SGBS: A novel smart garbage bin system for understanding household garbage disposal behaviour

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***Abstract*—Recently, there is a growing use of smart garbage management systems. Previous work on IoT garbage management systems presents an opportunity to provide a dynamic garbage collection and estimate future garbage growth. However, little attention has been given to understanding users' garbage disposal behaviour and the type of garbage contents produced and disposed by the households. To examine, we designed and developed a smart garbage bin system "SGBS", capable of tracking garbage amounts and identifying the contents of garbage disposed. The smart garbage bin was fastened with a ToF (time of flight), DHT22 (temperature and humidity), load cell and air quality sensors for measuring the amount of garbage. Households users used smartphones installed with a garbage annotation application to input the type of garbage contents they disposed. A sigfox antenna module was used as a gateway to send data into a cloud server. The developed system uses energy-saving algorithms with sleep and wake-up cycles to reduce energy usage and increase the lifetime of sensor devices on daily use. To evaluate our approach, we conducted an initial experiment on the smart garbage bin system in three households. Our findings show that households' garbage disposal behaviour depends on the amount and contents of garbage as well as the routine of disposing such garbage content. We discuss the potential of our system to be scaled in a smart city to influence behaviour change, provide healthier life, and improve garbage management operational efficiency.**

***Index Terms*—Smart garbage bin, households behaviour, Sigfox, IoT, garbage contents.**

I. Introduction

Recently, there is a growing use of smart garbage management systems. Such systems are vital as it is critically significant in providing dynamic collection and estimation of future garbage growth [1], [2]. Daily in homes, there will always be a lot of garbage produced. The type of garbage contents and amount varies due to family lifestyle, family type, family size, and other home daily activities, including eating and cooking behaviours. However, little attention has been given to the existing IoT-based smart garbage management system to understand households' garbage disposal behaviours and the type of contents disposed based on the households' heterogeneous characteristics.

To fill this gap, this research contributes to the use of a contemporary methodology able to establish garbage log service for households that can automatically track information about garbage amounts such as garbage level, weight, moisture, air quality, and identifying type of garbage contents disposed in order to learn household behaviour on the garbage disposal. The garbage log service for households users involves learning and analysing patterns, peaks, and trends of the garbage growth amount and identifying the type of contents of garbage disposed daily in their own homes. Therefore, by leveraging the Internet of Things (IoT) technologies, we propose a smart garbage bin system (SGBS) that can capture and provide such garbage disposal information from households. The proposed SGBS is capable of low energy usage and long data range. This study considered the sustainability of an IoT system deployment that relies significantly on prolonged efficient power consumption and reliable data rate transmission technologies of sensing devices. Meanwhile, the deployment of IoT-based smart garbage solutions is still limited by power-hungry devices and long data transmission. Most smart bin systems are usually installed in places where power outlets are unavailable [3] and far away from other network devices, thus facing energy constraints and data transmission obstructions. Using a battery could be an option, but a high frequency of replacing and charging a battery could be complex for the users and consistently impractical [3]. Besides, the use of conventional energy is more expensive. Contemplating these challenges could greatly benefit from the IoT technologies.

To this end, this paper presents a designed and developed SGBS with solar energy harvest capabilities that aims to provide garbage log service for household users. The SGBS has low energy usage, low data rate with enabling technology to sustain the system. The SGBS was deployed in three households of heterogeneous characteristics where the impact of a system can be easily measured and subsequently reproduced on a larger scale. It is vital to understand the households behaviour on garbage disposal and identify the type of content disposed. This is potentially significant to influence behaviour change to person and family on the garbage disposal, thus minimising garbage generation. Further, the system can help smart cities improve garbage-related services, provide more efficient garbage management, and encourage responsible citizens through data-driven evidence to live in cleaner, healthier, and safer environments. The remainder of the paper is organised into five Sections. Section 1 provides a brief introduction and background of the research. Section 2 lists some of the related work and details the state of the art of the existing systems. Section 3 provides methods and tools used in the study. Section 4 details the initial experiment

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conducted whereas section 5 concludes the study.

II. Related work

Recently, several IoT-based smart garbage management systems have been developed. Most of the existing work invests effort in using the amount of garbage to estimate its future growth and provide dynamic garbage collection. We discussed our related work by considering both aspects found in the existing work.

