diagram (Fig.3.4) comprises of various interconnected components such as a 230V/12V step down transformer, full wave bridge rectifier, 7805 voltage regulator Integrated Circuit (IC), resistors, capacitors and Light Emitting Diode (LED). The purpose of the PSU is to convert the 230V Alternating Current (AC) to 5V Direct Current (DC) that is required to power the microcontroller in the SSPL. To achieve this, the AC supply from the mains is stepping down from 230V AC to 12V AC by the transformer. The 12V AC is converted to 12V DC by the full wave bridge rectifier. However, the 12V DC output contains some ripples, which are filtered through the capacitor. The 7805 voltage regulator IC then converts the filtered 12V DC to 5V DC, which powers the microcontroller and all the electronic sensors. The AC power supply within the laboratory was utilized at the experimentation phase of this study. However, when the smart bin is deployed externally, the municipal authority will be required to provide the AC power sources.

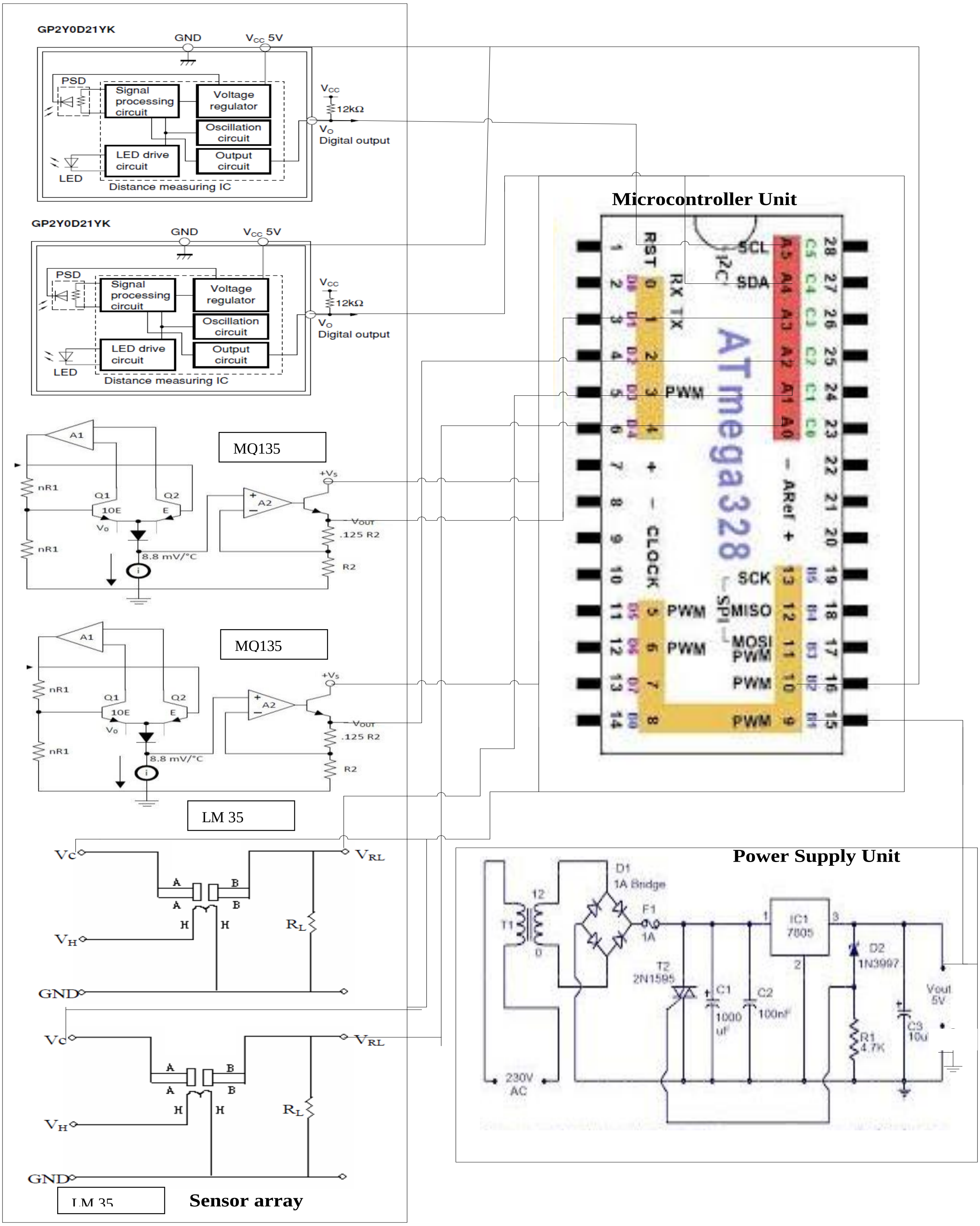

Figure 3.4: SSPL circuit diagram

3.3.1.2 Microcontroller Unit

Some of the microcontroller boards that are in common use for prototyping purposes are Arduino Uno, Raspberry Pi, BeagleBone, pcDuino, Uruk, Goldilocks, Sparkcore, DigiSpark and several others (Gridling and Weiss 2007). Arduino Uno was selected for this study because it is open-source, reliable and easy to program. The microcontroller within the Arduino Uno is the ATmega328 as shown in the circuit diagram in Fig. 3.4. Its operating voltage is 5V, which is obtained from the output from the PSU. There are 14 digital input and output pins on the microcontroller. The 6 of the 14 pins provides Pulse Wave Modulation (PWM) output while another set of 6 pins takes in analog input from the connected sensors. The six sensors utilized for this study are connected to the analog input pins as shown in the circuit diagram (Fig. 3.4). The direct current per input/output pin is 40 mA. The flash memory of the ATmega328 processor is 32 KB of which 0.5 KB is used by the boot loader. Its SRAM is 2 KB, EEPROM is 1 KB and its clock speed is 16 MHz (Arduino Datasheet 2012; ATmega328). The ATmega328 microprocessor translates the electrical signals from the sensors into digital data streams using the embedded program that was developed in this study and stored on the memory of the microcontroller. The algorithm of the embedded program is shown in Algorithm 1. The algorithm was implemented using the Arduino hardware support package in MATLAB R2015a. After being implemented, the embedded program is loaded into the microcontroller for full functionality.

Input: M, N, K, OpMode
M is number of readings/sensor,
N is the number of sensors
K is the number of analog output pins on the Arduino microcontroller unit
OpMode is the operation mode, which can be dev (for development) or dpl (for deployment).
Output: X(M,N) sensor reading values
(1) Clear the workspace
(2) Initialize the arduino microcontroller board
(3) **for all** i=1, 1,…,K **do**
(4) configure analog pins as input pins
(5) **end for**
(6) **M = 200: N = 6**
(7) **for all** i =1,2,…, M **do**
(8) **for all** j=1,2,……N **do**
(9) read analog values from each of the sensors in to the marix X(i,j)
(10) **end for**
(11) **end for**
(12) **If** (OpMode = "dev")
(13) assign the matrix X(M,N) to the workspace
(14) save the matrix X(M,N) to the memory
(15) **end if**
(16) **ElseIf** (OpMode = "dpl")
(13) write the matrix X(M,N) to ThingSpeak IoT Web Application
(14) **end if**
(15) Stop

Algorithm 1: Embedded program of the microcontroller unit

3.3.1.3 Sensor Array Unit

The sensor array unit in the circuit diagram (Fig. 3.4) is a connection of six sensors, which consist of two proximity sensors, two gas sensors and two temperature sensors. The six sensors have three pins - Vcc, GND and Vo, which are connected using male and female jumper wires to the 5V, GND and Analog pins 0, 1,2,3,4 and 5 respectively on the microcontroller board. The duplication of each of the sensors in the circuitry is to incorporate redundancy, eliminate data sparsity and provide holistic coverage of the entire RB. The proximity sensor is a Sharp GP2Y0A02YK0F infra-red IC that covers a distance of up to 150 cm. This functional range makes the sensor suitable for the refuse bin in Fig. 3.3, which is only 50cm in length. Other specifications of the proximity sensor are package size of 29.5×13×21.6 mm, consumption current of 33 mA and input voltage of 4.5V to 5.5 V. This input voltage is obtained by connecting the sensor to any of the power pins on the microcontroller, which also generates an output voltage of 5V. The sensor produces an analog output voltage that corresponds to the distance between the lid of the RB and the top of the refuse in the bin. The characteristic curve in the manufacturer's data sheet (GP2Y0A02YK0F Datasheet) indicates that the output voltage rises from 0V at 0cm to a peak output voltage of about 2.8V at 18cm. The voltage then drops gradually based on the reflective properties of the materials within the RB to about 0.5V at 150cm.

The MQ 135 gas sensor operates on 5V± 0.1 DC, which is obtained by connecting the sensor to any of the power pins on the microcontroller. The functional specifications of the gas sensor are oxygen concentration of 21%, storage temperature of -20ºC to -70ºC and related humidity of less than 95%. The sensor resistance varies at various concentrations of gases. Gaseous emissions that can be measured by the sensor include benzene, methane (CH4), hexane, carbon monoxide (CO) and air (MQ135 Datasheet). The sensor is suitable for this study because the most significant greenhouse gas that is produced from refuse is methane (Spokas et al., 2006).

The LM35 temperature sensor operates from 4V to 30V. This implies that the sensor can be powered conveniently from any of the microcontroller's power pins. It is calibrated directly in Celsius with linear +10-mV/°C scale factor and rated for full −55°C to 150°C. 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 Centigrade scaling. The characteristic curve in the datasheet (LM35 Datasheet) shows that the functioning of the temperature sensors exhibits a positive exponential behaviour over time. While refuse get decomposed in the RB, microorganisms consume the organic matter and generate both heat and other gases. Once the temperature sensors are powered, they read the internal heat within the RB. Because the RB was located in the laboratory for the current study (being a prototyping phase), the heat largely depends on the quantity of refuse in the bin.

3.3.1.4 GSM/GPRS and Wi-Fi Shields

The GSM/ GPRS shield is a SIM900 quad-band device that works on 850 MHZ, 900 MHZ, 1800 MHZ and 1900 MHZ frequencies. It is very compact in size and easy to use as a plug modem. The modem is designed with 3V3 and 5VDC TTL interfacing circuitry, which allows it to directly interface with 5V microcontrollers like PICs, AVRs, and Arduinos as well as 3V3 microcontrollers like ARMs and ARM Cortex XXs. The baud rate of the modem is configurable from 9600-115200 bps through AT (Attention) commands. It contains internal TCP/IP stack for connection to the internet.

Apart from the GSM/GPRS shield, the Wi-Fi shield is another alternative for the Arduino development board to connect wirelessly to the internet. The operating voltage of the Wi-Fi shield is 5V, which is supplied from the power pin of the microcontroller board to sustain the lifetime of the bin prototype within the experimental phase in the laboratory. The shields can connect to the internet via the 802.11b/g networks and transmit encrypted data using the WEP and WPA2 encryption standards (Atkinson *et al.* 2013).

The GSM/GPRS and Wi-Fi shields provide optional internet access for the SSPL to transmit data stream to the IoT web application (which will be discussed later in this chapter). The transmitted data stream contains intelligent information concerning the status of the refuse in the RB. Nevertheless, the Wi-Fi interface card on the development computer was used to emulate the Wi-Fi shield for connecting the microcontroller board to the internet wirelessly. This is because it contains all the characteristics of the Wi-Fi shield. The Wi-Fi option became paramount because using the GSM/GPRS shield is costly for a study of this nature, since the mobile operators require the GSM/GPRS shield to have a data subscription in order to gain connection to the internet. However, the GSM/GPRS option will be very handy for real-time deployment, which is beyond the scope of the current study. The SSPL circuitry is incorporated into the RB shown in Fig. 3.3 to produce the Smart Refuse Bin (SRB). The pictorial view of the SRB is presented in Chapter 4.

3.4 IoT Web Application Layer

The IoT Web Application Layer (IWAL) shown in Fig. 3.2 is primarily made up of IoT based web application. Internet of Things (IoT) is an emerging web technological paradigm. It involves a scenario in which connected systems acquire, process, store or communicate data gathered by electronic sensors, from machines, objects, environments, infrastructure and other physical entities. The data are processed into beneficial information that can be applied to “command and control” things to improve human lives on the planet (Karimi and Atkinson 2013). In a more general sense, IoT can be implied as creating smart devices that are interlinked with people and other devices. It has been projected that by the year 2020, 50 billion devices will be connected to the IoT (Maureira *et al.* 2014). Some examples of IoT web applications are ThingsSpeak, Carriots, SmartObject, Skynet Sensorthings, Nimbits, SensorCloud, Exosite, iDi, EVRYTHNG, Paraimpu, Manybots and Pachube (Doukas 2012, Maureira *et al.* 2014). ThingSpeak is selected out of these numerous IoT web applications for this study because of its notable advantages and strengths.

ThingSpeak is an open source IoT web application which uses Phusion Passenger Enterprise web application server. It provides Application Programming Interfaces (APIs) for storing and retrieving data from sensors and devices over the internet. According to Maureira *et al.* (2014), it is not clear if the server of the other IoT applications is running Phusion Passenger. Another clear advantage of ThingSpeak that motivates its selection for this study is that its APIs provide support for MATLAB R2015a as well as other programming languages such as Ruby, Python and Node.js.

Furthermore, ThingSpeak also provides free hosting for data channels. Each channel in ThingSpeak support data entries of 8 data fields, latitude, longitude, elevation, description and status. Incoming data from sensors into the channels are communicated via Hyper Text Transport Protocol (HTTP) POSTs through plain text, JASON or XML formats. The channels are set to private by default and machines or users need read or write key, which is generated by ThingSpeak to access the data (Doukas 2012, Maureira *et al.* 2014).

Given the above mentioned strengths of ThingSpeak over its rivals and following the DSR guideline 5, the writing of sensors' data and reading of data from ThingSpeak were implemented in this study with functions in the ThingSpeak Support Toolbox for MATLAB R2015a. The results obtained are presented in Chapter 4.

3.5 Intelligent User Application Layer

The Intelligent User Application Layer (IUAL) comprises of the non-browser client application software with internet capability (hereafter referred to as client application for convenience) and pattern recognition. The pattern recognition module and the design of the client application in IUAL are discussed in this section.

3.5.1 IUAL Pattern Recognition

The IUAL pattern recognition module in Fig. 3.2 comprises of the feature extraction from the sensors dataset obtained from the SSPL via the IWAL and the pattern classification sub modules. The pattern classification sub module incorporates intelligence into the proposed architecture. A pattern classifier usually assigns a pattern presented to it in the form of the extracted feature vectors into one of five SRB levels. This provides notification to the end users that is an Administrator, Supervisor and Janitor on whether the SRB is empty (level1), three-quarter-full (level 2), half-full (level3), one quarter-full (level4) or full (level5).

Nevertheless, the intricacy of pattern recognition depends on two primary factors. The first is the dimension and discriminatory power of the feature vectors. The second is the choice and configuration of pattern classifiers. The first order statistical features and pattern classifiers utilized in this research study are discussed in the following subsections.

3.5.1.1 Dataset and First Order Statistical Feature Extraction Strategy

To obtain the training and testing data sets for this study, the researcher collected wastes from refuse containers that are located within the Ritson Campus at the Durban University of Technology, South Africa. The refuse containers contain decomposing materials, papers and different varieties of solid wastes that were dumped by students, staff as well as visitors within the University. 200 values were iteratively mined by each of the 6 sensors to produce a 200x6 dataset for each level of the SRB. The procedure for generating the data sets using the embedded code that runs on the SSPL embedded circuit has been presented earlier in Algorithm 1.

