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THE INTELLIGENT WASTE CONTAINER

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ABSTRACT
This work involved the design of an intelligent waste container that is capable of notifying the waste disposal company immediately they are filled to capacity so that they may be emptied. The central container collection system of waste disposal which is the main form of waste collection and disposal in most developing countries has rather led to filthy surroundings. This is because the waste containers provided in the communities are never emptied immediately, they get filled to capacity. To counter this problem, this system was designed to use short messaging service (SMS) technique to alert the waste disposal company of a container that is full. The system makes use of a sensor, microcontroller and a global system for mobile (GSM) module in order to function. An application that uses a SMS server is deployed at the offices of the waste management company to complete the system. The sensor detects whether the skip is full or not. The microcontroller controls when the text message is sent the moment the skip is full. The message that is sent is received on a console at the offices of the waste management company through the SMS server. The driver assigned to that skip is then dispatched to empty the skip.

Keywords: Intelligent waste container, skip container, microcontroller, GSM server, text message, central container collection

INTRODUCTION

Solid waste is defined as household refuse and non-hazardous waste. The non-hazardous waste comprises waste generated by industries, commercial and institutional establishments such as markets and hospitals. It also includes street rubbish and scrap yard waste (Benneh et. al, 1993).
Solid waste disposal in a typical developing country such as Ghana is the main responsibility of the metropolitan and the municipal assemblies. In Accra, the capital of Ghana, the Accra Metropolitan Assembly (AMA) is responsible for waste management. However in light of the overwhelming nature of the task, the Assembly has contracted the services of private waste management firms to help in solid waste management (Zoomlion Ghana Ltd., 2022). Privatization of waste management began with the arrival of City and Country Waste, a Canadian firm in 1999. Currently there are about 16 waste management firms in Accra alone who are responsible for waste collection and disposal in the city. Each firm is responsible for a specific zone in the capital. The AMA pays these companies with national budgetary allocations from the state government and internally generated funds. Refuse collection is by either house-to-house or central container collection. House-to-house collection is enjoyed by approximately 20 % of residents who live in high income and low-density neighborhoods. The remaining 80 % of the population receive the central container collection (CCC) service. Central containers are placed at designated points for households to deposit their domestic waste (Rouse et. al, 2008). Trucks come in to collect the containers when they are full. These two disparate collection schemes allow the AMA to collect approximately 55 % of solid waste generated within the city. However, because the current systems in place are not efficient enough, technology has to be integrated to ensure better solid waste management. It is for this reason that the Intelligent Waste Container will serve to enhance waste collection and disposal timeously.
The failure of waste disposal trucks to empty the containers on time is mainly due to the following:

i. Ignorance of the status of the container
ii. Incorrect area prioritization
iii. Lackadaisical attitude to work.

In this study, an 'early warning system' that will ensure that garbage containers when full, are emptied within the shortest possible time is designed and implemented (Cointreau, 1983). This system would be useful to the waste management companies and will go a long way to ensure a clean environment.
For a fact, visitors to Accra are usually confronted with two narratives. In one, Accra is the posh clean "gateway to Africa". Streets are manicured, palm trees are coiffed, and all the amenities of the western world including regular waste removal can be accessed. In the other narrative, city residents are contending with congestion, illegal settlements, substandard housing, and poor sanitation (Hardoy et. al, 1993). This environment is the predominant experience of most city dwellers and is reflective of growing inequality that has come to represent Accra. The confluence of poor governance and human factors (such as indiscriminate dumping) has resulted in a city environment characterized by choked drains, clogged gutters, and garbage piles heaped in the open.
The objective of this work was to change the latter narrative in the city which is predominantly the façade of Accra to a first-time visitor. Accra city which has to live up to its name as the gateway to Africa deserves a well-managed and efficient waste disposal system in every suburb. With an efficient system of waste disposal in place, the wellbeing of the populace will be secured. The environment will then be rife with healthy able-bodied men, women and children bursting with energy and ready to engage in responsible work to aid in the country's quest for accelerated development.
The Intelligent Waste Container seeks to use sensors mounted on the containers to detect when a container is full (Pora et. al, 2009). The sensors when triggered send an SMS message to the cell phone of the driver responsible for that container (Ozeki Informatics Ltd., 2010). A notice is also sent to the central office and an entry is made into a database of containers and their states i.e. whether full or empty. A report of containers which are full may then be forwarded to the drivers who will then proceed to empty them at night-time which is the best time for transporting the refuse to the landfill sites. However, containers located in densely populated areas will be emptied immediately they are full. This system ensures that drivers move to only areas with full containers and

nowhere else. Thus resources such as manpower, fuel and time are never wasted on sites with partially filled or empty containers. The architecture of the proposed system is shown in Figure 1:

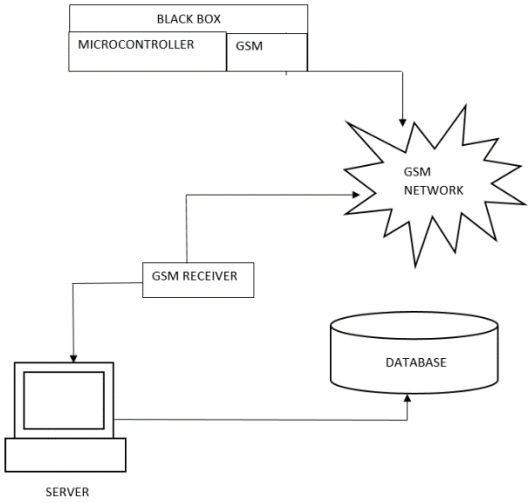

Figure 1: Architecture of proposed system

The proposed system consists of two parts:

1. The information management system which comprises a database with skips and their states i.e. full or not full.
2. The microcontroller-based circuit which has the capability of sending a predefined SMS to a specified number when a sensor input is triggered.

The first part involves the development of a management information system which will record the various skip locations, their current states and the truck drivers who are assigned to them (Chen, 1976, Codd, 1970, Feldman & von Halle, 1989). A means of automatically displaying the skips and their current status, as well as the drivers responsible for them will also be incorporated.
The second part of the system involves the design and implementation of a microcontroller-based circuit capable of transmitting SMS messages based on a sensor input.
Sensors-embedded waste bins provide a means to measure the content of the bins and to relay that information to persons far away from the bin. The means to measure could be by volume, weight or vertical level. Garbage collectors may therefore see remotely which garbage cans need to be emptied and which ones may be left until the next collection.
The ever-growing powers of innovations have ensured that the way of doing things such as municipal solid waste (MSW) management have also vastly improved. Today, smart solid waste bins have emerged to enhance the rate of solid waste collection and disposal. Weekly waste collection services have been around for decades but they are not the most efficient option. Traditionally the waste management industry has been slow to adopt new technologies in their businesses. Advancement in technology and the decrease in cost have made it possible for technologies such as RFID, GPS, SMS and GPRS to be incorporated into the waste management sector. The arrival of the aforementioned technologies has resulted in better monitoring of waste bins and tracking of frequency of waste collection.

In Ghana none of the afore-mentioned technologies have been employed by the waste management sector. The leading waste management companies all employ the same archaic method of waste collection and disposal.

Incorporation of technology in waste management may occur in two ways. These include:

1. RFID tagged waste bins and collection trucks fitted with GPS and
2. Sensorized waste bins.

In some countries RFID technology has been employed to maximize the efficiency of recycling and waste. In this system low frequency RFID tags which identify customers are embedded in the refuse bins of households. The garbage trucks too are fitted with RFID readers and scales which measure the mass of garbage collected from households. Customers are thus billed according to the mass of waste they produce. A similar concept is used to reward customers based on the amount of recycling their households produce. A more complex but effective form of this system has been developed and trialed in Malaysia. The system was developed using RFID, GIS (Geographical Information System) and GPRS interfaced with a low cost camera. An RFID tag is attached to each bin in order to monitor and track the bin during the collection of bins. The low cost camera is attached to the truck in order to get images. Once the truck enters within the bin area, the camera takes images before and after the bin collection, to estimate the waste in the bin and its surrounding area. The system is developed to be as compact, robust, energetically efficient and reliable as possible. Data from the truck network are recorded and forwarded to a control server through GPS and GPRS system. The control server monitors the information and optimizes the truck routes and bin locations according to the waste estimation. The proposed system is based on the web-access architecture of a network for distributed bin and trucks. The main layers of the proposed system are as follows:

a) RFID system
b) Camera
c) The geographical information storage
d) The database management system and
e) The control station for controlling the information access for making decision.