Dynamic polling algorithm for low energy garbage level [3] was proposed where the smart trash bin consists of an ultrasonic range finder to measure the amount of garbage level. The study used a polling algorithm to measure the maximum height of garbage based on historical information about the fluctuation in garbage height gathered in advance. The dynamic polling algorithm was used to reduce the power consumption of the device. The study mainly focused on dynamic garbage collection to eliminate the high cost and inefficiency of the existing static garbage collection systems.

A novel smart waste management approach for business IoT "SWAM" was suggested [1], the system was elaborated in the city of Luxembourg targeting businesses and large entities. The system used ultrasonic sensors to measure the amount of garbage level in smart bins. Driver mobile data and customer profile were combined and advise the driver on the best times to visit a customer and collect garbage. Also, the study proposed a multi-objective optimization layer, which compiles the collection routes that minimize the impact on the environment and maximize the service quality. Likewise, Hossain et al. [4] demonstrated an optimal route planning model based on Dijkstra's algorithm as one of the most important factors in the smart waste management system in the city. The authors considered the status of the amount of garbage level in a bin as one of the real-life parameters in calculating optimal distance link cost and other parameters such as road congestion status and distance travelled by the driver.

Idwan et al. [5] advances the use of IoT technology to determine the schedule and pathways of waste collection trucks. The study simulated multiple route trucks using a heuristic algorithm and developed a smart dumpster equipped with an ultrasonic sensor and GSM module to measure the level of waste and send updates into the central management system using a wireless network. The author asserts that data regarding the status of garbage in the developed dumpsters used to determine the most effective route of the truck, reducing the cost and time taken.

The dynamic features of IoT on human innovation with the remedy of an ever-increasing amount of garbage was demonstrated [6]. The author developed a smart garbage bin system able to record the status of the amount of garbage level periodically in a cloud server and send a report to waste management authorities and truck drivers for the automation of garbage collection.

Moreover, a prediction of fill-level containers using a BIN-CT (BIN for the city) software system was presented [2]. The study pivoted on paper waste containers due to their variability in collection frequency rather than organic waste. The system combined two main algorithms, one for next day prediction of the fill level of the containers based on the historical fill level data of each container using Machine Learning algorithms. Second, it computes the best routes to visit them; BIN-CT prioritized containers with fill level greater than 80 % for the collection schedule. The predictive system is designed to improve municipal waste collection planning. Similarly, Faye et al. [1] also argued the future system to include the predictive models in order to obtain an estimation of the fill level at least 48 hours in advance and plan for collection.

Previous studies have shown that IoT-based smart garbage management systems can use garbage amounts to predict garbage growth and provide a dynamic and optimal route for garbage collection to reduce cost and improve garbage operational services. However, our approach addresses a greater understanding of household garbage disposal behaviour and identification of the type of garbage contents disposed. The interpretation of garbage log data can help to influence behaviour change to users on the garbage disposal, thus minimising garbage generation. Consequently, our approach offers healthier living for users and ensure more efficient garbage management in the smart city.

III. Methods and tools

A. System requirements

In this section, we identified and described the requirements for the proposed SGBS as follows;

- It should detect the amount of garbage in the smart bin.
- It should detect the moisture condition and air quality of the garbage in the smart bin.
- It should be able to provide desirable low energy usage on devices
- It should be capable of transfer the detected data into a cloud server at a long-range.
- It should identify the type of garbage contents and guide users on how to dispose of garbage.
- It should allow household users to clean their smart bins for healthier living.
- It should allow safe installation and replacement of smartphone.