Irrefutably, pattern classification using original sensor measurements is often inefficient and may even hinder proper interpretation (Indonesia, 2011). Feature extraction therefore reduces the dimensionality of the raw data set by keeping the most discriminatory information. The performance of the feature extraction stage sturdily impacts the design and performance of pattern classifiers. If the best features are selected from the raw data, the task of the subsequent pattern classifier becomes trivial. Conversely, if the features with little discriminatory ability are chosen, a more complex pattern classifier may be required (Cevikalp 2005).

Principal Component Analysis (PCA) is one of the most commonly used algorithms for feature extraction and dimensionality reduction in fields like image processing, pattern recognition, Bioinformatics, telecommunications. It is an optimal linear transformation algorithm for keeping the subspace of a dataset that has largest variance. However, the computational requirement for PCA is very high (Jolliffe 1986; Kalkan 2007; Indonesia 2011). First Order Statistical Features (FOSF) are another strategy being employed for discriminatory feature extraction with lower computational requirements (Indonesia 2011). In line with the DSR guideline of research rigour, the computational advantage of the FOSF over PCA motivate its selection as the feature extraction method for this research work.

The FOSF utilised include the mean, standard deviation, kurtosis and skewness values computed from each of the 200 values generated for each of the 6 sensors (Kalkan 2007; Indonesia 2011; Aggarwal and Agrawal 2012). For a dataset X of N size and values

$\{x_1, x_2, ..., x_N\}$ the mean, μ, which is a measure of central tendency for the data is computed as:

$$\mu = \frac{x_1 + x_2 + ... + x_N}{N} \tag{3.1}$$

The standard deviation, σ is a measure of the dispersion of a set of data from its mean. The more spread apart the data, the higher the deviation. Standard deviation is calculated as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \mu)}{N}} \tag{3.2}$$

A low standard deviation indicates that the data points tend to be close to the mean of the dataset, while a high standard deviation indicates that the data points are spread out over a wider range of values.

Skewness is a measure of asymmetry of the probability distribution of a real-valued random variable about its mean. Skewness value can be positive, negative, or zero in which the distribution curve right skewed, left skewed or normal. Skewness, S_k is computed as:

$$S_k = \frac{\sum_{i=1}^{N}(x_i - \mu)^3 / N}{\sigma^3} \tag{3.3}$$

Kurtosis is a measure of whether the data distribution is heavy-tailed or light-tailed relative to a normal distribution. The data sets with high kurtosis tend to have heavy tails, or outliers while data sets with low kurtosis possess light tails (or lack of outliers). Kurtosis, K_u formula is thus given as:

$$K_u = \frac{\sum_{i=1}^{N}(x_i - \mu)^4 / N}{\sigma^4} \tag{3.4}$$

The computed mean, standard deviation, skewness and kurtosis for the six sensors are concatenated to obtain FOSF vectors in 24- dimensional space for each level of the smart refuse bin. The procedure for computing the FOSF was implemented in MATLAB R2015a programming environment. The plots of the feature vectors, which shows the distinctiveness of the features per level are presented in Chapter 4.

3.5.1.2 Pattern Classification

The feature vectors obtained with the FOSF extraction method discussed in the preceding subsection are transmitted to train the selected pattern classifiers. A trained pattern classifier will thus be able to categorise an incoming raw data stream from the SSPL, which have been processed with the FOSF into one of the empty, quarter full, half full, three quarter full and full bin status.

Two competing state-of-the-art pattern classifiers investigated for the classification of the features in this study are the Multilayer Perceptron Artificial Neural Network (MLP-ANN) and Support Vector Machine (SVM). They are extensively engaged in the literature to solve pattern classification problems (Adetiba and Olugbara 2015). Nevertheless, each of the classifiers has inherent merits and demerits. MLP neural networks have the capability to detect complex non-linear associations between variables, they are very fast to use for classification problems and generally achieve good performance. Because MLP is based on the traditional empirical risk minimization principle, it often suffers from overfitting and multiple local minimal. Conversely, the SVM has the advantage of good generalization performance because it is based on the structural risk minimization principle. It has a modest geometric interpretation, its computational involvedness do not depend on the dimensionality of the input space and its solution is global and unique. SVM is, however a shallow model and its performance result relies heavily on the selected kernel function. The joint strength of both MLP and SVM is that they yield good performance in high-dimensional classification problems (Plamondon and Shirari,2000; Cristianini and Shawe-Taylor 2000; Lippmann, 1987).

Generally, the best classifier for a given problem depends on the problem domain, the number of classes to be classified and the number of example(s) available per class (Sande et al 2010). Furthermore, based on the DSR guidelines 3, 5 and 6 (design evaluation, research rigour and design as a search process), experimentation becomes handy to compare the performance of the two classifiers for the classification problem in this study. The configuration of the MLP and SVM pattern classifiers utilized in this study is presented.

3.5.1.3 Configuration of MLP and SVM Pattern Classifiers

The MLP-ANN and SVM in this study were tuned to determine the configuration that gives the most optimal performance through established parameters in the literature as well as via experimentations.

An MLP-ANN consists of an input, one or more hidden and an output layers of neurons with each layer fully connected to the next one. The size and number of classes in the dataset determine the number of neurons in the input and output layers respectively (Abayomi *et al.* 2016). Each feature vector in this study is a 24- dimensional vector and there are 5 different levels for the SRB, hence, the MLP-ANN contains 24 neurons in the input layer and 5 neurons in the output layer. Popescu *et al.* (2009) recommended that more hidden layers with a high number of neurons usually lead to fewer local minima. Thus, to achieve high optimality and low complexity, the MLP-ANN were configured with two hidden layers. Furthermore, 20, 40, 60, 80 as well as 100 neurons per hidden layer were investigated to experimentally determine the appropriate number of neurons for each of the hidden layers. Except for the input neurons, which contain linear activation function, each neuron in neural network has a nonlinear activation function. For the MLP-ANN in this study, the neurons in the hidden and output layers were configured with the hyperbolic tangent function. The nonlinearity and differentiability properties of the function have been deemed as essential qualities for optimal performance of neural networks (Popescu *et al.* 2009). The MLP-ANN utilizes a supervised learning technique called scale conjugate gradient backpropagation for training the network, based on its record of performance (Rumelhart *et al.* 1986;, Cybenko 1989; Abayomi *et al.* 2016). The FOSF computed in subsection 3.4.2.1 were used to train the MLP-ANN based on a data partitioning ratio of 70% training, 15% validation and 15% testing (Abayomi et al 2016). The MLP-ANN contains additional configurations as follows (Abayomi et al 2016):

Training epochs = 10,000,
Learning rate = 0.1,
Maximum training time = 180sec,
Minimum performance gradient = 1e-6,
Validation checks = 10,000

SVM possesses the ability to capture both linear and nonlinear patterns in feature space by employing a mapping function which transforms the feature space into a higher domain that exhibits multiple dimensionalities (Jordaan 2002). The mapping function is usually implemented by using specialised kernels. Minh et al. (2006) opined that SVM kernels must satisfy Mercer condition for it to be effective. Examples of kernels that satisfy the Mercer condition are linear, polynomial, radial basis function and perceptron kernels (Oyewole *et al.* 2015). Since the performance of the SVM is determined by the choice of kernel selected for the experiment, the four listed kernels were tested using 10 fold cross validation and their performances were compared.

SVM was customarily developed for binary classification problems (Liu *et al.* 2005) but it has recently been extended to solve multiclass problems (Abe et al., 2014), which is the case in this study. The two popular techniques that are employed for multiclass problems are the One-Against-One (1A1) and One-Against-All (1AA) (El-Yaniv *et al.* 2008; Galar *et al.* 2011). The 1AA is selected for this research study because it was described by Eichelberger and Sheng (2013) as a simple and efficient technique. The same data partitioning for MLP-ANN was used for training the SVM.

In compliance with the DSR guideline 3 (design evaluation), the performance evaluation metrics of accuracy and Mean Square Error (MSE) were adopted in this study for the MLP-ANN and SVM. These two metrics are the two most commonly used in the literature (Popescu *et al.* 2009; Lu 2004; Adetiba and Olugbara 2015). The accuracy is the degree of closeness of the measurements of a quantity to its true value (Taylor and Robert 1999). Whereas MSE is the mean of the square of the difference between the expected output and the actual output.

Implementation, training as well as all the experimental configurations of the MLP-ANN and SVM pattern classifiers in this study were carried out in MATLAB R2015a. The computer system for the implementation and experiments contains Intel Core i5-2540MCPU @2.60GHz speed with 4.00GB RAM and 64-bit Windows 8 operating system. The results of all the experiments based on the evaluation metrics of accuracy and MSE are presented in Chapter 4.

3.5.2 IUAL Client Application Design

The client application is a graphical user interface (non-browser-based) web client scripts, which carry out operations such as algorithmic computation, database query, fetching of data from input/output interfaces, transmission of data to or from the internet and host of other complex computations. Examples of tools for creating non-browser-based client applications include Delphi, Java and MATLAB (Pieczul *et al.* 2010). Based on the DSR first guideline, requirement analysis and design specification are highly paramount in the development of artefacts. Therefore, in this research study, the client application was designed with the Unified Modelling Language (UML). UML has become a standard for modelling and design of software systems. UML diagrams represent two different views of a system model, which are the static (or structural) or the dynamic (or behavioural view) (Padmanabhan 2012).

UML2 defines 13 basic diagram types that are divided into two generic groups, namely behavioural and structural modelling diagrams. Behavioural diagrams are used to capture the interactions and state instantiations within a model over its execution time. On the other hand, structural diagrams are used to emphasize the things that must be present in the software application being modelled, such as the classes, objects and interfaces. Structural diagrams are also used to represent the relationships and dependencies between the various elements of the modelled software. According to Bell (2013), the most useful standard UML diagrams are *use case, class, sequence, statechart, activity, component* and *deployment* diagrams. However, four of these diagrams sufficiently captures the different views of the IUAL client application as well as the prototype of the proposed architecture. Hence, in this research study, use case diagram was used to model the behavioural view while class diagram was used to model the structural view of the IUAL client application. However, activity diagram was adopted to model the operational step-by-step workflow of the hardware and software components of the full prototype. Deployment diagram was also adopted to model how the entire prototype can be deployed, even though, the deployment of the prototype is beyond the scope of the current study. All the four diagrams are presented in the succeeding sub-section

3.5.2.1 IUAL Client Application Use Case Diagram

Escalona and Koch (2004) opined that use case diagrams represent the functionality of a software system in a graphical way. The use case diagrams of a system and the relationship between the entities provide greater understanding of the system. In alignment with the DSR guideline 1, the high level functional requirements needed to develop the system can be derived from the use case diagram. Furthermore, the use case diagrams illustrate the role and responsibility of service agents and their functions, which practitioners can easily translate into valuable software. Fig. 3.5 shows the use case diagram for the IUAL client application in this study. The human figures, oval shapes and interconnection lines represent actors, use case and association respectively (Sarma *et al.* 2007). There are three main actors in the diagram, which are the administrator, supervisor and janitor. These actors represent the refuse disposal management agents within a governmental unit. The roles and responsibility of the actors vis-à-vis their interactions as captured in the use cases are explained in Table 3.1.

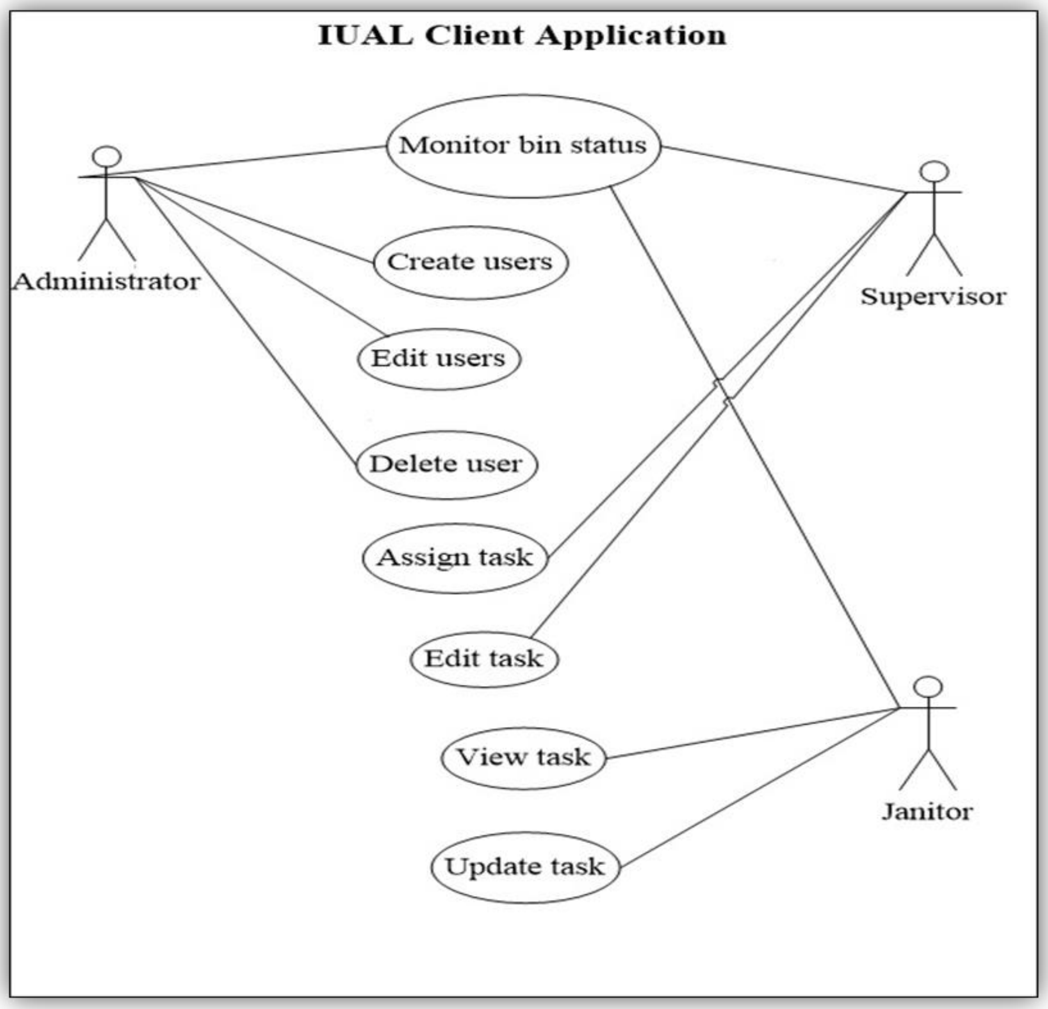

Figure 3.5: UML use case diagram for the client application

Table 3.1: Roles and responsibility of the users

User	Role and responsibility
Administrator	By logging in into the system, the administrator is able to check SRB information and an automatic display of bin status at different locations. The administrator possesses the access right to create, edit or delete both the supervisor and the janitor profiles.
Supervisor	The supervisor logs in and undertake the task assigned by the administrator. The tasks include assignment of task to the janitor for refuse disposal action. The supervisor can also edit tasks that are assigned to the janitor.
Janitor	The janitor logs into the system and carry out collection task assigned by the supervisor. Through update task role, there is the provision of feedback to both the administrator and supervisor.