The main role of the proposed system is to acquire data in real time from the truck and the camera to provide solid waste status of the bin and the truck position.
Sensorized waste bins provide a means to measure the content of the bins and to relay that information to persons far away from the bin. The means to measure could be by volume, weight or vertical level. Garbage collectors may therefore see remotely which garbage cans need to be emptied and which ones may be left until the next collection.
Two forms of the above-mentioned system have been trialed and implemented. The first system was trialed in the Pudong area of Shanghai, China. The Cleanwings Project as it was named was funded by the Italian Ministry of Environment, Land and Sea with assistance from the EU-China Energy and Environment Programme. The system consists of a set of sensors and a camera mounted onto the containers to estimate the weight of the waste,

its volume and the type. The sensors could also measure the temperature inside the container and liquid levels. Geographic data on the location of the container was also recorded. After significant development in the laboratory, two fully equipped prototypes were developed.

The system successfully measured weight and volume of waste, providing a means to monitor the overall amount of waste. Another goal of the system was to detect materials that could be a potential risk for the incineration plant, such as bricks or concrete. This could be done by calculating the density using weight and volume data. From this, the researchers could calculate a density threshold over which the content might be considered risky. This was estimated at 1kg per litre over more than 1000 trials during field tests.

The second objective of the system was to devise the most efficient route for the waste collection trucks. Again, this used measurements of waste weight and volume. Assuming that a truck can only hold a certain amount of waste and must serve a certain number of waste collection points, routes were identified to make collection as efficient as possible, specifying the location and order of collection points. This led to reduced traffic emissions and costs and helped prevent and manage problems with collecting waste.

The second system was developed by Molok Oy, a company which produces deep collection systems for solid waste. In a deep collection system waste is collected in a deep container, most of which is underground. A deep collection system takes up less than a third of the surface space required by aboveground waste containers. The deep collection containers are emptied by raising the lifting bag located inside the robust well-like structure to the truck bed, and then opening the bottom of the bag to empty its contents onto the truck bed. The section of the well-like structure above ground has an aesthetic covering that blends into the surroundings. The GSM-based sensor system is known as ÄlyMolok and is now on the market after being tested in Finland, Norway and Switzerland. The sensor system reduces unnecessary waste collection visits and is also useful for preventing overfilling at busy waste disposal sites. The sensor in the waste container notifies the company responsible for collecting the waste. The project was conducted in two stages. The sensor technology required a detector system in which the sensor can report on the container's vertical capacity. The second stage was creating an information technology (IT) application that would allow the battery in the sensor to remain operable for about one year in all weather conditions. A map system for the waste management companies was also developed.

MATERIALS AND METHODS

The hardware part of the system was developed using a sensor interfaced with a microcontroller and a GSM module.
The sensor chosen to implement was a weight sensor. It is triggered by the weight of a full skip which is approximately 4 tonnes. The reasons for choosing a weight sensor are:

1) It is cost effective
2) It is easy to maintain
3) Capacity of loading trucks is based on weight

The second part of the design was the choice of a suitable microcontroller development board. The requirements of the microcontroller board are:

i. GSM and GPRS functionality
ii. Low power requirements
iii. Small size
iv. Water resistant housing
v. Reasonable amount of EEPROM to store codes

The development board chosen was the AVR-GSM board because it satisfied the above requirements. The block diagram of the hardware components is shown in Figure 2.