TABLE I
Sensor properties and purposes

	Sensor device	**Max current (mA)**	**Voltage (V)**	**Purpose**
1.	DHT22	2.5	$3 \sim 5$	Temperature and humidity
2.	ToF	10	$2.8 \sim 5$	Filling level
3.	Load cell and HX711	1.6	$2.6 \sim 5.5$	Weight
4.	CCS811 Air quality sensor	26	$3 \sim 5$	TVOC and CO2

In order to achieve the above requirements for the SGBS we selected hardware devices, where in the heart of the

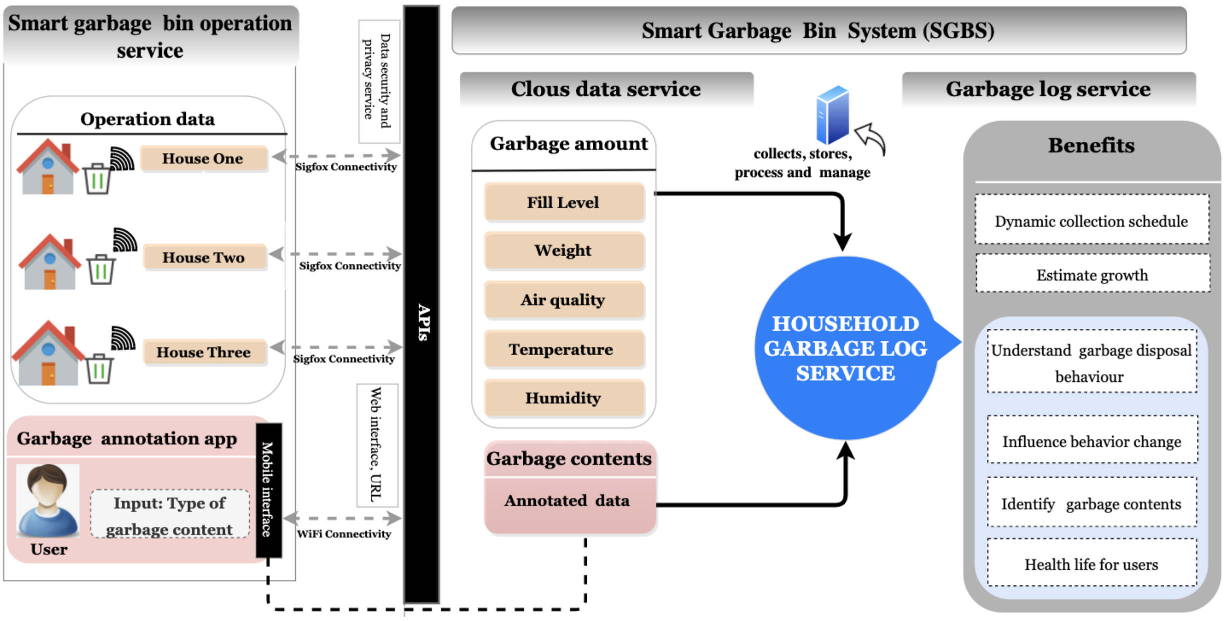

Fig. 1. High level architecture of smart garbage bin system

proposed SGBS, an ATmega328-Arduino Pro Mini microcontroller used. The ATmega328 uses a 3.3V, 8 MHz and consumes 16mA before the sleep mode state; this is suitable for implementing a low energy smart garbage bin. In addition, we selected the Low Power Wide Area Network, sigfox Antenna module programmed with the ATmega328 to transfer small chunks of measured garbage data into a specified cloud data service. Google Pixel 3a 64 GB simple smartphone with Wi-Fi capability used for installing garbage annotation application. Furthermore, we selected small, low power and lightweight sensors for determining the state of garbage amount (fill level and weight), moisture and air quality (Total Volatile Organic Compounds (TVOCs) and Equivalent CO2 (eCO2)). Table I provides the purpose and power consumption properties of the chosen sensors used in the development of smart garbage bin.

B. Architecture design

Fig. 1 demonstrates the high-level architecture of the SGBS which consists of three primary services. First, the smart garbage bin operation service, where the smart garbage bin is embedded with ToF (time of flight), DHT22 (temperature and humidity), HX711-load cell, CCS811 air quality sensor and a solar panel battery. Using a sigfox antenna module as a gateway garbage data are sent to the cloud data server through the API calls. In addition, the smart garbage bin operation service consists of the garbage annotation application installed on smartphones that guide users in disposing their garbage in the smart garbage bin appropriately. Secondly, the Cloud data service collects, stores and processes all sensor data from the smart garbage bin. Thirdly, the garbage log service “GLS” established by using the garbage amount and garbage contents from households to learn the garbage disposal behaviour of households which is the focus of this study.

