IOT based Smart Waste Management Framework

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Abstract: As the amount of solid waste is increasing, the need for innovative ideas to help improve solid waste management is growing by the time. To provide a cost effective solution to this problem, a new framework has been proposed that enables the remote monitoring of the parameters of the bin with the help of X-bee and GSM technology. The proposed system keep a check on the filling of the bin, temperature, humidity, volume of CO2 inside the bin and accordingly transmits the information to the base station which further sends the information to the control station where it is used for route optimization problems to reduce the operation costs and greenhouse gas emissions. An additional feature is a text message that is sent to the authorities with the location of the bin whenever the bin filled above 90%, keeping 10% as a safe limit before the garbage starts to overflow. The design of the bin is such that it keeps the people using the bin motivated towards protecting our environment..

Keywords: Solid Waste, Wireless Sensor Network, X-Bee Pro, Arduino, GSM/GPRS.

Introduction

The solid waste generated in India amounts to 188,500 tons per day or 68.8 million tons per year. Since 2001, there has been a 50% increase in MSW generated in India [1]. With an increase in population, change in consumption habit, economic uprising and change in lifestyle of urban population, the amount of Municipal Solid Waste (MSW) generated is increasing at a very high rate [2]. Although many municipal corporations are involved in developing efficient waste management systems but the solution to the problem of managing MSW becomes complex due to a large urban population [3].

In a traditional waste management system, the litter bins are emptied at certain intervals which pose several drawbacks such as: (1) the filling rate of some bins is high as compared to their emptying rate which fills them before the next emptying session. This leads to overflowing of bins causing environmental pollution and posing hygiene risks. (2) During festivals, weekends the bins get filled up quickly. So, there is a need to increase the collection intervals during these periods. With different stakeholders, transportation cost and financial/economic collection, keeping a city clean becomes a complex job [4] [5].

Managing of solid waste becomes more crucial due to a potential of generating electricity from MSW. The energy sector of India is reviewed by International Energy Agency (IEA) which also recognizes the challenges towards attaining sustainable energy future [14]. A power potential of about 1500mW has been predicted by MNRE (Ministry of New and Renewable Energy) from the solid waste generated in India. According to the Municipal Solid Waste (Management and Handling) Rules, 2000 (MSWR) the management of waste should be efficient but these rules do not specifically state anything about generating electricity from solid waste. The promotion for waste to energy plants and fixed charges or tariff for this generated power have only been recommended in the changes proposed in these rules in April, 2016. Waste management when performed effectively leads to opportunities for generating electricity from this waste.

Related Work

Although a lot of researchers have done work on various aspects of solid waste management, but only a few have considered the monitoring of bin. Some researchers have worked on RFID (Radio Frequency Identification Device), GIS (Geographic Information System), transportation model, GPS (Global positioning system) [6] [7] and some have worked with bin monitoring in which the collected data from the bin is transferred to a remote server through GSM/GPRS which increases the operating cost [8] [9]. Only a few have considered Wireless Sensor Network (WSN) as a possible solution to the increased operating cost [10] [11] but none of them have actually considered the hardware design of the waste management system in it. This paper is focused on thehardware implementation of a smart waste management system in which multiple parameters of the bin are acquired using a microcontroller and are transmitted to a base station using a sensor node from where they are saved in a database accessible by the user. The acquired parameters could be used for route optimization problems.

A Wireless Sensor Network(WSN) is a network of programmable sensor nodes or micro-devices that monitors various parameters like temperature, humidity, acceleration, volume of gases and transmits the acquired information to a base station which further updates the information to a remote server so that it could be used for a more valuable purpose [12] [13].

Problem Statement

The collection intervals for the litter bins are an important part in the effective waste management systems. Increased collection intervals increases the cost of operation and lesser collection intervals might result in overflowing of bins causing hygiene risks. An efficient waste management must accurately monitor the status of the bin and use that information to decide the collection intervals .The information can be transferred using GIS, WSN, and GSM/GPRS.
Among the above mentioned technologies, WSN is an efficient and low cost way of transmitting information from the bins to the base station. The aim of this proposed framework is to design and implement a Smart Waste Management System involving a Smart Bin whose parameters (filling of bin, temperature, humidity, volume of CO2) are to be remotely monitored at a control station to decide collection intervals for cleaning the bins.