3.5.2.2 IUAL Client Application Class Diagram

The class diagram depicts a static view of a software and it is primarily used to show implementation classes. As shown in Fig. 3.6, a class is depicted on the class diagram as a rectangle with three horizontal sections. The upper, middle and lower sections represent the class names, attributes and methods respectively (Bell, 2003). The IUAL client application contains four base classes named as *BinStatus*, *WebAppGateway*, *UserManagement* and *Users*. The *Users* class, however, contains three derived classes which are named *Administrator*, *Supervisor* and *Janitor*. The attributes and methods for each of the classes are detailed in the class diagram. For example, the *WebAppGateway* class contains two properties, namely *sensorValues,* which is of type double and *dateTime,* which is of type Date. The class also contains two methods, namely, *dataRead()* and *dataWrite()* both of which return double data types. The *WebAppGateway* class as a dependency relationship with the *BinStatus* class. The latter uses the former in order to access the IoT based web application services. The relationship between the *Users* class and the *BinStatus* class is one-to-many since all the derived classes (i.e. *Administrator*, *Supervisor and Janitor*) utilises the *BinStatus* properties and methods to determine the SRB status and location as well as to display its location graphically. The *Administrator* class has a one-to-one relationship with the *UserManagement* class to manage users profile on the IUAL client application.

The designed IUAL client application in this section was developed with the Graphical User Interface Development Environment (GUIDE) in MATLAB R2015a. The testing results of the developed client application are presented in Chapter 4.

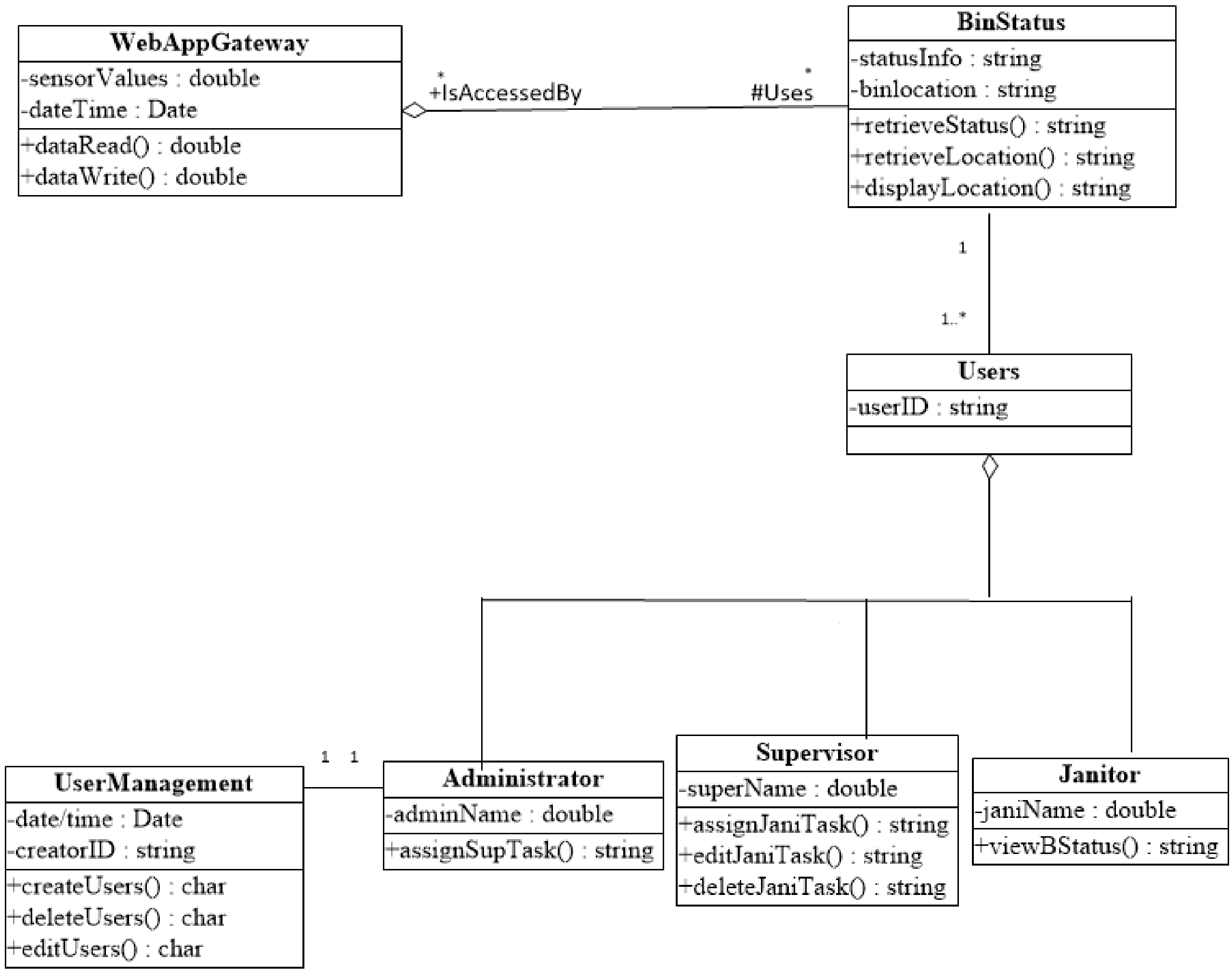

Figure 3.6: UML class diagram for the client application

3.6 Activity Diagram of the Full Prototype

According to Bauer and Odell (2005) activity diagram models the activity sequence and emphasizes the conditions for coordinating lower-level behaviours in a system. It also illustrates the flow of the signal across the different aspects of a system (Padmanabhan 2012). Activity diagrams usually consist of shapes such as round-cornered rectangle, diamond, circle, can and interconnection lines, which symbolise action state, decision, start or stop, database and association respectively (Bastos and Ruiz 2002). Fig 3.7 shows the activity diagram of the full prototype that have so far been designed in this chapter. The diagram consists of 10 action states, 3 decisions, 3 forks, 1 database, 1 start and 1 stop symbols. The operation of the entire activity diagram starts with the loading of the intelligent client application in the *Load Client App* action state. A decision on the appropriate user group is taken, which branches out to *Janitor* and *Others*. The *Janitor* user group branches out to 2 action states, which are *View/Update Task*, and *Check Bin*. The second decision symbol splits into the *Administrator* and *Supervisor* user groups. The *Administrator* user group links to action states, which are *Create Users* and *Edit*/*Delete Users*. The Supervisor also links to 2 action states, namely *Assign Task* and *Edit/Delete Tasks*. Similar to *Janitor*, both the *Administrator* and *Supervisor* also link to the *Check Bin* action state. The *Smart Refuse Bin* section has only 1 *Signal Sensing and Transmission* action state which sends refuse status and location data into the *ThingSpeak Services* action state at the *IoT Web Application* section. The *ThingSpeak Services* action state transmits the data it receives to the *Bin Status and Location View* action state for the *Administrator*, *Supervisor* and *Janitor* view the status and location of the SRB. The last decision symbol is for the different user group to determine if more tasks should be performed or all activities should end. If several tasks are desired by any of the user group, a link is returned back to first decision symbol and there is a link to end the activities if otherwise.

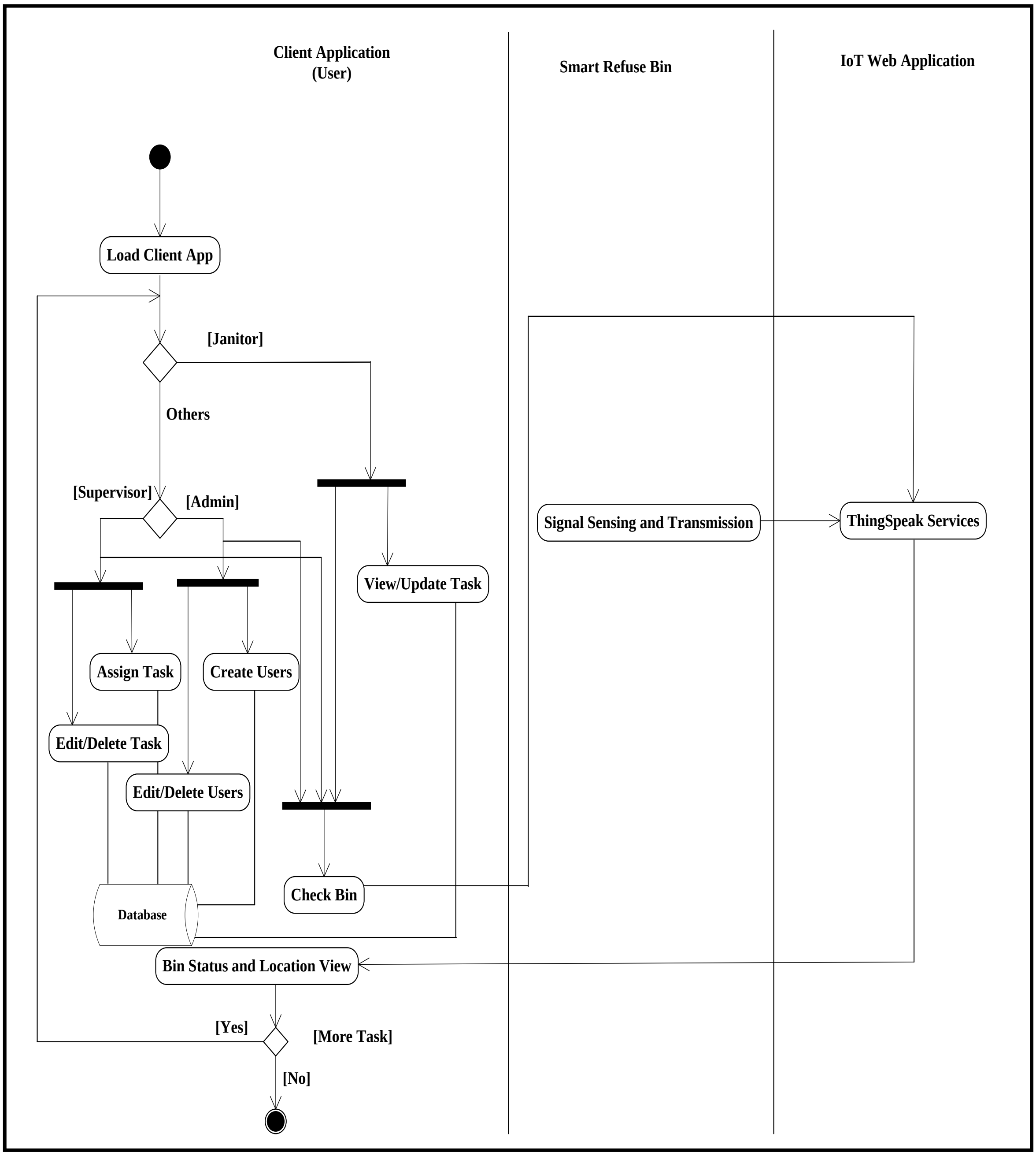

Figure 3.7: UML activity diagram for the full prototype of the proposed architecture

3.7 Deployment Diagram of the Full Prototype

Deployment diagram displays the physical entities of the significant artefacts in a project within a real world setting. The concept of a node is used to represent a physical machine or a virtual machine. A node is drawn as a 3 dimensional cube indicating its name at the top of the node (Bell 2003; Padmanabhan 2012). Fig. 3.8 shows the deployment diagram for the full prototype in this study. There are three main hardwares in the diagram, which are the *Smart Refuse Bin*, *IoT Web App Server* and the *Refuse Disposal Management PC*. These hardwares represent the execution environment of the different refuse disposal management infrastructure artefacts that were designed in this chapter. The *Smart Refuse Bin* node is a refuse bin that is affixed with the circuitry of the SSPL. The *Embedded Program* in the node runs in the microcontroller within the SSPL circuitry and transmit data on the refuse status and location of the *ThingSpeak Services* running on the *IoT Web App Server* node. The *Refuse Disposal Management PC* is the node that the different user groups (Administrator, Supervisor and Janitor) access to work on the intelligent *Client Application* that runs on the node.

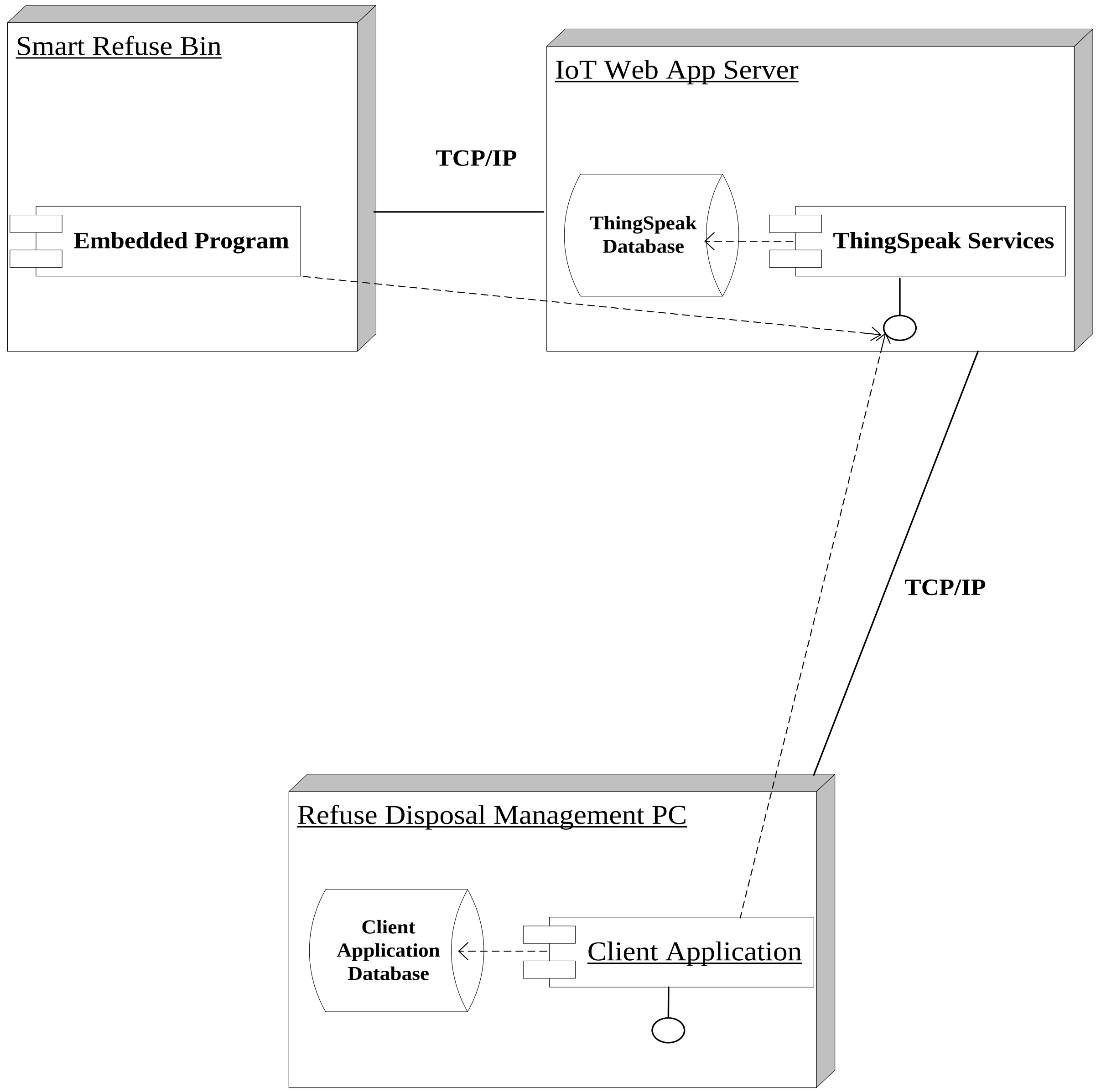

Figure 3.8: UML deployment diagram for the full prototype of the proposed architecture

3.8 Conclusion

This chapter presented the application of the DSR approach to develop the architecture and design the proof of concept prototype of the web based smart city infrastructure for refuse disposal management. The architecture and prototype are the two DSR artefacts developed in this study. The architecture amends Jalali generic reference smart city architecture, thereby providing several advantages for refuse disposal management. The design of the hardware aspect of the prototype through a meticulous selection of electronic components aligns with a research rigour of DSR. In codicil, the research also aligns with relevant DSR guidelines to select ThingSpeak as the IoT web application and to configure MLP-ANN and SVM for experimental comparison in order to choose the appropriate one for pattern classification. Furthermore, this study adopted UML notations and diagrams (such as use case, class, activity and deployment diagrams) to design the software aspects of the prototype and model the interactions vis-à-vis the deployment of the full prototype. The design using UML agrees with the first DSR guideline which enforces requirement analysis and design specifications for the development of artefacts. The synergy of DSR approach, emerging IoT technological, electronic circuit design, UML and pattern recognition techniques provided sound theoretical guidelines in this chapter for addressing the study research question.