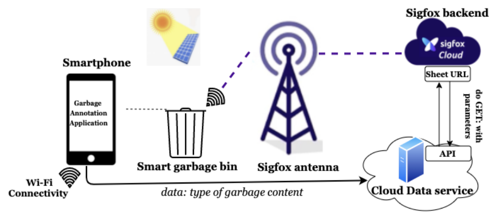

Fig. 2. Smart garbage bin system design

C. System design

This subsection describes the design of the SGBS. Fig. 2 illustrates the design of the Smart garbage bin system. The SGBS design consists of four components:

- ***Smart garbage bin:*** Where sensors, solar panel battery, sigfox antenna, and smartphones are attached for the purpose of garbage data collection.
- ***Sigfox antenna module:*** That uses low power ultra narrowband sends data to the backend of the sigfox cloud.
- ***Sigfox cloud:*** That uses a custom callback service type to integrate with google cloud API through the created google sheet URL to receive the bytes of data via the sigfox antenna module.
- ***Google sheet cloud service:*** That receives data from sigfox cloud using the *doGet* parameter function, storing and processing all sensor data from the smart garbage bin that are sent in a defined system time interval.

D. Sigfox as the enabling data communication infrastructure for SGBS

Sigfox network is part of the Low Power Wide Area Network(LPWAN) with an ultra-narrowband technology that uses a standard radio transmission method called binary phase-shift keying (BPSK). Sigfox operates in unlicensed bands worldwide, with radio frequencies of 868 to 869 MHz and 902 to 928 MHz using a data rate of 100bps to 600 bps [7] depending on the region. Sigfox network is employed mainly for developing IoT more reliable than Wi-Fi because it can handle a data transmission without object obstruction to 6km/h from the installed location. Conversely to Wi-Fi technology standards 802.11abgn which involve short-range, high cost and high power consumption. As mentioned in the above sections, we wanted to achieve low energy usage on the proposed SGBS. Therefore, in this study, we installed a Kit breakout board sigfox BRKWS01 (RC3+915Mhz) antenna. The registered antenna contains a low-cost one-year contract for the network provision and subscription. With the sigfox module, the devices can send a maximum of 6 messages per hour (36/6) in a 10-minute duty cycle, which means a total of 144 messages per day. So we used this scenario to define the SGBS time interval for sleep and active mode. This way, the SGBS sends new garbage data into the cloud service using the designated 10-minute break continuously in a day. To receive data, we used the custom call back service at the back end of sigfox cloud to integrate with the google sheet cloud server through google API, whereas data are received with the help of the *doGet* function query.

E. Energy saving algorithm

In this section, an energy-saving algorithm is proposed and described to reduce power consumption on the smart garbage bin. We assume the contents of the garbage differs from one household to another in a day. Thus, the proposed system has to record such patterns without missing an important garbage disposal behaviour of the user in specified time intervals.The energy-saving algorithm operates in active and sleep modes to collect information about garbage contents;

1) Active mode: During the active mode is where the measurement of garbage contents occurs using the sensors. The smart garbage bin starts by waking up for two seconds, all the sensors to measure the available garbage contents. Because the frequency of measurement directly affects the power consumption, it is important to reduce the system active time as much as possible. The measured garbage values are uploaded as bytes of a message into the cloud server via the sigfox antenna module. This process requires a delay time of about 1.5 seconds before the system enters sleep mode.

2) Sleep mode: In sleep mode, we achieved a low energy usage of the smart garbage bin. During this state, the microcontroller enters sleep for 8 minutes. We used a Low Power Mode (LPM) that puts inactive functions that consume power to run in a microcontroller, including; Timer 0, 1, 2, SPI and UART Communication, External Oscillator through an Arduino lower power library. This method results in low usage of power in the smart bin devices. To avoid confusion on the solar battery and consistently power the system devices using this algorithm, we introduced a 1-minute wake delay in the energy-saving duty cycle. Therefore, using this energy-saving algorithm is expected to be an efficient power consumption on the proposed SGBS.