Motivation

A survey was conducted by Ministry of Urban Development during 2014-2015 under National Sanitation Policy, 2000 in which all the 476 class-1 cities in 31 states and Union Territories were accessed based on total sanitation practices that included parameters like solid waste management, treatment of water waste, surface water quality of surface bodies, quality of drinking water, extent of open defecation. Among the 100 cities that came at last only 2 were from south, 3 from west and 21 from east. Rest 74 was from North only [15].
Again a survey was conducted by Ministry of Urban Development in Jan, 2016 under the name of 'Swachh Survekshan-2016' which categorized some cities as slow movers and some that required acceleration [16].
Both of these surveys showed the crucial need of innovative ideas in the area of Solid waste management in India.

Work Flow

The proposed smart waste management system shown in Figure1 focuses on the design of smart bin. A normal litter bin is made smart by monitoring its parameters (Filling of bin, temperature, humidity, Volume of CO2) and transmitting these values to a remote base station with the help of Zigbee Technology, where these parameters are saved in a local database. The acquired data is further transmitted to a control station using GPRS communication. Another feature of the smart bin is the notifying message it sends to the cleaner on filling of the bin above 90%.

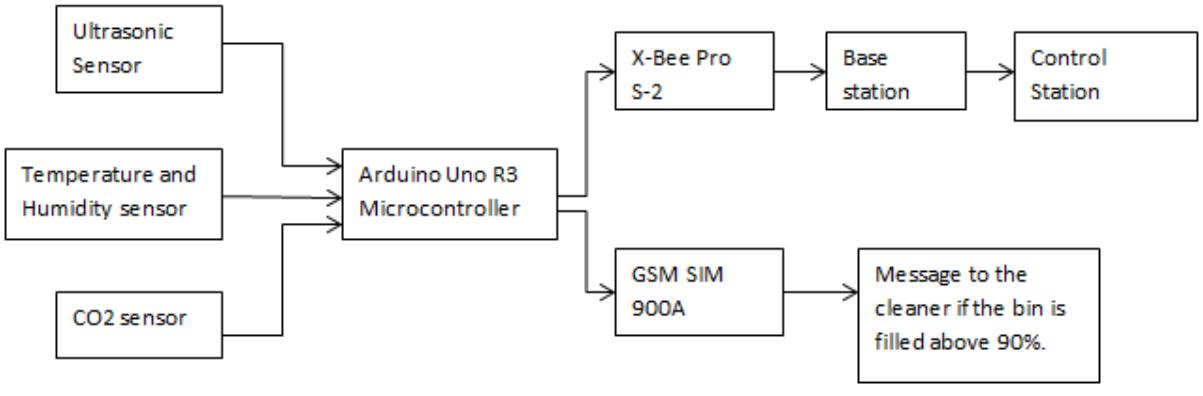


Figure1. Block Diagram of Proposed work

Simulation Environment

The focus of this work is to develop a smart bin using a programmable microcontroller unit (MCU). MCU [17] [18] has CPU (Central Processing Unit), ROM (Read Only Memory), RAM (Random Only Memory), I/O unit (Input/output Unit) and PC (program counter) all on a single chip. Earlier only assembly language was used to program the microcontrollers but nowadays high level languages like Verilog, VHDL, C, C++ are used.
The use of programmable microcontrollers makes this framework more flexible. Arduino family is categorized in 3 major classes: Arduino Mega 2560, Arduino Uno and Arduino Nano [18]. In the proposed framework, Arduino Uno R3 microcontroller is used as shown in Figure2.

Figure2. Arduino Uno R3 Microcontroller

Arduino is an easy to use open source microcontroller unit [18]. The free development software used for programming Arduino uses a simpler version of C / C++ language. The Integrated Development Environment (IDE) software used to configure and program Arduino has Graphic User Interface (GUI) as shown in Figure3. This software can be downloaded free of cost from the official website of Arduino.