CHAPTER FOUR

PROTOTYPE IMPLEMENTATION AND EVALUATION

This chapter presents the implementation and evaluation results of the prototype that was developed based on the proposed architecture. The design of the hardware and software prototypes underpinned by the DSR guidelines have been achieved and exhaustively reported in the preceding chapter. The functionality of the electronic sensors and microcontroller that were used to construct the hardware circuitry of the prototype were tested first and foremost before being integrated into a circuit. This helped to isolate malfunctioning components that may eventually hinder the smooth functioning of the hardware circuitry of the prototype. The embedded program was loaded into the microcontroller and the sensor array of the hardware circuitry was affixed to the top of the refuse bin to produce the Smart Refuse Bin (SRB). Once the SRB gets powered up, it becomes operational and transmits data on the status of the refuse in the bin to the configured ThingSpeak web application, which is one of the software aspects of the prototype.

The other software aspects of the prototype are the non-browser client application (simply referred to as client application as stated in Chapter 3) and the pattern recognition (that is feature extraction and pattern classifier) modules. The client application provides a platform for different user groups who are responsible for refuse disposal management to carry out their respective tasks. It uses appropriate functions (or methods) to connect with the ThingSpeak web application based on users' query to acquire the latest data from the SRB. Afterwards, it connects with the feature extraction function to process the data and the trained pattern classifier model to classify the data into one of empty, three quarter full, half full, quarter full and full status. The client application thereafter presents the status so obtained to the user for necessary action. The following sections pedantically present the prototype hardware testing, the implementation and unit testing of the client application, the first order statistical features as well as the evaluation results of the pattern classifiers.

4.1 Testing of the Prototype's Hardware Unit

The testing results of the electronic sensors and the Arduino microcontroller development board are presented in this section.

4.1.1 Arduino Development Board

The Arduino Uno development board, which contains the ATmega 328 microcontroller was connected through USB 2.0 cable to the PC to evaluate its functionality. The board gets powered up by the 5V voltage that is supplied to it from the PC via the USB 2.0 cable. The On LED situated on the board emits a steady green light to indicate the device is in good and proper working conditions as shown in Fig. 4.1.

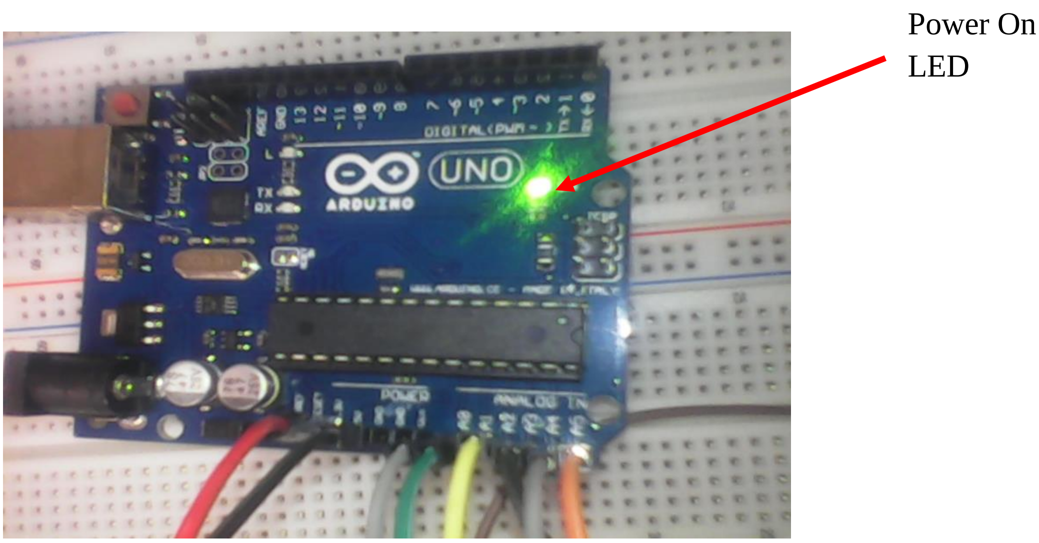

Figure 4.1: Arduino Uno development board at ready state

However, the Arduino Uno development board cannot capture data through the sensors until its driver is installed and it is loaded with the embedded program, which was developed in this study based on Algorithm 1 in subsection 3.3.1.2, Chapter 3. Once these programs are running on the microcontroller, it commences data capturing from the SRB using the electronic sensors. Consequently, the Arduino board transmission (TX) and reception (RX) LED emits a steady amber coloured light as shown in Figure 4.2. Data transmission from the SRB to the MATLAB R2015a workspace during the development phase and to the IoT web application of the operational phase are deemed successful once the amber coloured LED are on. It is noteworthy that the pins on the Arduino Uno board connect directly to the corresponding pin on the ATmega 328 microcontroller in the circuit diagram presented in Fig. 3.4.

Data transmission and reception LEDs

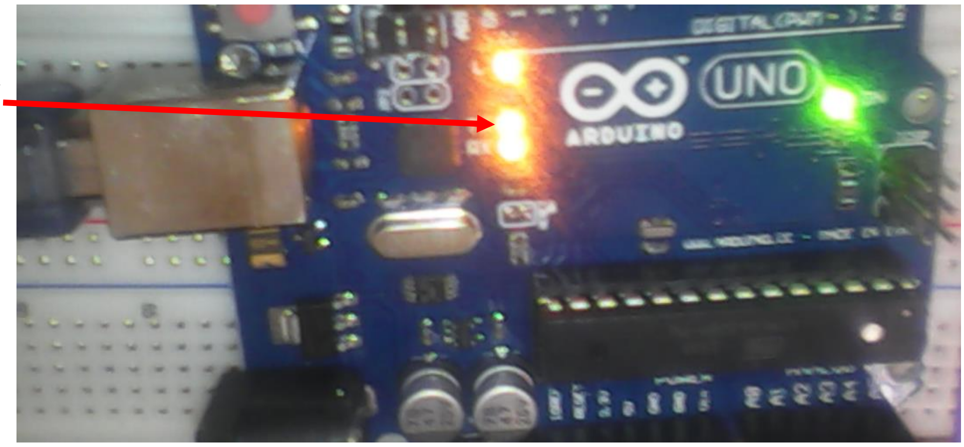

Figure 4.2: Arduino Uno development board at TX and RX states

4.1.2 Electronic Sensors

The functionality of the proximity, gas and temperature sensors were evaluated by connecting them to the appropriate pins on the Arduino Uno board and capturing the sensor readings at different levels of the SRB. The plots of the mean voltages obtained from each of the sensors against the distances marked on the SRB are shown in Fig. 4.3. The graph of the proximity sensor is highly similar to the characteristic curve of the sensor in the data sheet, in which the voltage output was plotted against distance (GP2Y0A02YK0F Datasheet). The graph of the gas sensor indicates an initial spike at level 1 but reduces drastically and almost remains constant thereafter. The spike is obviously due to high gaseous concentration at that level. This behaviour may also be obtained in real life scenario, if the initial refuse that was dumped in the bin contains decomposing waste while those that were dumped afterwards until the bin is full have minimal decomposing refuse. The temperature sensor graph also peaked at level 1 but reduces steadily to lower values at level 2 and beyond. With this graph, it can be deduced that the initial refuse in the bin generated more heat since more gaseous emission was also indicated by the gas sensor. As the concentration of the gas reduced, the heat also reduced up to level 2 and afterwards. The test results that were obtained from the three sensors apparently illustrate that they are all suitable for acquiring the appropriate signals, which represent the status of the refuse in the SRB. The SRB, showing the refuse bin, microcontroller board, sensor array and connection wires as constructed in the laboratory is shown pictorially in Fig. 4.4.

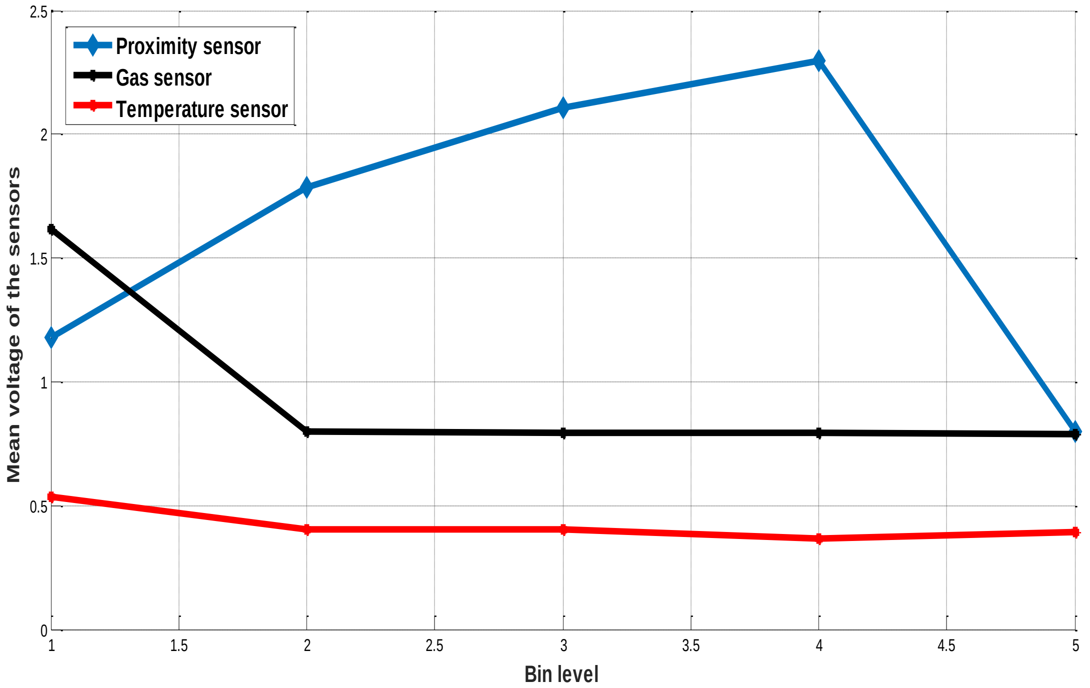

Figure 4.3: Mean voltage against the bin levels

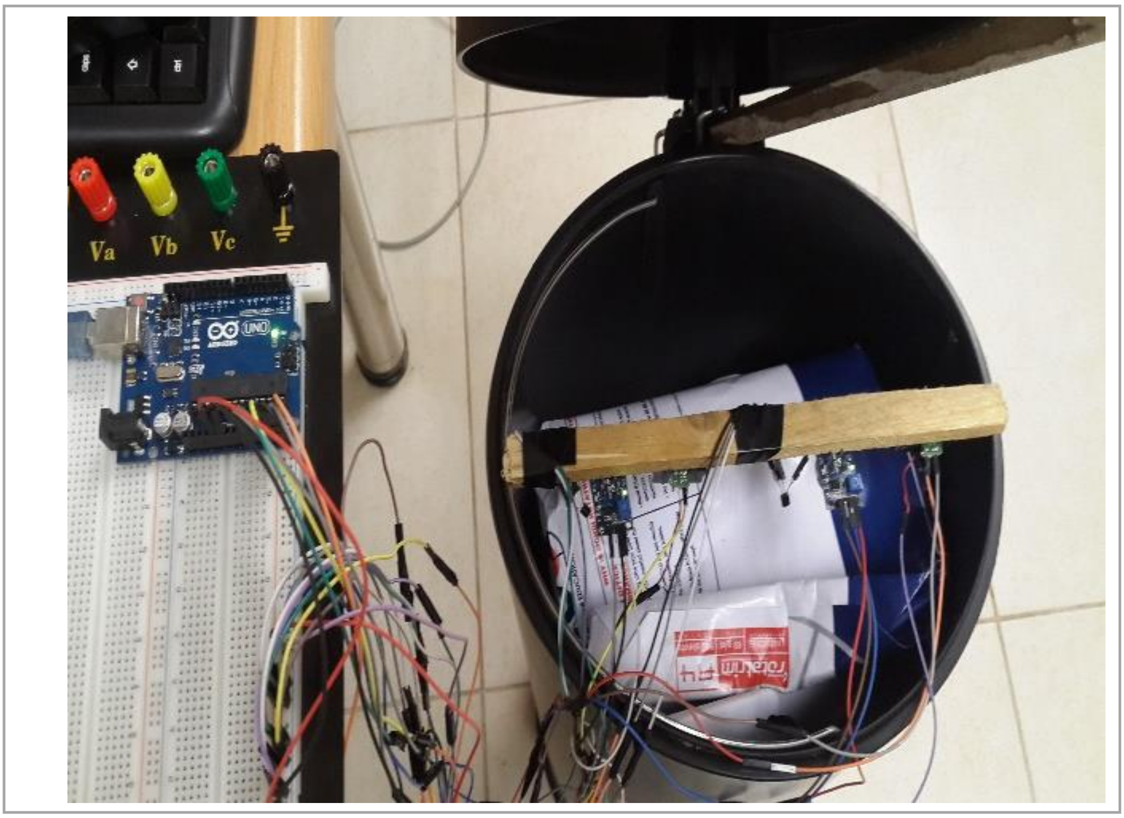

Figure 4.4: SRB constructed in the laboratory

4.2 The Software Units of the Prototype

This section presents the configuration, experimental evaluation, implementation and unit testing of the prototype's software units.

4.2.1 ThingSpeak Web Application Configuration Results

In order for the ThingSpeak web application to be ready for use, a user account was first of all created with username and password. Thereafter, a channel of six fields was created and configured to accept data from each of the six sensors in the SRB. Fig. 4.5 shows the home page of a fully configured and customized ThingSpeak web application for this research study. The page contains a generic menu bar at the top, which contains the commands that were used for the configuration. After the menu bar, there are labels such as *Page title, ChannelID, Author* and *Access.* It also contains link tabs in the middle with labels, *Private View*, *Public View*, *Channel Settings, API Keys, Data Import/Export.* After this, there are clickable buttons such as *Add Visualization*, *Data Export*, *MATLAB Analysis* and *MATLAB Visualization.* The bottom of the page contains the *Channel Stats*. There are 200 entries indicated under the *Channel Stats* for each of the six fields. This clearly illustrates that the data from the SRB were successfully streamed to the ThingSpeak web application. The *Access* option was initially set to public in order to test the functionality of the application. However, it was eventually set to private in order to secure the data and settings for this research on the ThingSpeak application.