TABLE II
POWER CONSUMPTION CHARACTERISTICS

Mode		Current consuption
Active mode	Wakeup current	50.1 mA
	Wakeup time	3.5 sec
Sleep mode	Sleep current	38 mA
	Sleep time	9 min

F. Evaluation of power consumption

In this section, a method for measuring the power consumption by the smart garbage bin is introduced and in order to confirm its low energy attributes, as discussed in the previous section. The proposed SGBS aims to track garbage amounts, including; garbage level, weight, moisture, and air quality. Thus, the energy-saving algorithm was used to increase lifetime sensor devices. Using Cen-Tech digital multimeters, we measured the total current consumption by the smart garbage bin during the active mode, when it performs measurements and communicates the data to the cloud server. Also, we measured the power when the smart garbage bin is in sleep mode.

1) Power Measurement method: To calculate the power measurement by the smart garbage bin, we measured the total current consumption by the devices over time (3,600 seconds in one hour). As mentioned above we divided the measurement into two ways; during measurements (Active mode) and at sleep mode. Table II recorded the power consumption characteristics of the smart garbage bin during active mode and sleep mode.

2) Results: By referring to Table II in active mode, the smart garbage bin consumes 50.1 mA as a wakeup current in a total of 3.5 seconds, six times in every one hour. If it is expressed into milliamp-hours (mAh) units, the power consumption of the smart garbage bin can be calculated as follows;

$$50.1\,\mathrm{mA} \times (3.5 \text{ sec} \times 6\,/3600 \text{ sec}) = 2.9 \times 10^{-1}\,\mathrm{mAh} \quad (1)$$

Again from Table II during the system sleep mode, the smart garbage bin consumes 38 mA as a sleep current in total of 9 minutes which is equal to 540 seconds. If it is expressed into milliamp-hours (mAh) units, the power consumption of the smart garbage bin can be calculated as follows;

$$38\,\mathrm{mA} \times (540 \text{ sec} \times 6\,/3600 \text{ sec}) = 34.2\,\mathrm{mAh} \qquad (2)$$

3) Estimate Battery life: To confirm the lifetime of smart bin devices using our energy-saving algorithm, we estimated the battery life of the solar panel battery in powering the smart garbage bin. We conducted our experiment using a 26,800 mAh solar panel battery to power the smart garbage bin. Therefore, we used power consumption characteristics as demonstrated in Table II and assumed the percentage wasted

Fig. 3. Smart garbage bin system deployed in a household

capacity of the solar battery is less than 5%. Thus, the battery life of the smart garbage bin was calculated as follows;

$$\begin{aligned}
\text{Average current} &= \frac{(38\,\text{mA} \times 540\ \text{sec}) + (50.1\,\text{mA} \times 3\ \text{sec})}{(540\ \text{sec} + 3.5\ \text{sec})} \\
&= 38.0779\,\text{mA} \\
\text{Battery life time} &= \frac{26,800\,\text{mAh} \times 0.95}{38.0779\,\text{mA}} \\
&= \frac{668.63\,\text{h}}{24\,\text{h}} \\
&\approx 29\,\text{days}
\end{aligned} \tag{3}$$

IV. Deployment and Data Collection Experiment

We conducted an initial experiment to verify the feasibility of the SGBS for 11–21 days in three households to understand households' behaviours on the garbage disposal and identify the type of garbage contents disposed. We used age group, family size, family type and cooking and eating habits as criteria to select the participants for the experiment. Table III outlines the information of the participants of the initial study. We ensured safe data collection and storage to users by protecting users' anonymity and confidentiality, and the collected data was used only for the intended purposes of this study. We did not sample for specific experience with smart home technology, but we assumed all participants have experience using smartphones and general knowledge of sensors Fig. 3 shows the deployed SGBS in the household. The subsequent section illustrates how households use a mobile application that guides during the garbage disposal.