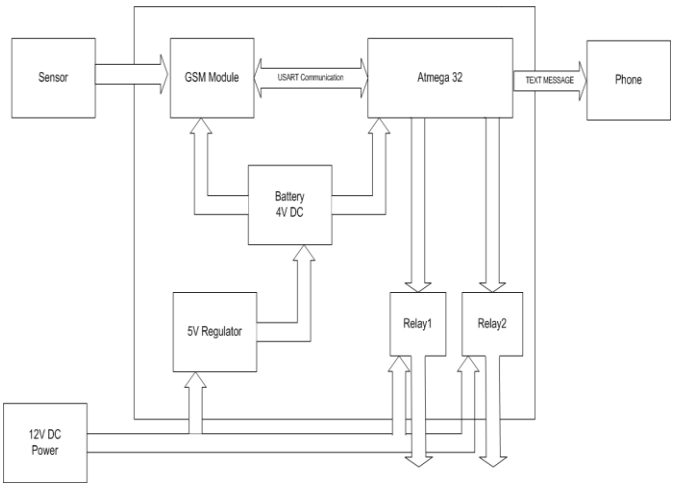

Figure 2: Hardware block diagram

The software part of the system comprised of a SMS Gateway and a MIS web application.
The MIS web application was developed with regard to the business operation logic of a typical waste management company (Wong & Katz, 1979). The case study for this work is Zoomlion Ghana Limited, the leading waste management companies in Ghana. The company provides janitorial services to corporate bodies, house-to-house waste collection and central container waste collection. For the purposes of this work, the central container waste collection service was adopted.
The Director of Operations of the company is responsible for organising and scheduling the waste collection and disposal activities of the company (Sprague & Carlsson, 1982, Sprague & Watson, 1996). Under the central container waste collection service, skips have been provided in various localities and each skip has its assigned driver who is responsible for picking up the skip when it is full and disposing its contents at the landfill site. Each driver has a waste disposal truck with which he performs his duties (Fuseini, 2007). Under the current system each driver has a locality whose skips he is responsible for. He patrols the locality daily and picks up the skips which are full. This was found not to be very efficient. This study proposes a system whereby the drivers only move after receiving information that one of their designated skips is full.

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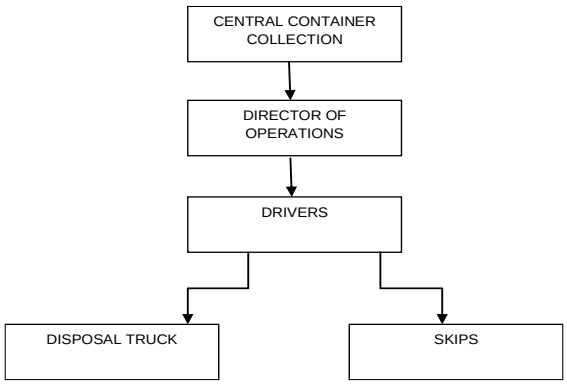

Figure 3: Operation logic

A. System User

For purposes of simplicity and security this work factored in a single user for the application. This is the administrator who will have the sole prerogative of using the application and making changes to it. The administrator will be in the person of the Director of Operations. The system use case diagram which describes the various actions which may be performed by the user is shown in Figure 4.

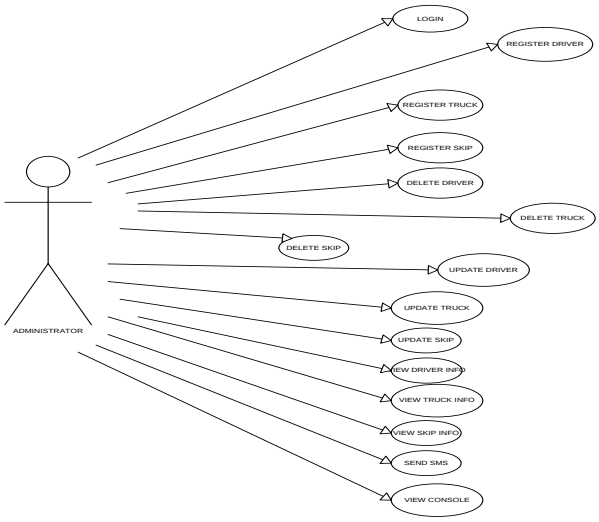

Figure 4: Use case diagram

B. System Architecture

The web application developed has a 3-tier Client-Server architecture. A Client-Server system is one in which the server performs some kind of service that is used by many clients (http://www.dossier-andreas.net/software_architecture/tiers.html). The clients take the lead in the communication. The basic Client-Server architecture has 2 tiers (Client and Server). However the three-tier architecture is widely used because it has a simple structure and it is easy to set up and maintain. These three tiers are the presentation, application, and database tiers. The Three-tier Client-Server Architecture is shown in Figure 5.