After installing the IDE software, Arduino is connected to computer for uploading the program. The output of the program can be seen by printing on the serial monitor

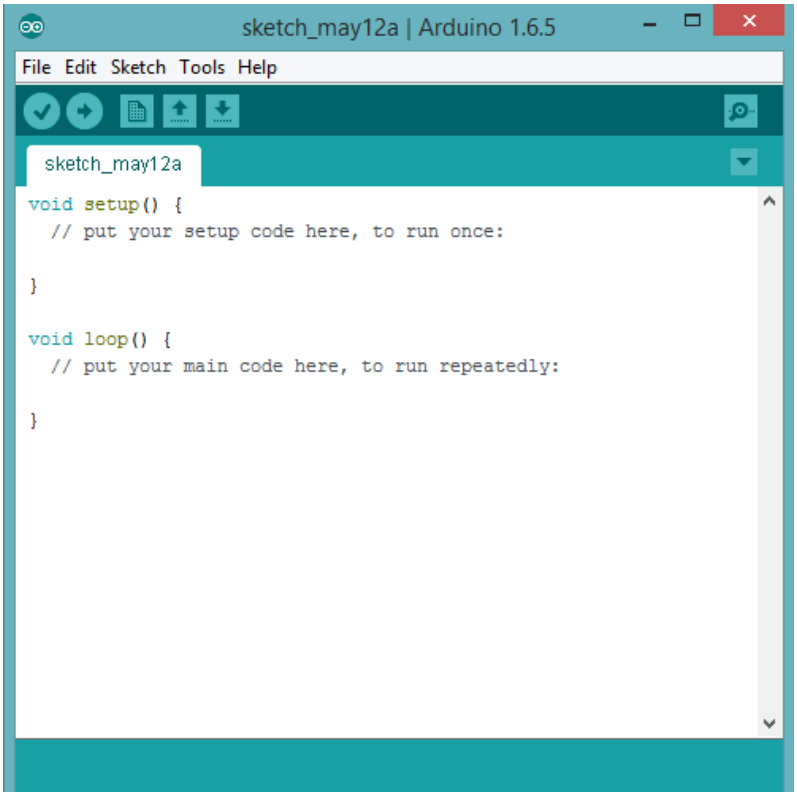


Figure3. Arduino IDE

Hardware Design and Evaluation

The implemented hardware design of the Smart Waste Management System is shown in Figure4. Physically the smart waste management system proposed here has 3 main units namely i) Smart bin ii) Base station iii) Control station.

Smart Bin

The sensor node as shown in Figure5 mounted on the top of the bin helps in the acquisition and transmission of data to the base station. The sensor node consists of the sensors that measure the parameters of the bin as well as the technologies that help in the transmission of the data. Following are the components of the smart bin:

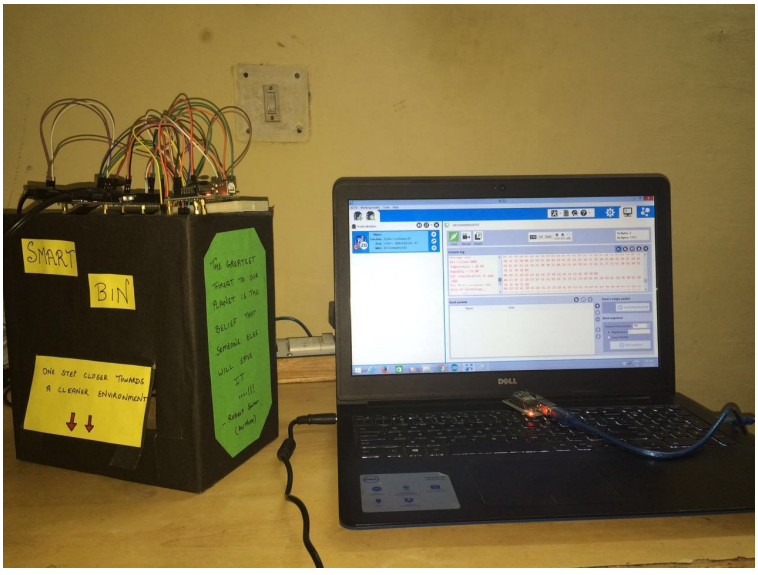


Figure4. Smart Waste Management Framework

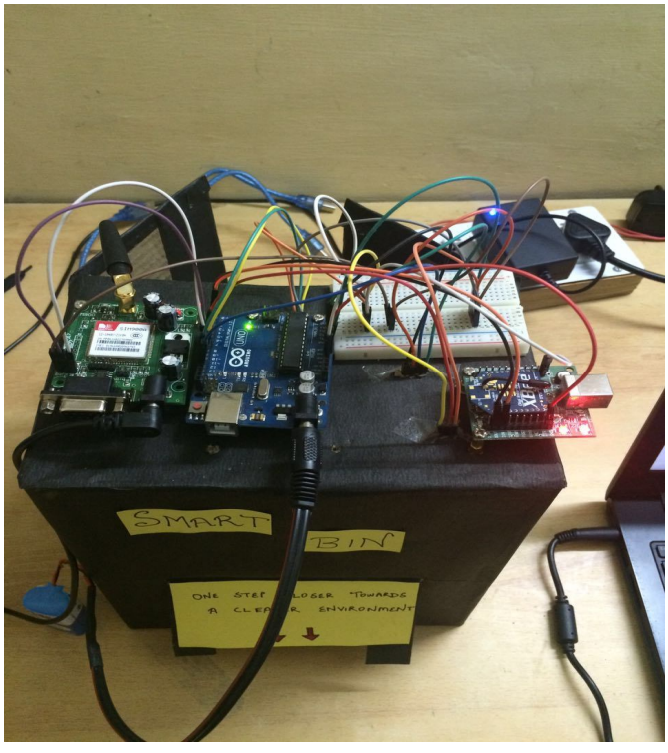


Figure5. Sensor node of Smart Bin

- Ultrasonic Sensor (HC-SR04):This sensor helps in measuring the distance between the object and the sensor in the range of 2cm to 400cm with an accuracy of 3mm by sending an echo signal [19]. The measured distance is converted to percentage of bin filled with the help of a map function in Arduino programming. The collection interval for all types of waste such as organic waste, metal waste, plastic waste, food waste, paper waste and E-waste depends on this parameter.
- Temperature and humidity sensor (DHT 11): DHT 11 sensor measures relative humidity in the range of 20-90% with an accuracy of ±5% and measures temperature with an accuracy of ±2ºC [20].The monitoring of temperature and humidity becomes an important aspect when storing organic waste whose decomposition process speeds up as temperature or humidity increases inside the bin. So, if due to any reason temperature or humidity inside the bin is at a higher value, to avoid decomposition of the organic waste, the bin needs to be emptied before even the bin is filled.

- CO2 sensor (MQ-135): MQ-135 sensor helps in the detection of NH3, NOx, alcohol, benzene, smoke and CO2 [21] but in this proposed framework only CO2 is monitored. The monitoring of CO2 is important when organic waste is being stored. The decomposition of organic waste liberates CO2 (A small amount is liberated in Anaerobic decomposition in comparison to Aerobic decomposition [24]). So, even if the bin is not filled, but the organic waste starts to decompose, a necessity is there to empty the bin. So, for this reason, keeping an eye on the level of CO2 becomes a key aspect.
- Arduino Uno R3: Arduino is an open source microcontroller based on the ATmega328P. Arduino has 6 analog input pins and 14 digital input/output pins out of which 6 can be used as PWM inputs. [18].The information from the sensors is processed by Arduino and is transmitted to base station. The flexible nature and easy to use hardware and software make Arduino the best choice for this framework.
- GSM SIM 900 module: This GSM shield uses a SIM card to send/receive messages and make /receive calls in a similar way as a mobile phone. The module uses AT commands to communicate with Arduino [22]. Although the parameters of the bin are being remotely measured at the base station, using a GSM module adds an extra feature of notifying the cleaner about filling of the bin through a text message. The text message is sent whenever the bin is filled more than 90%. The 10% safe limit is set to avoid the overflowing of garbage before the concerned person reaches the site to empty the bin. The mobile number of the cleaner is already programmed in the microcontroller. The text message that is sent consists of the bin ID and Location of the bin that is to be emptied.
- X-Bee Pro(S-2): X-Bee Pro(S-2) transmits data at the rate of 250 kbps up to a range of 300 ft. (90m) in indoor /urban range and up to 2 miles (3200m) in outdoor RF line of sight Range [23].X-bee Pro(S-2) is configured as a router in AT mode when connected to the bin. The data retrieved from the sensors after processing by the microcontroller is converted in a more suitable form. This data is transmitted to the base station through X-Bee communication.