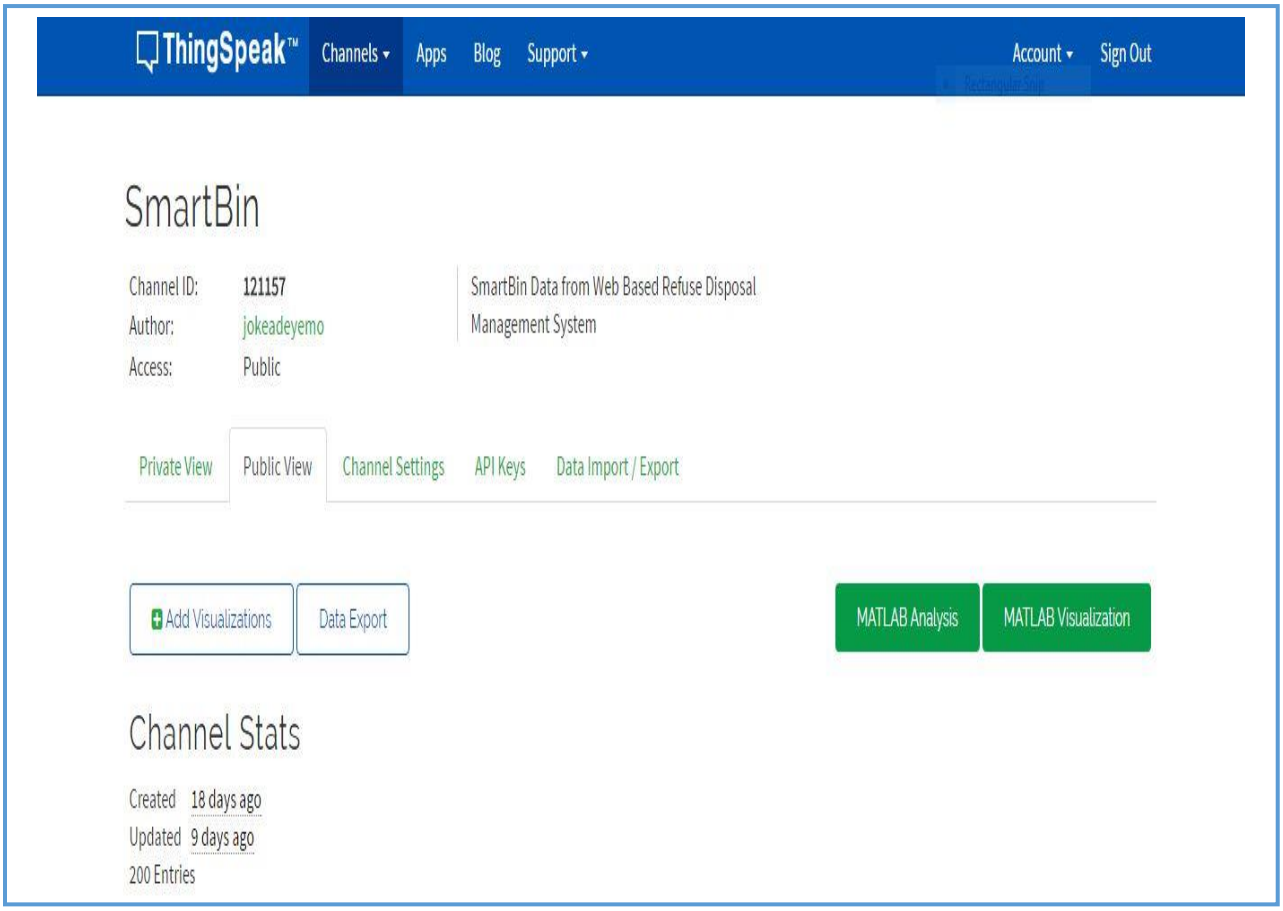

Figure 4.5: The customised home page on ThingSpeak web application

The streamed data from the SRB to each of the data fields are graphically captured as shown in Fig. 4.6. Each graph shows the real-time streaming of data from each of the sensors with values on the Y axis and the date/time stamps on the X axis. The data from each sensor were fully available in the ThingSpeak web application within 90 seconds. This shows that the SRB as well as the configured ThingSpeak web application are functioning optimally. The ThingSpeak web application provides ubiquitous computing for this study. This implies that the data generated from the SRB are available at anytime and anywhere.

Figure 4.6: ThingSpeak field data visualization

4.2.2 Acquired Dataset for Pattern Recognition Model Training and Testing

The SRB generates 200 values for each sensor to produce a 200x6 dataset. However, to acquire sufficient data that caters for possible variations in the electronic sensors while taking the measurement, the researcher deemed it necessary to run several trials for the data acquisition. Overall, there were 15 different data acquisition trials for each of the 5 levels in the SRB that is empty, quarter full, half full, three quarter full and full). This implies that for each bin level, there were 15 different instances of the 200x6 dataset. The entire dataset cannot be presented here because of the huge size. However, to grasp a graphical view of a portion of the data, the histogram plots of the first training instance for each level is presented in Fig 4.7. The histogram plots, which represent the distribution of the dataset, clearly show that the acquired data are different for each of the levels. For instance, the distribution of the data with high frequencies is concentrated in the middle for level 1 and contains unique values from 0.1 up to 2.3 with 0.5 having the highest frequency of about 320. Even though the distributions of the data with the highest frequencies are left skewed for level 2, level 3, level 4 and level 5, the range of the data distributions and the frequencies within the range are uniquely different. However, the raw dataset could not be used to train the pattern classifiers directly so as to avoid structural complexity, high computational time, overfitting as well as the curse of dimensionality.

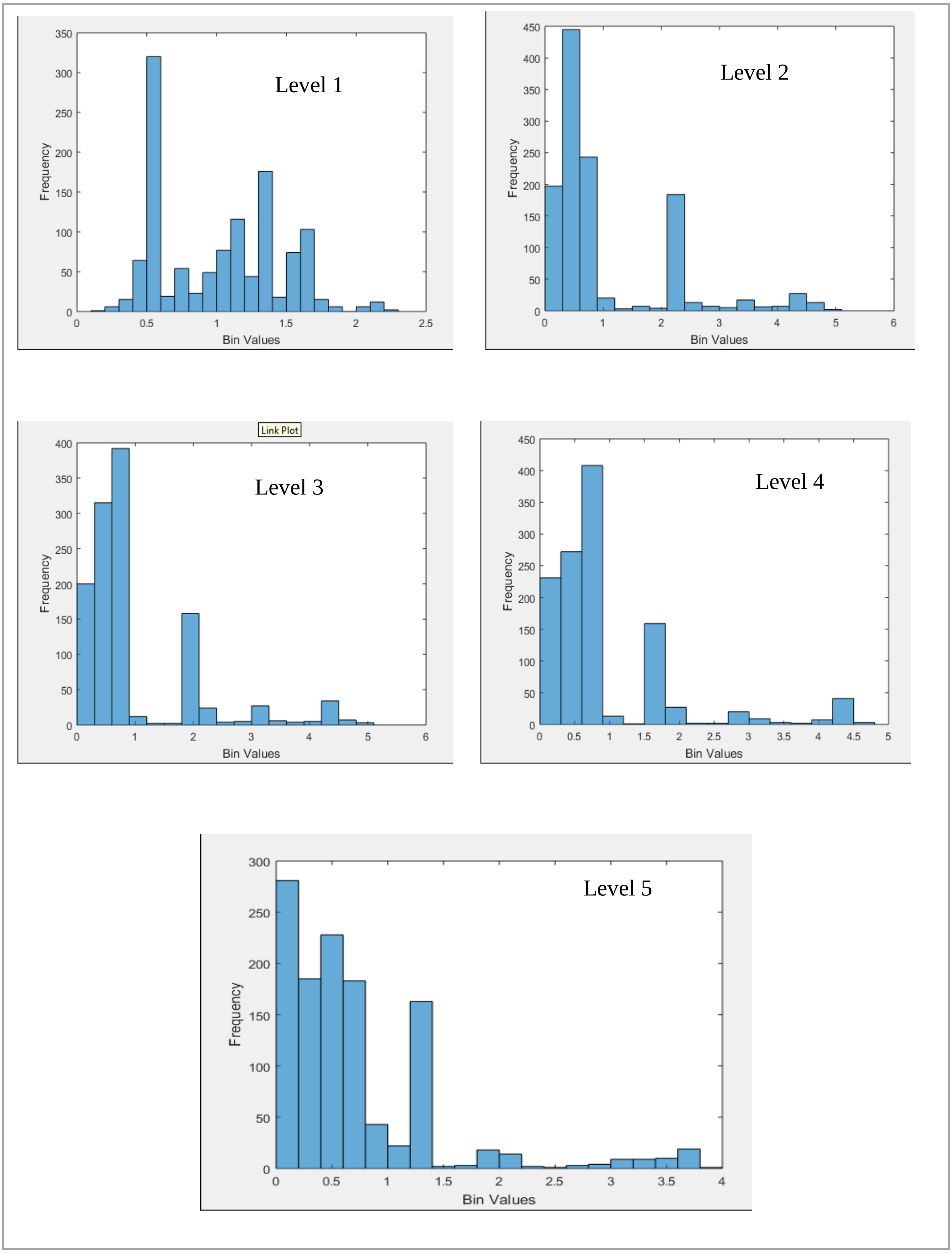

Figure 4.7: Histogram of the first instance of each dataset level.

4.2.3 First Order Statistical Features

The first order statistics, which include mean, standard deviation, skewness and kurtosis were employed to compute discriminatory features from the extracted dataset in this study. These statistics have been well described in Chapter 3. These values were computed for each level of the SRB and for all the 15 instances. Due to space constraint, the computed values of the first instances of all the levels per sensor are shown in Tables 4.1 - 4.6. To obtain the feature vector, the 4 statistical values were concatenated for all the 6 sensors, which culminated in a vector of 24 elements per level. Meanwhile, 10 instances of the feature vectors per level were earmarked to train the pattern classifiers. The remaining 5 instances were reserved to test the pattern classifiers after they were successfully trained. This strategy helped to examine the generalization ability of the selected pattern classifier.

Table 4.1: Training features of the first instance (proximity sensor 1)

First order statistics	Level 1	Level 2	Level 3	Level 4	Level 5
Mean	0.799219	2.29736	2.106429	1.809084	1.180542
Standard Deviation	0.25591	0.306592	0.394689	0.378025	1.476893
Skewness	-0.63462	3.241509	2.289615	2.384963	0.723901
Kurtosis	-0.77378	9.347518	3.601996	4.034126	-1.23699

Table 4.2: Training features of the first instance (proximity sensor 2)

First order statistics	Level 1	Level 2	Level 3	Level 4	Level 5
Mean	1.419203	1.972265	1.800417	1.673436	1.321982
Standard Deviation	0.235412	1.647593	1.733071	1.750432	0.254037
Skewness	2.640203	0.548416	0.641825	0.717871	2.259699
Kurtosis	5.212119	-1.41934	-1.39643	-1.33211	3.343006

Table 4.3: Training features of the first instance (gas sensor 1)

First order statistics	Level 1	Level 2	Level 3	Level 4	Level 5
Mean	1.616528	0.820964	0.79427	0.816668	0.785904
Standard Deviation	0.068306	0.043423	0.040463	0.037331	0.042574
Skewness	1.47168	1.469281	1.558457	1.493716	1.331493
Kurtosis	2.277974	1.67282	2.441205	2.272133	2.24741

Table 4.4: Training features of the first instance (gas sensor 2)

First order statistics	Level 1	Level 2	Level 3	Level 4	Level 5
Mean	1.165215	0.603432	0.631059	0.679001	0.530381
Standard Deviation	0.07955	0.03700	0.040171	0.039554	0.041842
Skewness	1.163583	1.619728	1.636785	1.636944	1.491508
Kurtosis	1.494947	3.393422	3.31708	3.138641	2.597338

Table 4.5: Training features of the first instance (temperature sensor 1)

First order statistics	Level 1	Level 2	Level 3	Level 4	Level 5
Mean	0.533245	0.4023555	0.400932	0.3686225	0.393465
Standard Deviation	0.076625	0.049017042	0.047616	0.046628489	0.050713
Skewness	2.434672	1.364553498	1.890093	2.02748014	1.657682
Kurtosis	4.858106	1.74581813	4.589131	4.74427181	2.66225

Table 4.6: Training features of the first instance (temperature sensor 2)

First order statistics	Level 1	Level 2	Level 3	Level 4	Level 5
Mean	0.537227	0.136798	0.1335565	0.119321	0.127751
Standard Deviation	0.07701	0.052638	0.053772598	0.051175	0.058253964
Skewness	2.301849	1.597178	1.57778951	1.337485	1.381509892
Kurtosis	4.295723	3.282271	4.183634034	2.078237	1.663229517

4.2.4 Pattern Classifiers' Training and Performance Evaluation

The basic configurations of the classifiers as well as the motivation for the choice of the evaluation metrics have been presented in Chapter 3. As shown in Table 4.7, the one-per-class coding method was used to encode the MLP-ANN target output while decimal values were used for the SVM target output (Dietterich and Bakiri, 1995; Aly 2005).

Table 4.7: Target output of the MLP-ANN and SVM classifiers

Level	Bin Status	MLP-ANN Target Output	SVM Target Output
1.	Empty	1 0 0 0 0	1
2.	Quarter Full	0 1 0 0 0	2
3.	Half Full	0 0 1 0 0	3
4.	Three Quarter Full	0 0 0 1 0	4
5.	Full	0 0 0 0 1	5

The first order statistical features earlier computed were used to train the MLP-ANN and SVM classifiers and the outcome of the trainings were evaluated using the accuracy and Mean Square Error (MSE) metrics. The performance results of the trained MLP-ANN for 20, 40, 60, 80 and 100 neurons in the hidden layers are reported in Table 4.8., while the results of SVM for polynomial, linear, RBF and perceptron kernels are shown in Table 4.9. Table 4.8 shows that the MLP-ANN with 60 neurons in the hidden layers produced the best result, amongst other MLP-ANN configurations with an accuracy of 98% and a MSE of 0.0036. Table 4.9 also shows that the SVM classifier with polynomial kernel functions gave the highest accuracy among the other kernel functions, with an accuracy of 88.89% and MSE of 0.1558. The MLP-ANN with 60 neurons in the hidden layers is therefore nominated as the pattern classifier for this study based on its superior performance over the other.