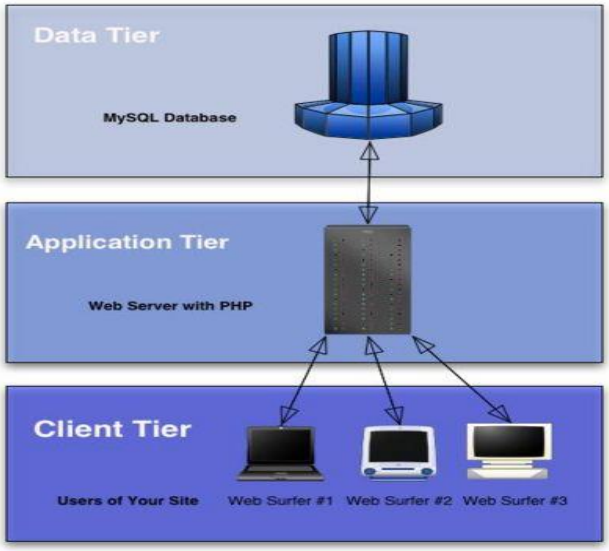

Figure 5: System architecture

C. System-User Interaction

The Administrator interacts with the application in four main ways, namely registration, viewing of records, update of records, deletion of records, sending SMS, viewing the console. Before any of these functions may be performed the administrator has to log in with his username and password.

Assuming the login is successful the administrator is presented with a menu from which he can choose a task to perform. The options available are:

1. Driver registration
2. Truck registration
3. Skip registration
4. Driver information
5. Truck information
6. Skip information
7. Send message
8. Console view

The registration options lead the administrator to pages which contain forms which he uses to register either drivers, trucks or skips (Imhoff et. al, 2003, 2004). The information options lead him or her to pages which display tables containing the records of the corresponding entities namely drivers, trucks or skips. Record updates and deletion can only be done on the information pages. The send message option displays a page where the user may send SMS to any of the drivers. The console view page sends the

user to a page where information on skips which are full is displayed in real time. The flowchart of the application is shown below.

The Console View page exhibits the primary functionality of the application. It is responsible for displaying the name, location and designated driver of a skip which is full. It does this by retrieving the required data from the database (McDonald, 1996, Motgomery, 1970, Raisinghani, 2000). It also displays the response of the driver to the task at hand. The driver may accept the task or decline task. This is communicated via SMS to system.

The SMS gateway used for this work is the Ozeki Message Server 6. Ozeki Message Server 6 - SMS Server is a powerful, flexible SMS Gateway application that enables one to send and receive SMS messages to mobile devices with a computer. It has an easy to use user interface, and an excellent internal architecture. The application can use a GSM mobile phone attached to the PC with a phone-to-PC data cable or GSM modem or IP SMS technology to transmit and receive the messages. Ozeki Message Server works on Microsoft Windows 7 operating systems and later.

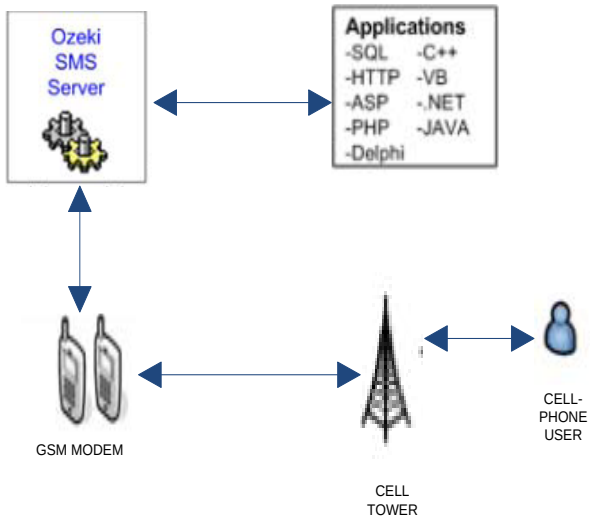

Figure 6: Application and message server interaction

IMPLEMENTATION AND TESTING

The main idea of this work was to have the AVR-GSM send an SMS to a predefined number after receiving an input from the sensor. In order for the task to be carried out the sensor had to be interfaced with the AVR-GSM. The type of message to be sent and the receiver's number also had to be defined in the hardware codes. The waste container and the sensor were mounted on a miniature scale for demonstration purposes. A miniature wooden platform which rested on a spring and on which the waste bin was to be mounted was built. A two-way switch was placed in the centre of the spring to serve as the sensor. With this setup the switch becomes activated any time the spring is compressed by the platform lying on top of it. This action made the switch behave like a weight sensor which becomes activated based on the weight of the bin bearing down on it. The setup is shown in Figure 7.