Base Station

The Base station acts as a gateway for the data being received from the sensors to be transmitted to the control station. It receives data from the smart bin and stores in its local database.
Following are the components of a Base station:

- X-bee Pro S-2 Receiver: X-Bee Pro is configured here as a coordinator in AT mode to receive data from the X-Bee Pro transmitter and display the values from the sensors on the computer to which it is attached. The values are displayed on the console log in the same way as it is being transmitted as well in the form of ASCII values. The X-Bee Pro can act as router, coordinator or an end device as per the requirement of the framework [23].
- Computer: The X-Bee is attached to a computer, which displays the values of the parameters of the bin as received from the smart bin over the console log of X-CTU software.

Control Station

The control station receives the data from the base station through GPRS communication and stores it in the central server. The central server hosts the Data Base Management System and the Database used for the storage of the parameters of the bin.The data is available through a Graphical User Interface (GUI) for the interaction of user with the system.

Results and Discussion

The smart waste management system involving a smart bin has been successfully implemented. The data received from the sensors is displayed on the serial monitor of IDE as shown in Figure6. The Serial Monitor shows the values of the sensors connected to Arduino and calibrated as per the requirement. The printed string before every display of the data from the sensors showing bin ID and Location of the bin helps to identify the bin whose parameters are being displayed. Here, in this case the bin whose parameters are being displayed has Bin ID: 52 and is its location is in PEC University of Technology, Sector 12.
The values displayed on the console log of X-CTU software at the Base station as per Figure7 are the ones that are transmitted to the control station. These values are stored in the local database of the Base station. Along with the data received is the representation of the data using ASCII characters which may help to encode the data if required. The Record tab shown in the figure helps to create a video of the live data monitoring.
The database named Smart Waste Management System at the control station that shows the real time data received from the sensors is shown in Figure8. This database is created with an online application tool named Caspio. For the testing part, 3 bins have been installed in hostel premises whose data has been collected. The information such as bin ID, Location, date and time, filling percentage, temperature in degree Celsius, humidity in percentage and amount of CO2 in parts per million (ppm) is collected and shown in the database. A Graphical User Interface (GUI) intended for the user interaction with the system. The Table Design tab in the database helps to select the parameters to be included and also defines the data type for each data in the database.