A. Garbage annotation mobile application

In order to collect information about the type of garbage contents disposed by household users, we designed and developed a garbage annotation mobile application to guide users in the garbage disposal. The developed mobile application consists of four categories with ten different types of burnable garbage contents; kitchen garbage; (*all food garbage*), plastic/unclean products; (*storage containers, toys, unclean packages, unclean containers*), paper/textile; (*tissues, mixed papers, milk/juice box, unclean cloth*) and other related types of garbage contents as shown on Fig. 4. The classification of burnable garbage based on the catalogue as instructed by the Ikoma city in Japan thus creates the menu for garbage annotation mobile application. The garbage annotation application

TABLE III
Information of the Participants

Household one	**Particulars** - Age group:(23) - Type of family: Single - Size of family: 1 - Life style: 1 absence on day on weekdays - Cooking & Eating habits: often evening
Household two	**Particulars** - Age group:(29) - Type of family: Young married couple - Size of family: 2 adults, 1 child - Life style: 1 absence on day on weekdays - Cooking & Eating habits: often all the days
Household three	**Particulars** - Age group:(55-50) - Type of family: Married Couple - Size of family: 2 adults - Life style: 1 absence on day on weekdays - Cooking & Eating habits: often all the days

Fig. 4. Garbage annotation mobile application

allows individual households to select the type of garbage content each time they dispose garbage in the SGB from a handy smartphone installed outside on top of the SGB cover, then data about the garbage content are sent into the cloud data server using a Wi-Fi network.

B. Result and discussion

The discussion below is on the general aspects of understanding behaviour of household users on garbage disposal from the established garbage log service "GLS" of each family. First we discuss the tracking of garbage growth amount from the users of the three households, then identified important types of garbage content for each household and lastly we describe the routine behaviuor of disposing such garbage contents. This discussion is more on general households' adoption, experience and limitation in using the SGBS.

1) Tracking garbage growth amount: The objective of the initial experiment was to verify the feasibility of the SGBS in understanding the behaviour of households on garbage disposal as mentioned in the previous chapters. Fig. 5 to Fig. 13 depicts the results of tracking the garbage amount into all three households users when using the smart garbage