Figure 7: Implemented model

The administrator is the only user of the web application developed. The various functionalities of the system which are available to the administrator were implemented. The following subsections describe each of these functionalities.

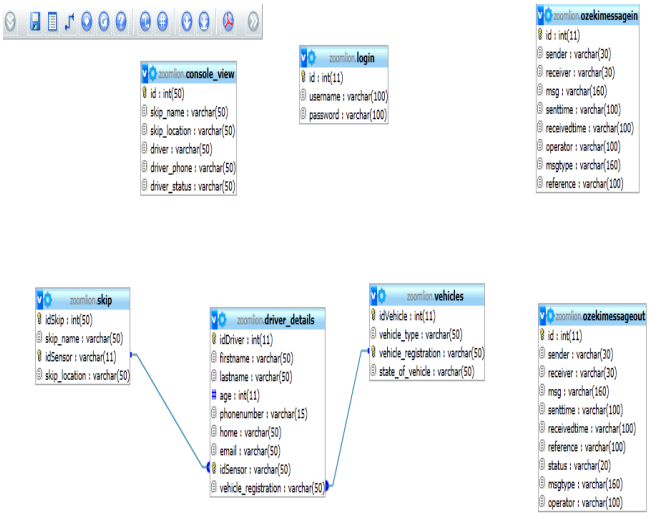

Figure 8: A screenshot of the system database

The administrator was registered by obtaining the username and password. After this the administrator was able to login.

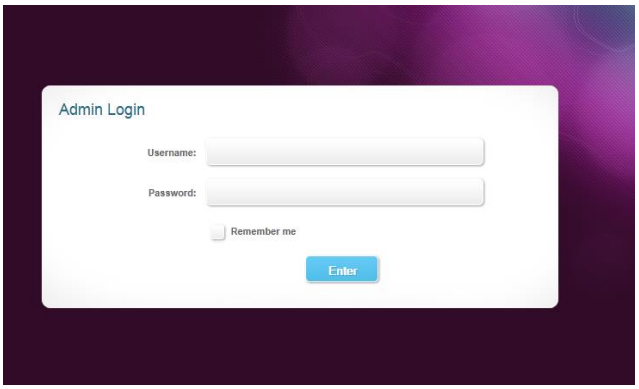

Figure 9: A screenshot of the login page

Registration may be in the form of driver registration, truck registration or skip registration. Figure 10 shows a screenshot of driver registration.