Table 4.8: Performance result of the MLP- ANN pattern classifier

ANN Type	Number of Hidden layer neurons	Accuracy (%)	MSE
ANN1	20	94	0.0322
ANN2	40	96	0.0171
ANN3	**60**	**98**	**0.0036**
ANN4	80	98	0.0168
ANN5	100	98	0.0191

Table 4.9: Performance result of the SVM pattern classifier

Kernel	Accuracy	MSE
Polynomial	**88.89**	**0.1558**
Linear	77.78	0.1519
RBF	22.22	0.1920
Perceptron	44.44	0.1557

The confusion matrix of the nominated MLP-ANN pattern classifier is shown in Fig. 4.8 to illustrate its performance for each class in the training data set. The 10 training instances in each of the 1^{st}, 2^{nd}, 4^{th} and 5^{th} classes were correctly classified. However, 9 of the training instances in the 3^{rd} class were correctly classified while 1 instance, was wrongly classified as belonging to the 2nd class. The sum of the percentages of correctly classified in classes across the diagonal culminated in the 98% accuracy earlier reported in Table 4.8.

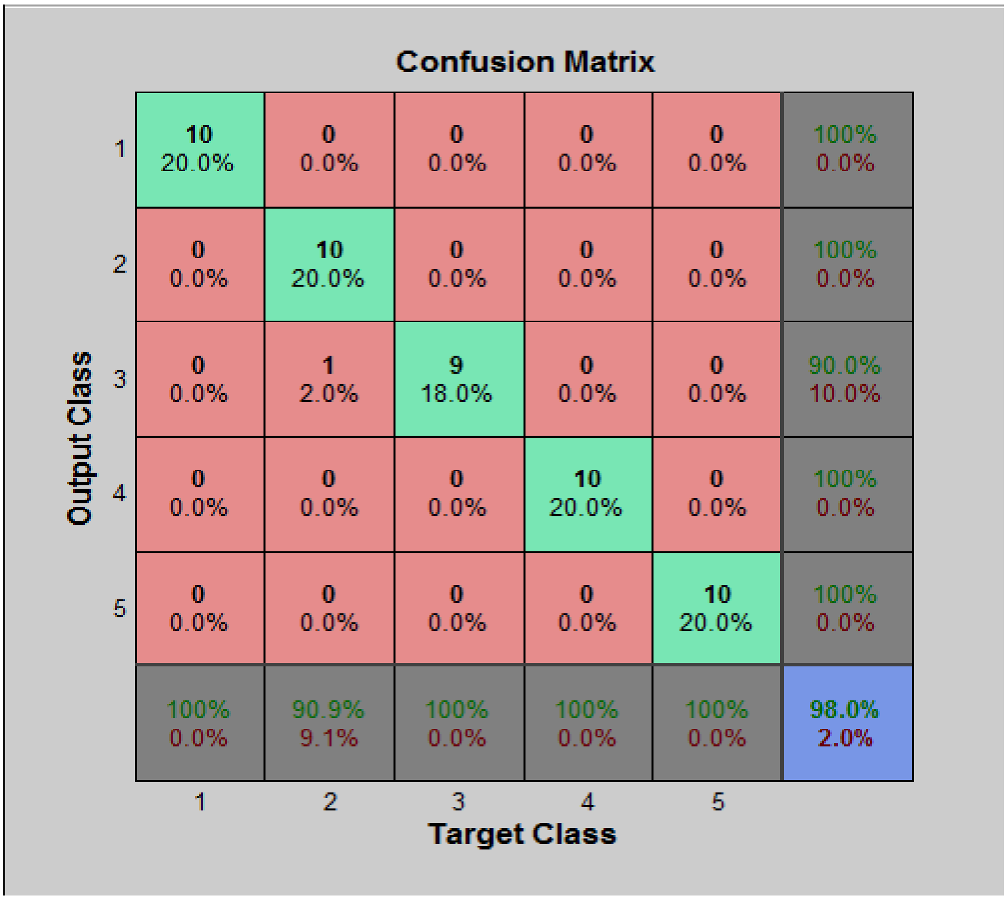

Figure 4.8: Confusion matrix for the best MLP-ANN in Table 4.8

4.2.5 Testing of the Best Pattern Classifier

The 5 testing instances were used to test the nominated MLP-ANN classifier so as to investigate how it generalises. These testing instances were not part of the dataset used for training the classifier. The same results were obtained for all the testing instances as shown in Tables 4.10 to 4.14. Generally, the expected and actual outputs are the same for levels 1, 2, 3 and 5. These imply that these levels were correctly classified. For all the 5 testing instances, the expected and actual outputs for level 4 are not the same. Notably, level 4 was wrongly classified as level 3 in all cases. The decision for refuse collection is taken when the classification output produces level 5 (full status). It can therefore be stated that the wrong classification of level 4 (three quarter full) as level 3 (half full) does not have any major negative implication. For example, the wrongly classifying level 4 (three quarter full) as level 5 (full status) would have resulted in more adverse effects like wasted effort, time and resources by the refuse collection agents. Essentially, since only one level was wrongly classified for all the testing instances, it can be inferred that the nominated MLP-ANN generalizes well on unseen dataset. The performance of the nominated pattern classifier for this study is therefore adequate and acceptable.

Table 4.10: Testing result of the best MLP-ANN using the first testing instance

Level	Bin status	Expected output	Actual output	Remark
Level 1	Empty	1 0 0 0 0	1 0 0 0 0	Correct
Level 2	Quarter Full	0 1 0 0 0	0 1 0 0 0	Correct
Level 3	Half Full	0 0 1 0 0	0 0 1 0 0	Correct
Level 4	Three Quarter Full	0 0 0 1 0	0 0 1 0 0	Incorrect
Level 5	Full	0 0 0 0 1	0 0 0 0 1	Correct

Table 4.11: Testing result of the best MLP-ANN using the second testing instance

Level	Bin status	Expected output	Actual output	Remark
Level 1	Empty	1 0 0 0 0	1 0 0 0 0	Correct
Level 2	Quarter Full	0 1 0 0 0	0 1 0 0 0	Correct
Level 3	Half Full	0 0 1 0 0	0 0 1 0 0	Correct
Level 4	Three Quarter Full	0 0 0 1 0	0 0 1 0 0	Incorrect
Level 5	Full	0 0 0 0 1	0 0 0 0 1	Correct

Table 4.12: Testing result of the best MLP-ANN using the third testing instance

Level	Bin status	Expected output	Actual output	Remark
Level 1	Empty	1 0 0 0 0	1 0 0 0 0	Correct
Level 2	Quarter Full	0 1 0 0 0	0 1 0 0 0	Correct
Level 3	Half Full	0 0 1 0 0	0 0 1 0 0	Correct
Level 4	Three Quarter Full	0 0 0 1 0	0 0 1 0 0	Incorrect
Level 5	Full	0 0 0 0 1	0 0 0 0 1	Correct

Table 4.13: Testing result of the best MLP-ANN using the fourth testing instance

Level	Bin status	Expected output	Actual output	Remark
Level 1	Empty	1 0 0 0 0	1 0 0 0 0	Correct
Level 2	Quarter Full	0 1 0 0 0	0 1 0 0 0	Correct
Level 3	Half Full	0 0 1 0 0	0 0 1 0 0	Correct
Level 4	Three Quarter Full	0 0 0 1 0	0 0 1 0 0	Incorrect
Level 5	Full	0 0 0 0 1	0 0 0 0 1	Correct

Table 4.14: Testing result of the best MLP-ANN using the fifth testing instance

Level	Bin status	Expected output	Actual output	Remark
Level 1	Empty	1 0 0 0 0	1 0 0 0 0	Correct
Level 2	Quarter Full	0 1 0 0 0	0 1 0 0 0	Correct
Level 3	Half Full	0 0 1 0 0	0 0 1 0 0	Correct
Level 4	Three Quarter Full	0 0 0 1 0	0 0 1 0 0	Incorrect
Level 5	Full	0 0 0 0 1	0 0 0 0 1	Correct

4.2.6 Client Application Implementation and Unit Testing

The non-browser client application was implemented in a prototype form using the GUIDE in MATLAB R2015a. The implementation is based on the *use case* and *class* diagrams designed in Chapter 3. Some of the key pages in the implemented application are *Welcome page*, *Main window*, *Bin status page*, *Bin location page*, *Create user page* and *Delete user page*. Appropriate codes were written based on the class diagram earlier designed to ensure that all the interfaces perform the functions in the requirement specification as depicted in the use case diagram.

Fig. 4.9 shows the *Welcome page* in the running mode. It contains introductory information on the project. The two buttons on the page are *Ok* and *Cancel*. Clicking the *Ok* button allows users to navigate to the Main page while clicking *Cancel* will terminate the application. These buttons were tested and they worked perfectly as expected.

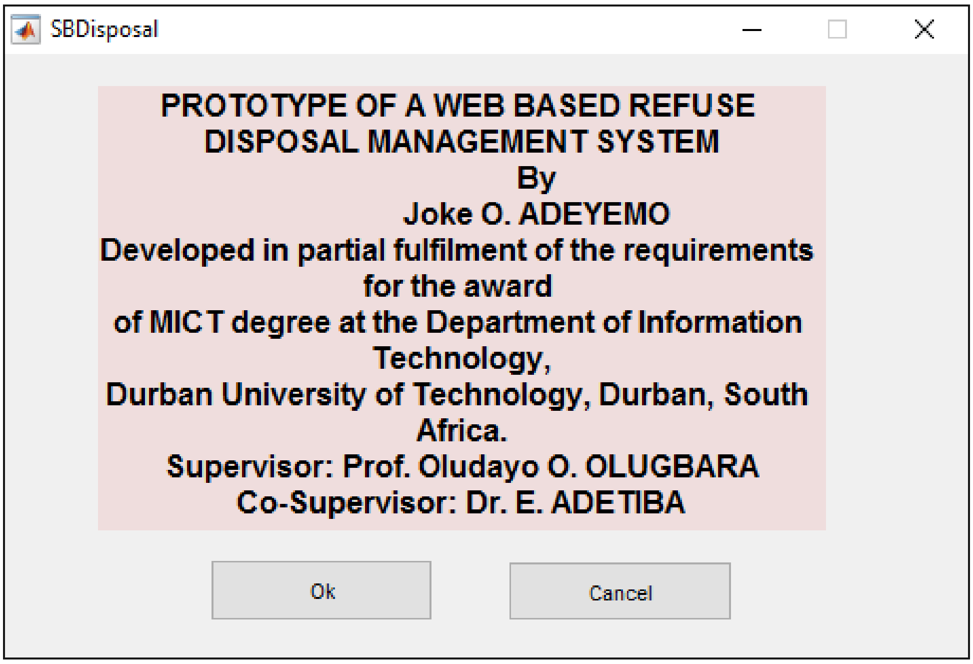

Figure 4.9: Welcome page

The *Main window* in its running mode is shown in Fig. 4.10. It contains the menu bar at the top of the window with menu items such as *File*, *Tasks*, *Admin* and *Help*. The *File* menu contains commands such as *Page setup*, *Print option* and *Exit*. The *Task* menu contains *Bin status* and *Bin location* commands. The *Admin* menu contains *Create users* and *Delete user* commands. The *Help* menu contains only *About page* command, which loads the page that contains a brief information on the application. The manual testing of the functionality of the different commands in the Main window to ensure the integrity of the codes was successful.

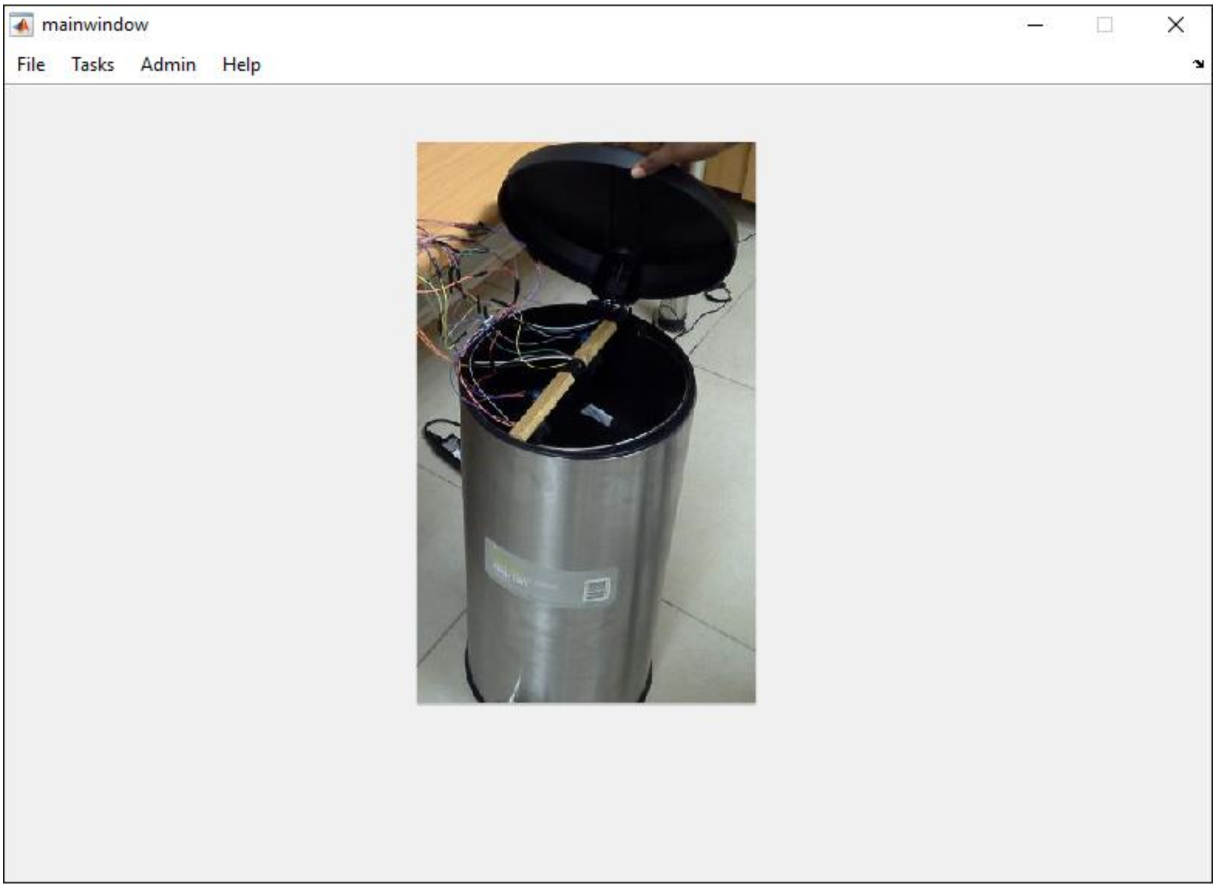

Figure 4.10: Main window

Fig 4.11 shows the *Bin status page,* which loads when the *Bin status* command on the menu bar of the *Main window* is clicked. The page contains *Enter Bin ID* box, *Check Status* button, 2 textboxes to display the retrieved status and the date/time information respectively. The page also contains a graph plotting frame for visual appeal and a *Cancel* button for closing of the page. In order to test the functionality of the page, the researcher clicked on the *Check Status* button. This produces the bin status information and the date/time as shown in the figure. Notably, the returned status actually corresponded with the actual status of the SRB. This shows that the page as well as the pattern classifier are functioning properly.

Fig. 4.12 shows the *Bin location page*. Specifying the Bin ID using the combo box and clicking on the *Check Location* button on the page produces the coordinates of the bin location as well as its Google earth^{TM} image. Theis information can be seen clearly in the figure. Similar to the bin status information, the location information is also very essential. This is because it provides accurate direction for the Janitor to locate bins that are ready for collection.