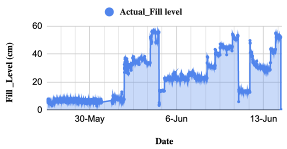

Fig. 5. Garbage filling level in household one

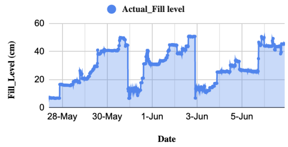

Fig. 8. Garbage filling level in household two

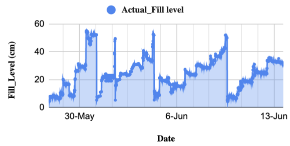

Fig. 11. Garbage filling level in household three

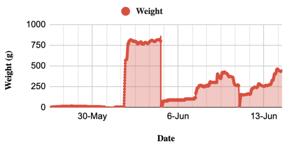

Fig. 6. Garbage weight in household one

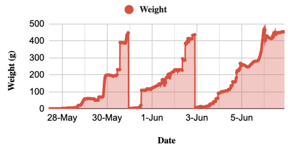

Fig. 9. Garbage weight in household two

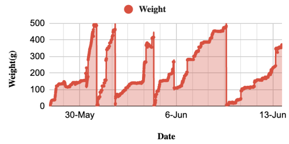

Fig. 12. Garbage weight in household three

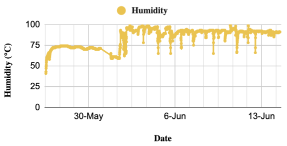

Fig. 7. Garbage moisture in household one

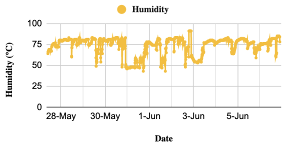

Fig. 10. Garbage moisture in household two

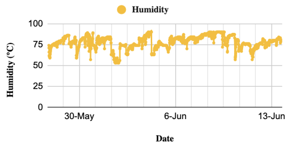

Fig. 13. Garbage moisture in household three

bin. The size of the smart garbage bin used in the experiment was Width 31 $\times$ Depth 39 $\times$ Height 57.5 cm and 45 L Capacity. From the Fig. 5 to Fig. 13 the Y-axis of garbage level shows the fill level in cm unit, and Y-axis of garbage weight graphs shows the weight of garbage in gram units respectively and the X-axis of both shows the date when the data was collected. The actual fill level was measured between the lid of the smart garbage bin and the garbage disposal bag inside the smart garbage bin. So a narrow distance shows that the garbage is reaching the maximum fill level and a long distance shows that the smart garbage bin is almost empty. The actual behaviour of garbage fill level amount is directly proportional to the growth amount of weight of the garbage however the fill level was much affected by compression behaviour causing huge fluctuations of the fill level from the steady state. The behaviour of changing garbage disposal bags inside the smart garbage bin differs from household to household. In addition, the tracked garbage growth amount from the households is helpful in predictions of future growth behaviour as proposed in our previous work [8] where a time series machine learning algorithm was used to forecast future garbage growth experimented at a single house level. Furthermore, predicting future garbage growth behaviour can be scaled from the households to a larger scale of the city in a different season of operation, thus providing more efficient garbage management. The subsequent section provides a brief understanding of household behaviour on garbage disposal using the tracked amount of garbage.

- **Household one:** Was a single family occupied by one individual. During the first seven days (27-May to 2-June) of the experiment in this household, the garbage amount as illustrated in Fig. 5 and Fig. 6 remained at the lowest steady-state with slight sensor fluctuations. This behaviour validated the assumption that either the participant was absent from home or the participant did cook or eat at home at all thus, there was no any garbage disposal behaviour observed. On the following days of the experiment, the garbage growth started to be observed using the collected sensor data and annotation app. Surprisingly, the garbage amount grew faster than expected and remained at high peaks for four days before changing the garbage disposal bag in the smart garbage bin, whereas the sensor values began from their initial value on around 4-June. Further on the experiment, we also observed that the garbage amount continued to grow for six days around 6-June to 11-June with some fluctuation due to garbage compression behaviour, thus verifying that the household did not change the garbage disposal bag for all six days. This was also revealed as the sensor values did not begin from their initial values but continued. Such a pattern found to be both strange and interesting compared to the observed behaviours of household two and three as described below.
- **Household two:** While the household one had an unpredictable garbage growth behavior, household two which consisted of a family size of two adults with one child had a constant behavior on garbage disposal. As shown on Fig. 8 and Fig. 9 the participants used the smart garbage bin every day and changed the garbage disposal bag mostly after every two days, This occurrence was also realized by using the collected sensor values as they changed and began from its initial values every time the disposal bag was changed. However the garbage compression behavior was also highly perceived, which explains that probably participants always want to keep the garbage bin from reaching its maximum thresholds or heavier garbage came after lighter garbage.
- **Household three:** The household consisted of two married couples. The behaviour of garbage growth as shown in Fig. 11 and Fig. 12 looked similar to household

two, although the peak, trends and patterns of garbage growth were different. In this household, the behaviour of changing garbage disposal bags varied from one day (31-May to 1-June) to a maximum of four (4-June to 9-June) as depicted in both Fig. 11 and Fig. 12. This trend was also realized using the collected sensor values as they changed and began from their initial values.

2) Identification of garbage content: Further, this study aimed to identify the type of garbage contents disposed by the households. Households used the garbage annotation app to select and input the type of garbage contents each time they disposed garbage in smart garbage bin. The type of garbage contents was first identified through the data from the garbage annotation app, which had four categories of burnable garbage with ten different types of garbage contents, as described in the above sections. Also, the garbage contents were realised through the moisture conditions and the air quality found in the smart garbage bin since the type of garbage contents affects the moisture and air quality in the smart garbage bin. Therefore, using data from the garbage annotation application and moisture inside the smart garbage bin, we identified and ranked the type of garbage contents that were more important to the households (high produced and disposed) than the other (low produced and disposed).