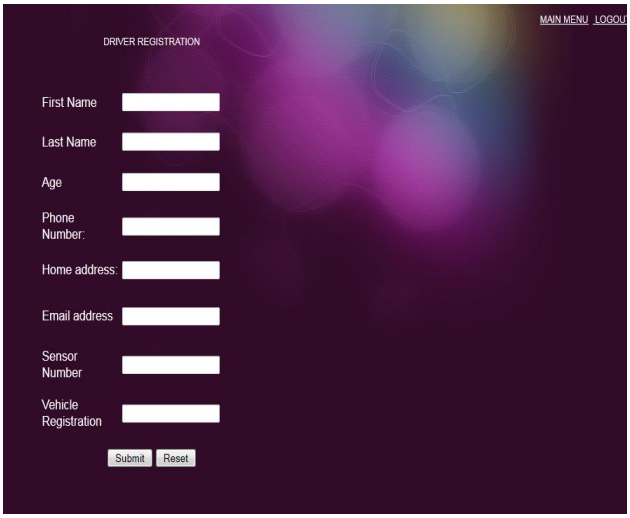

Figure 10: A screenshot of the driver registration form

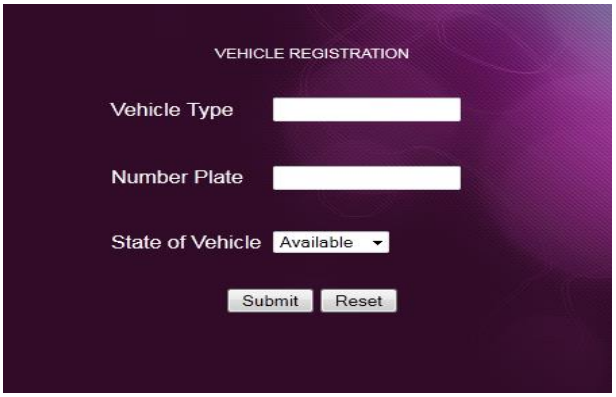

Figure 11: A screenshot of a truck registration form

C. Skip Registration

The skip registration form allows the details of the various skips to be recorded. The field labeled sensor ID is the phone number of the SIM card which will be used in the GSM module for the skip.

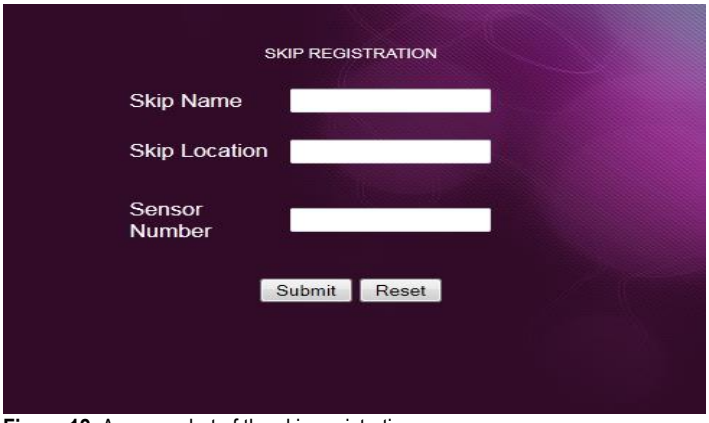

Figure 12: A screenshot of the skip registration

The capability of the AVR-GSM to send SMS to a predefined number was tested. The communication between the board and the computer was first tested using AbsoluteTelnet. Following this the board was programmed to send an SMS to a predefined number.

In accordance with the proposed system architecture, testing of the web application was done using 2 laptop computers. One served as the client and the other as the server. The Apache web server, MySQL database and the project files resided on the server. The files created were placed in the root folder htdocs folder found in the XAMPP package. A wireless ad hoc network was created between the 2 laptops. The application was then accessed from the client side. The various functions were then tested.

The SMS functionality of the MIS application was tested using two mobile phones and a GSM modem. The GSM modem was connected to the server side. The SMS server was initialized and configured on the server side. One of the mobile phones was to serve as a GSM module attached to the skip. The other mobile phone was to serve as driver's phone. For a successful test the message sent from the skip phone had to be received by the server and displayed in the Console View page. Concurrently the same message is to be relayed to the driver's phone. Upon receipt the driver must reply to the server and his reply must be displayed in the Console View under the Driver Status.

RESULTS AND DISCUSSION

In the hardware testing the message which was sent from the board was received on the phone of the specified number. The message was received approximately 15 seconds after it was sent from the board. This shows the capability of the board to send SMS successfully.

In the web application test the client was able to access the various pages and perform all the functions required of the administrator. The Console View was also accessed and the message parameters used in the test were displayed under their respective headings in the table. The real time functionality proved successful since the columns were filled immediately the messages were received by the server.

Conclusions

The objective of this work which was to design an intelligent waste container has been achieved. A web application which will facilitate

the operations of the waste disposal company has also been developed. The entire system is easy to set up, operate and maintain. It requires a sensor for detecting whether a skip is full, a GSM development board to transmit the SMS and a GSM modem and SMS server to receive the SMS from the skip. By incorporating the Intelligent Waste Container and the I-Waste Monitor 1.0 in their operations waste management companies stand to minimize their overall operating costs, increase productivity among staff and realize a well-ordered data repository. The impact on the environment will be profound and the health of the general public will be secured.

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