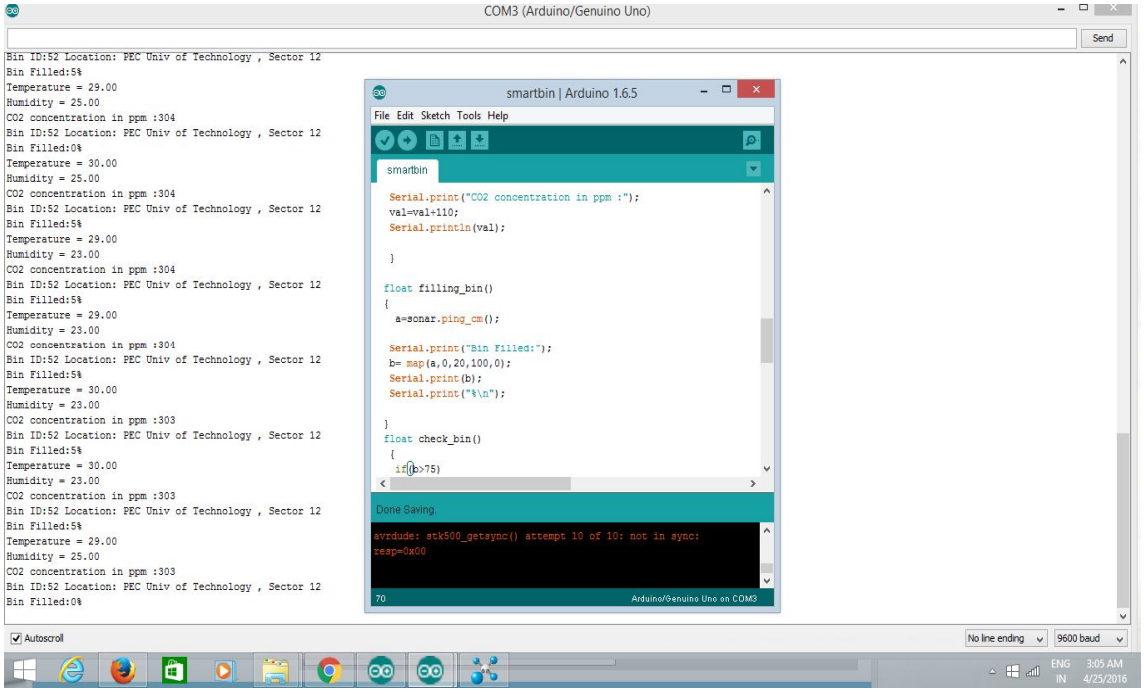


Figure6. Serial Monitor of IDE

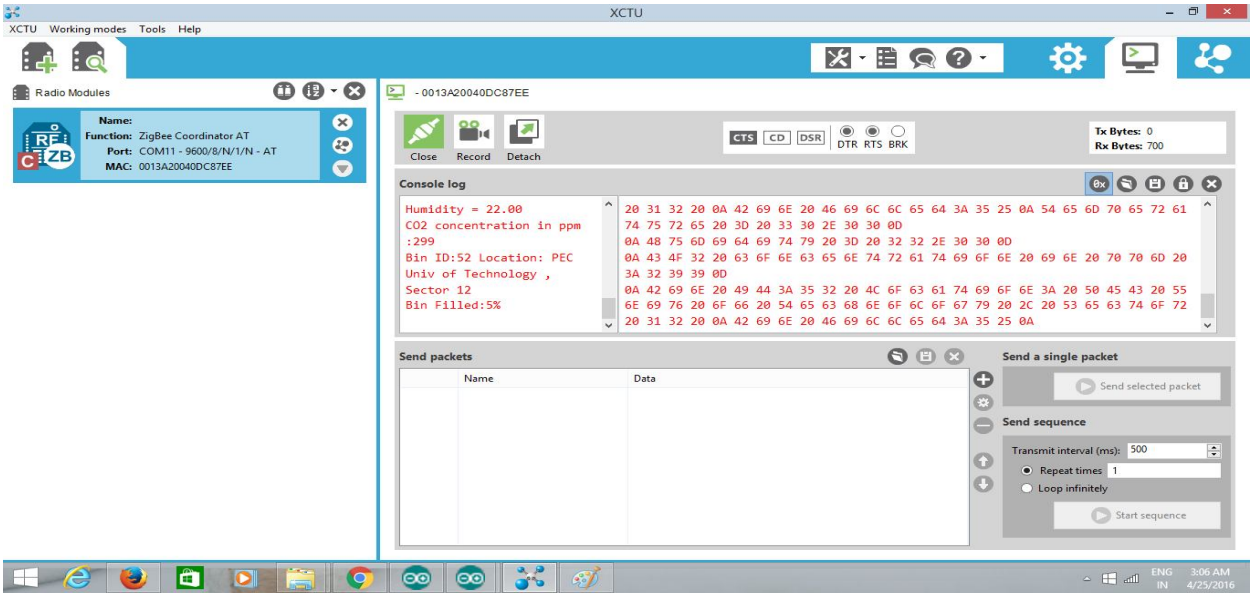
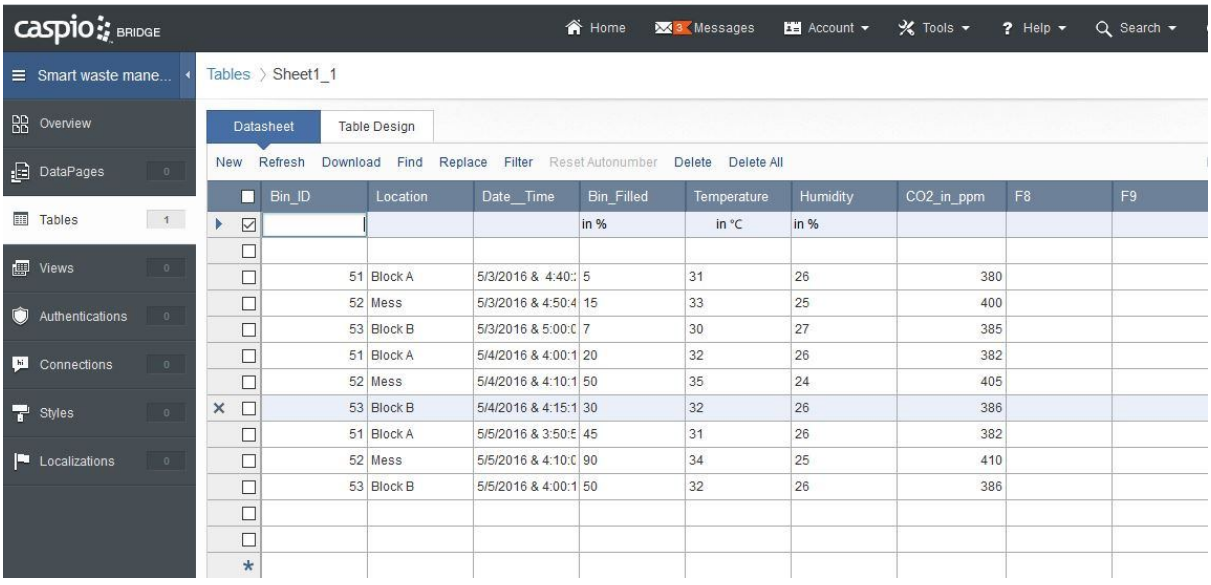