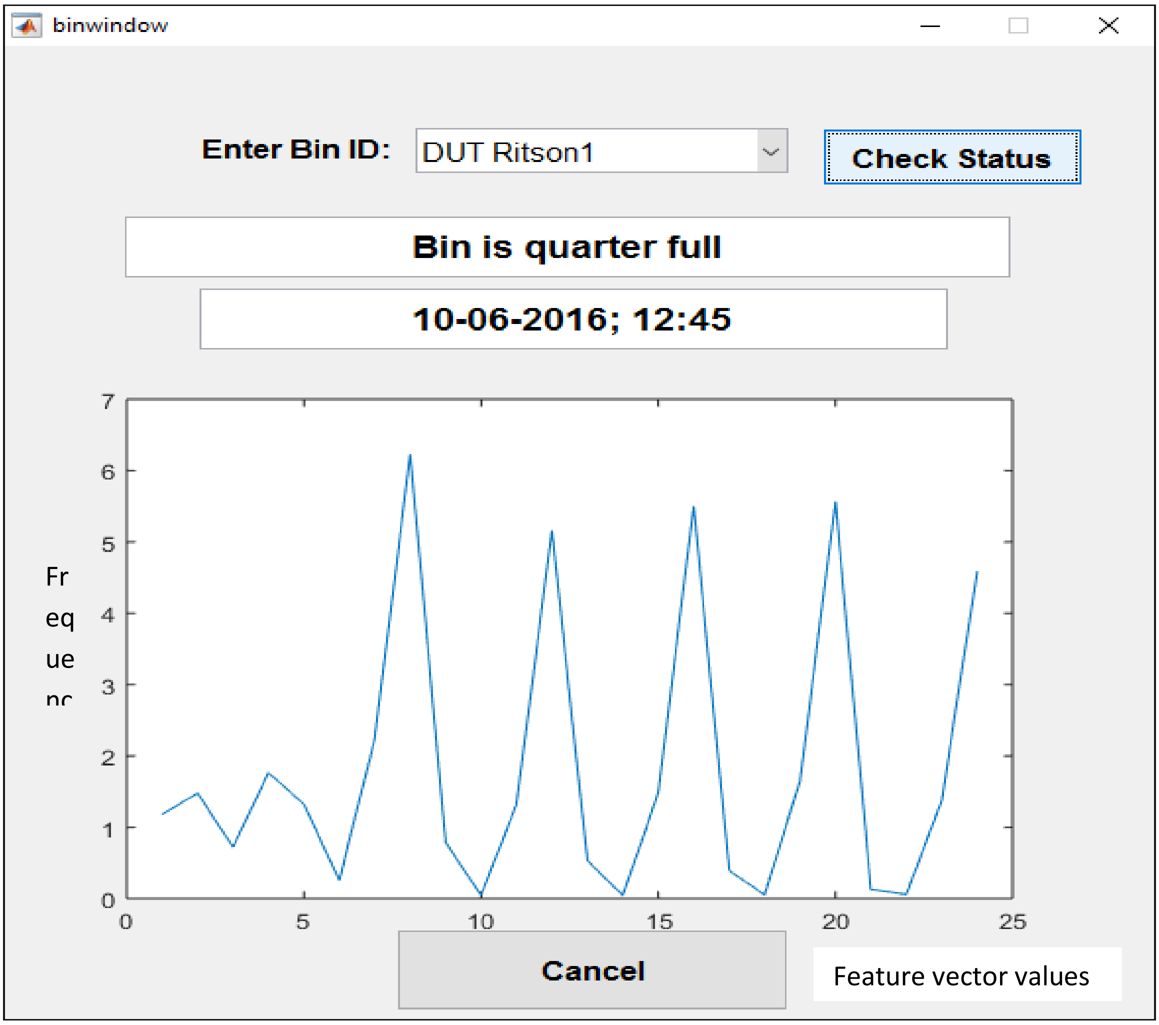

Figure 4.11: Bin status page

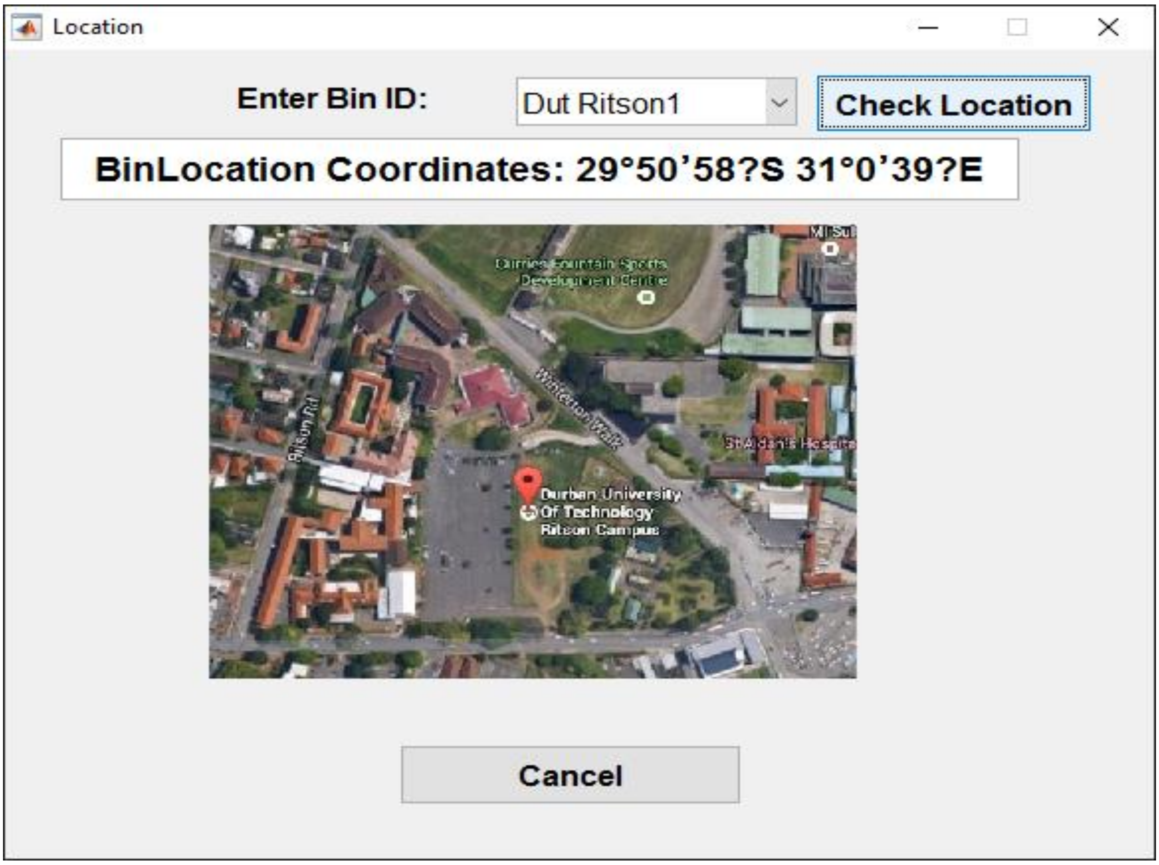

Figure 4.12: Bin location page

The *Create user page* is shown in Fig. 4.13. The page is used by the *Administrator* to create a new account for him/her self and for other user groups such as the *Supervisor* and *Janitor*. The page contains *Staff ID, First Name, Last Name, Usernname, Password* text boxes and *User Group* combo box. It also contains *Create Account* and *Cancel* buttons. The *Update/Delete user* page in Fig. 4.14 is similar to the *Create user page* in all respects except that it contains *Update User* and *Delete User* buttons in place of the *Cancel button.*

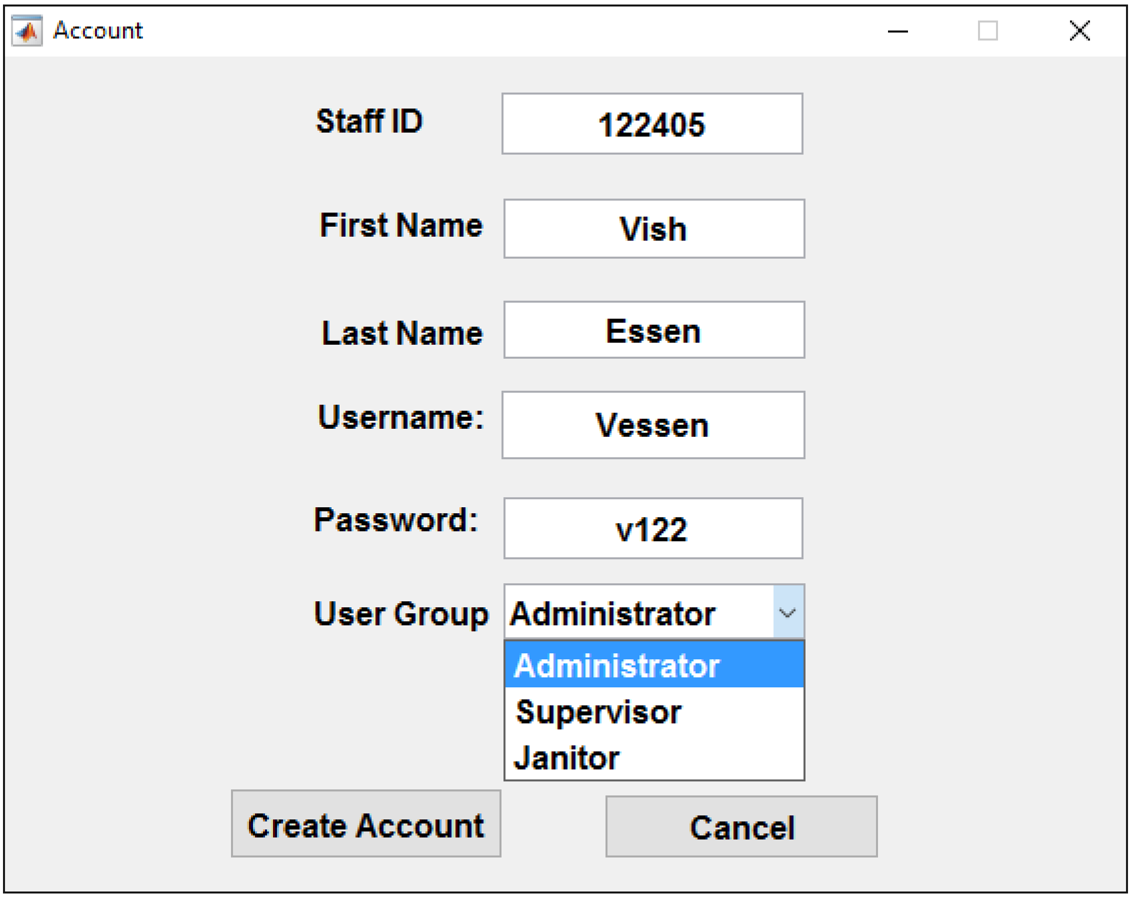

Figure 4.13: Create user page

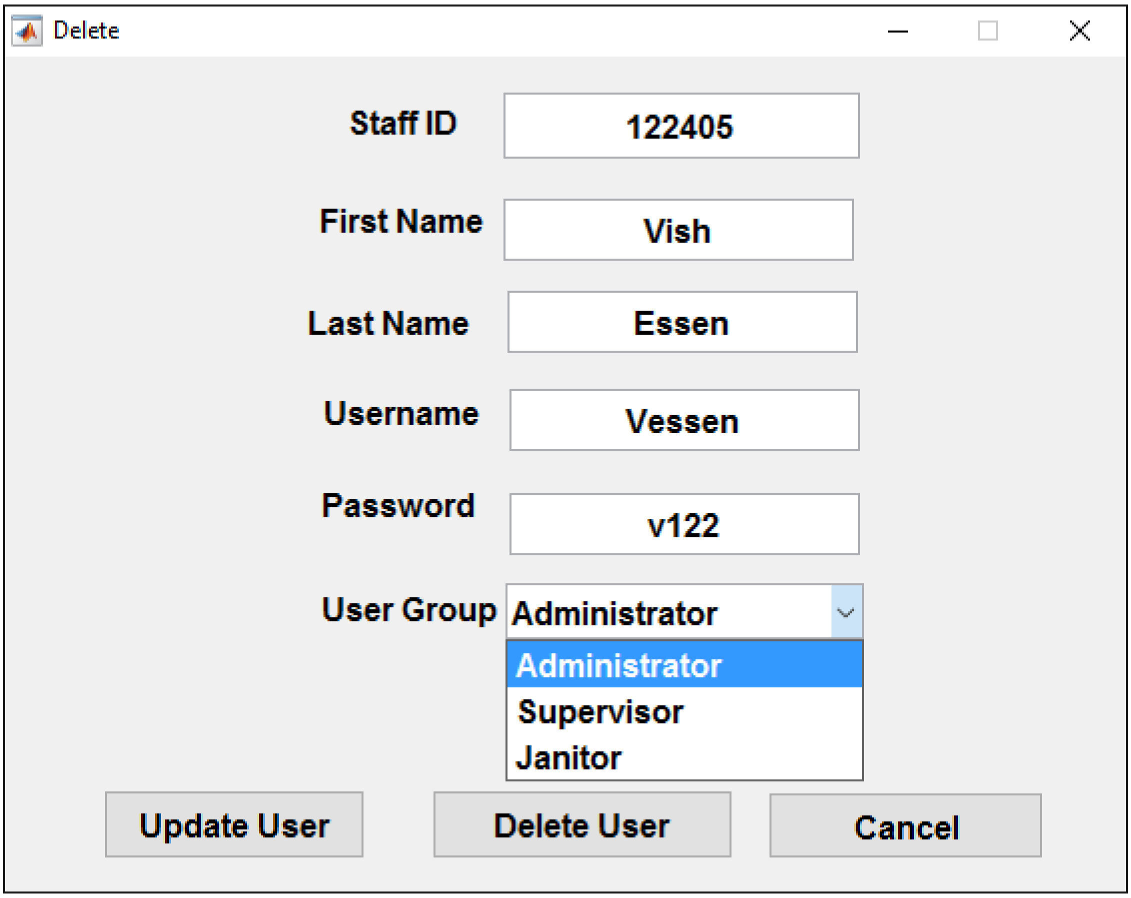

Figure 4.14: Update/Delete user page

Evaluation of a software application involves the investigation of whether the developed application satisfies specified design requirements. However, based on the DSR guideline 5 (that is research rigour), it becomes important to establish a demonstrable methodological foundation in the relevant knowledge base to carry out such evaluation. The implemented client application in this study was evaluated through laboratory experiments using the method of unit testing. Koomen and Pol (1999) define unit testing as "a test executed by the developer in a laboratory environment that should demonstrate that the program meets the requirement set in the design specification". The researcher is the developer in the context of this study. Unit testing is mostly engaged to test the functionality and quality of software components or a collection of components because it allows easy identification of bugs within the code (Whittaker 2000). Unit testing was realised in this study using the *xUnit-style* MATLAB unit testing framework in MATLAB R2015a. Although the researcher is aware of other unit testing frameworks such as *MS Test*, *JUnit* and *NUnit*, the *xUnit-style* framework becomes handy because all the codes in this study were implemented using MATLAB. The output of the unit test is shown in Fig. 4.15. All the modules in the client application passed the test successfully as shown and the average execution time for any of the tested module is 225.52ms. This clearly illustrates that the implemented client application is devoid of coding errors and the running time is optimal. The evaluation of the implemented client application in this study was limited to unit testing because the deployment is beyond the scope of the present study.