Figure7. Console log of X-CTU software

The bins whose data has been collected are placed at Block A, Mess and Block B in Aravali Hostel, PEC University of Technology, Chandigarh having bin ID's 51, 52, 53 respectively. The data in the database shows that more waste is generated in the mess as compared to Block A and Block B. The type of waste generated in the mess is more of a food waste and the waste generated in the blocks consists mainly of paper waste. The temperature in the mess is comparatively at a slighter higher value than in the blocks due to the heating process for food preparation in the mess



Bin_ID	Location	Date__Time	Bin_Filled	Temperature	Humidity	CO2_in_ppm	F8	F9
			in %	in °C	in %			
51	Block A	5/3/2016 & 4:40::	5	31	26	380		
52	Mess	5/3/2016 & 4:50:4	15	33	25	400		
53	Block B	5/3/2016 & 5:00:(	7	30	27	385		
51	Block A	5/4/2016 & 4:00:1	20	32	26	382		
52	Mess	5/4/2016 & 4:10:1	50	35	24	405		
53	Block B	5/4/2016 & 4:15:1	30	32	26	386		
51	Block A	5/5/2016 & 3:50:5	45	31	26	382		
52	Mess	5/5/2016 & 4:10:(	90	34	25	410		
53	Block B	5/5/2016 & 4:00:1	50	32	26	386		

Figure8. Information on parameters of bin in database

Conclusion and Future Work

The successful implementation of the proposed framework paves way for technology to improve the condition of solid waste management in India. The design of the outlook of bin is chosen as a motivational factor for the people to protect our environment. The proposed waste management system is based on the remote monitoring of the parameters of a bin and the display of these values in a GUI which helps to reduce the Greenhouse gas emissions and the operating cost of the traditional waste management system. An effective use of manpower and infrastructure through this proposed framework adds an extra benefit to the Waste Management System.

In Future, the design of the waste management system can be extended to improve the segregation of the waste at the source level and to provide innovative ideas for recycling of the collected waste.

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