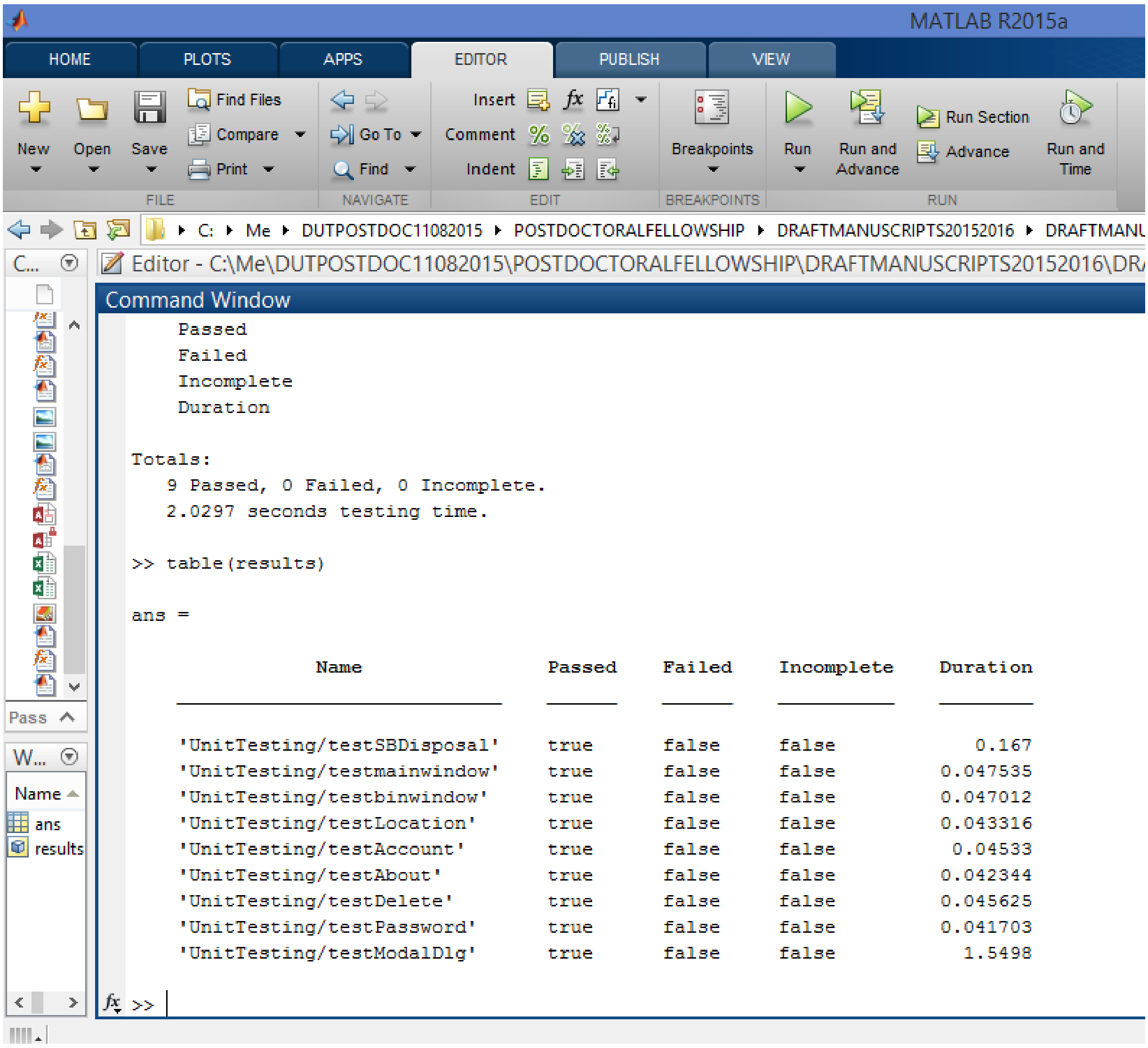

Figure 4.15: The client application's unit testing result

In summary, Fig. 4.16 provides an overview of the different parts of the prototype and the communication of signals between them to produce a functional system. The figure is based on the deployment diagram presented in Chapter 3. The SRB sends data on its current status to the ThingSpeak web application periodically via the internet. This provides ubiquitous data availability. A user sends relevant queries in the ThingSpeak web application to retrieve the SRB data. Applicable functions (methods) on the client application process the retrieved data and display the bin status as well as the location information for the user to view and take the necessary actions.

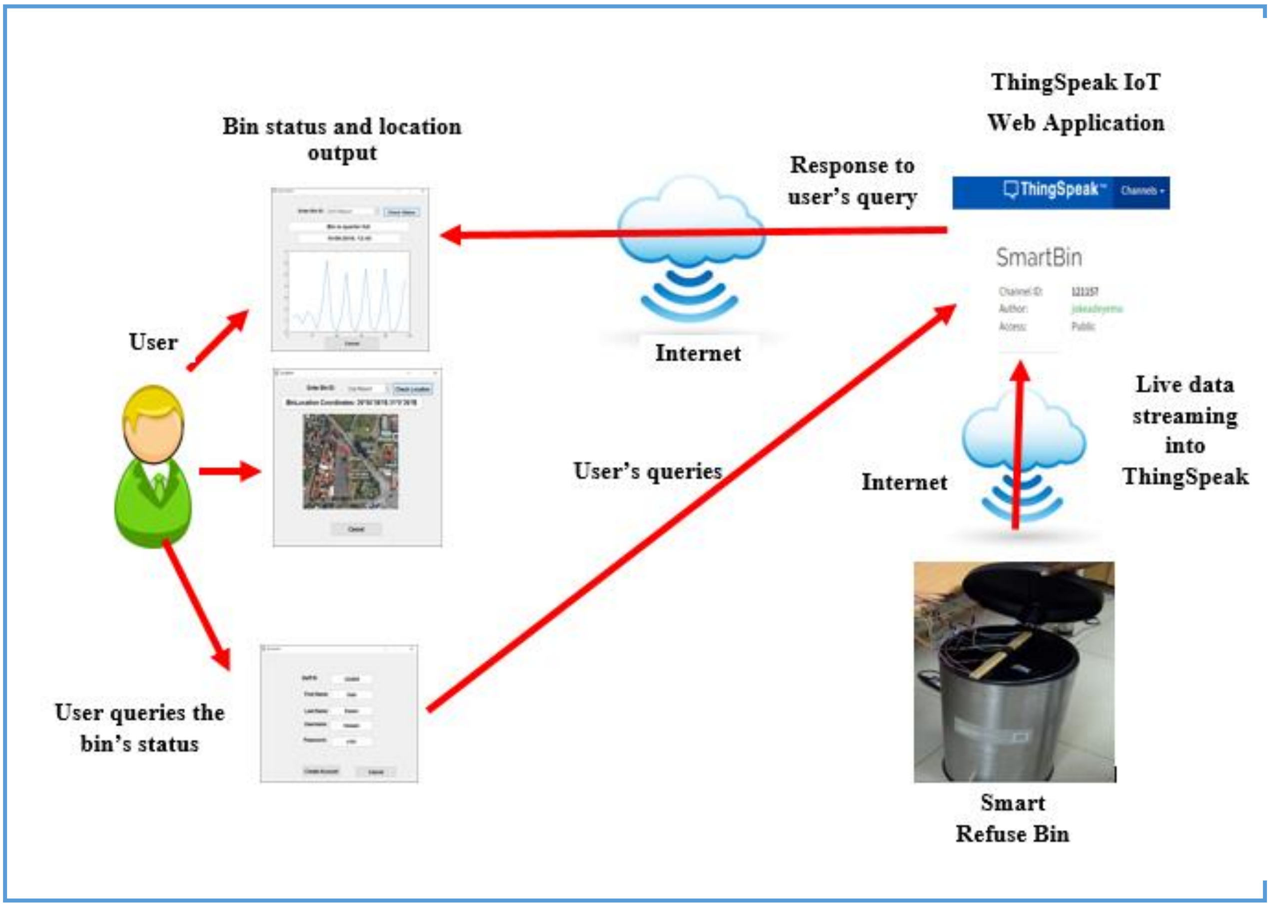

Figure 4.16: Integrated functional prototype

4.4 Conclusion

A prototype of the web based smart city infrastructure for refuse disposal management has been fully implemented and evaluated by the researcher as reported in this chapter. The hardware circuit was constructed in the laboratory and loaded with the embedded program to produce the SRB. Evaluation results showed that all the electronic sensors, the microcontroller board, other electronic components as well as the embedded program were working optimally. The ThingSpeak web application was properly configured and the evaluation result showed that it was able to seamlessly and consistently establish connection with SRB. The researcher also implemented and evaluated the client application in the laboratory. The unit testing of the client application was highly successful. MLP-ANN was experimentally established as the appropriate pattern classifier for the refuse bin status detection. The choice of diverse evaluation tools for the different aspects of the prototype follows the DSR design evaluation guideline. All the software components of the prototype were appositely implemented and evaluated using applicable toolboxes in MATLAB R2015a.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

One of the ways to maintain a smart city is for the society to adopt smart environmental initiatives that can promote cleanliness as a culture of its citizens. The development of a web based smart city infrastructure presented in this dissertation provides a foundation in this direction. The summary of the findings in this study is presented in the current chapter. The chapter discusses how the research aim and objectives were achieved. Furthermore, recommendations into possible future works and concluding remarks are presented.

5.1 Summary of the Study

A web based smart city architecture for refuse disposal management has been successfully developed and a prototype of the smart city infrastructure has been implemented and evaluated. Previous authors have developed multi-tier architectures of five layers in response to the general demand for refuse disposal management in a smarter way (Chowdhury and Chowdhury (2007). The primary aim of the current research study was to develop a web based smart city infrastructure for refuse disposal management. The research objectives have been achieved in order to realise this aim. The objectives are hereby restated along with how they have been achieved:

a) To provide a framework for enhanced refuse disposal management.

This objective was realised through the development of a smart city architecture as an amendment of a previous smart city architecture by Jalali *et al.* (2015). The proposed architecture in this study is compact and incorporates pattern recognition (feature extraction and pattern classification) for intelligent decision making on the status of refuse bin. Pattern classification provides the advantage of making better decision based on the multivariate dataset that is extracted from the bin internal environment. The IoT web application in the proposed architecture also provides some remarkable benefits for refuse disposal management.

b) To provide timely and accurate information on the status of refuse bins to the relevant refuse disposal management agents.

This objective was realised through the hardware and software components of the prototype. SRB sends regular updates on the bin status to the ThingSpeak web application and through the client application, any of the user groups can send a query to ThingSpeak for the latest data. The data are processed in the pattern recognition module (FOSF and MLP-ANN) to return the status of the bin via a user interface on the client application. The time to achieve this procedure based on the evaluation is about 90.05s and the accuracy of the status detection is 98%. Hence, the objective to provide timely and accurate information on the status of refuse bins has been achieved.

c) To enhance the ease with which full refuse bins are located by refuse collection agents.

This objective was realised through the prototype similar to the realisation of the second objective. The user can query the location of any refuse bin via the client application once the status has been obtained. The ThingSpeak web application returns the coordinates of the SRB location as well as the corresponding google earth image. This helps refuse collection officials to easily find the route for disposing the refuses in the bin.

d) To inject cost effectiveness into refuse disposal management.

This objective was achieved through the prototype which provide prompt and up-to-date information on the location and status of the SRB. Based on this, there won't be any need for refuse bin collectors to roam around the city to locations whose SRB are not ready for disposal. Resources such as time, fuel and energy will then be efficiently and optimally utilised.

e) To provide flexibility and ubiquity in the monitoring of refuse disposal activities by supervisors and administrators.

This objective has been achieved through the web capability of the client application, SRB and ThingSpeak. Administrators and supervisors can monitor the activities of the refuse collection officials at any time and in anywhere on the earth where there is internet facility. This injects a psychological check on the refuse collection officials, who may ordinarily want to be lackadaisical.

Refuse management process, which implements an on-site handling and transfer optimization has been previously studied using sensor nodes and browser based remote monitoring solutions. Even though the authors did not implement decision support systems, they projected it as a future feature that could boost the performance of the developed solution

(Longhi *et al.* 2012). Furthermore, pattern recognition techniques such as Partial Least Square with SVM (Abbasi *et al.* 2013) and linear regression with weighted k-means clustering (Livani *et al.* 2013) have been recently employed for forecasting the quantity of municipal refuse generation. Based on the results obtained in the current study, it has become more apparent that pattern classifiers like multi-layer perceptron neural networks are viable for accurate detection of refuse bin status. This fulfils the expectation of a boost in the performance of refuse disposal management systems through decision support.

Energy efficiency cannot be over emphasised when it comes to the development of initiatives for smart environment. In this light, a previous work was presented on the development of an energy efficient sensing algorithm for measuring the parameters of bin status (Al Mamun *et al.* 2013). The current study inherently caters for energy efficiency through the choice of the hardware components that was used for implementing the prototype. The microcontroller board and all the electronic components require only 5V DC to function accurately and optimally. In addition, the location vis-à-vis the bin status detection in the current study provides an energy saving medium for operators of refuse disposal management.

The accuracy achieved through the use of first order statistical features and MLP-ANN in this study strongly corroborates the position of other authors, who reported improved performance when the feature selection algorithm is implemented alongside pattern classifiers (Abbasi *et al.* 2013; Livani *et al.* 2013). Adetiba and Olugbara (2015) have also previously reported that MLP- ANN is often used as a pattern classifier because of its accuracy and effectiveness.

5.2 Recommendation for Future Work

This research study considers how a web based smart city infrastructure can be used to handle refuse disposal management within a city. The work, like any other worthwhile project provides direction for future improvement. Future work may consider how the implemented prototype can be deployed en masse into communities for real time use. This will bring about the availability of real-time data, which may eventually be useful for prediction of refuse generation pattern in a given community. Availability of refuse generation pattern may be used by municipal authorities for town planning and judicious allocation of refuse disposal budget. Moreover, other IoT web applications, feature extraction methods and browser based web client application may be explored. In codicil, pattern classifiers such as Bayesian networks and deep neural networks may be explored for predicting the status of refuse bins. Non-supervised pattern classifiers may also be considered as an autonomous strategy for bin status and location prediction.

5.3 Concluding Remarks

Thus far, this study has been able to realise the five research objectives, namely: a) To provide a framework for enhanced refuse disposal management b) To provide timely and accurate information on the status of refuse bins to the relevant refuse disposal management agents c) To enhance the ease with which full refuse bins are located by refuse collection agents d) To inject cost effectiveness into the refuse disposal management e) To provide flexibility and ubiquity in monitoring of refuse disposal activities by supervisors and administrators. The DSR guidelines, electronic circuit design, UML, IoT technological paradigm and pattern recognition techniques provided a rich set of theoretical toolkits for the realisation of the study objectives.

The results obtained in this dissertation has proven the efficacy of the prototype and its readiness to upgrade into a full system. Such a system can be deployed within South Africa and other foreign countries. The system also has huge commercial prospects for government authorities and business organisations. Normally, citizens pay for waste disposal services to the municipal authorities through taxes or levies. The value addition that will derive from such a system will encourage citizens to make payment on a prompt basis. Electronics and plastic companies may also leverage on the prototype to manufacture smart refuse bins. The client application with the associated IoT web application may be deployed using the Software-as-a-Service (SaaS) cloud computing model. Apart from the healthier environment that will be derived through the deployment of the system, more jobs can be created for the citizens at large.

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