- **Household one:** As shown in Fig. 14 we found that food garbage contents ranked as the most important garbage produced and disposed of by the participant. In this household, the participant often disposed the food garbage content causing the moisture to rise in the smart garbage bin. Therefore, the moisture condition was observed to be consistently high, as depicted in Fig. 7. Furthermore, Tissue contents were second in rank, followed by other type of burnable garbage content. The unclean package was the fourth in high ranking. The mixed paper was the lowest in the rank of garbage content produced and disposed only three times by the household. The result has shown that mixed paper was only disposed three times between 3-June and 5-June and once on 13-June. An unclean container disposed six times, whereas storage containers appeared seven times during the experiment.
- **Household two:** Like in household one (Fig. 14), it also observed that tissue garbage content ranked second in household two as illustrated in Fig. 15. The unclean package garbage content ranked first, followed by unclean container. Lastly, the food garbage content ranked fourth among the important garbage produced and disposed by the participant, only five times that the storage containers were disposed made it the lowest in rank. Although toys garbage seemed to be not important in other households, it was exciting to find it few times in household two. Moreover, in this household, the moisture inside the garbage bin was observed with a shifting tendency, as shown in Fig. 10 , because participant used to collect and park garbage in a small disposal bag before disposing it in the smart garbage bin. This justifies the observation that the unclean package was identified as the first garbage content produced.
- **Household three:** On the contrary to the observation to household one and two where tissues garbage content was the second in rank, in household three, as shown in Fig. 16 tissue was ranked first as the most important garbage content, followed by other types of burnable garbage content. Food garbage contents ranked third, whereas unclean packages ranked fourth. The unclean cloth was the lowest in the rank as it was observed only once on 9-June throughout the experiment. Even though tissue contents are frequently disposed, the moisture inside the smart garbage bin was high as observed in Fig. 13; this proves the assumption that the tissues were slightly wet and also the food contents contributed to the rise of the moisture in a smart garbage bin

3) Routine behaviuor of garbage disposal: In addition, we have also learned the routine of garbage disposal by the households. In general, the study found that households can dispose of different types of garbage simultaneously and annotate all types of garbage content at the exact incidence. The study further observed that certain types of garbage content were frequently disposed of and annotated daily by the households. For instance, food garbage contents in household one, Unclean packages garbage content in household two and tissues garbage content in household three Fig. 14 to Fig. 16 thus, were identified as the most important type of garbage contents disposed by the household every day in the experiment.

C. Limitation of using SGBS

Apart from the attained objectives in this initial experiment, however, the study had some limitation and technical challenges in using the SGBS as follows;

- **An unimportant garbage content identification:** The study followed the burnable garbage manual to categorise the garbage content in the annotation app, yet some garbage contents were not important to be identified by household users, e.g. toys.
- **Wrong and forgotten garbage annotation:** Although from the observed data, households users were able to annotate the different types of garbage each time they dispose garbage. However, it was also possible for the household user to wrongly annotate the garbage content or forget to annotate the garbage because it was hard to know if the household annotated all types of garbage.
- **Garbage compression behaviour:** The compression of garbage in the smart garbage bin by the participant's hand during the disposal as one way of keeping the garbage bin from reaching its maximum thresholds shifts the values from its steady-state and disturbs both fill level and weight sensor readings.
- **Use several garbage bins:** Households often use several bins for different types of garbage; however, this initial study is based on burnable garbage only.

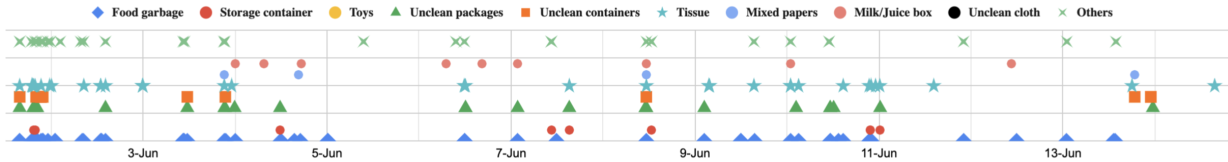

Fig. 14. Identified garbage contents in household one

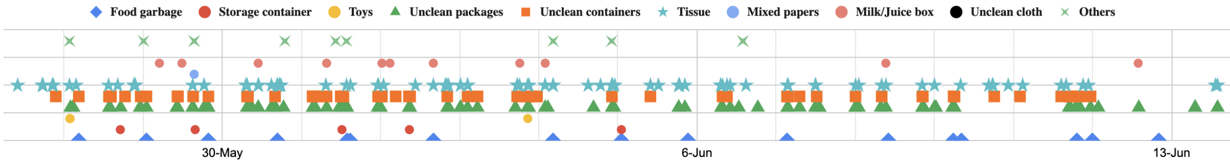

Fig. 15. Identified garbage contents in household two

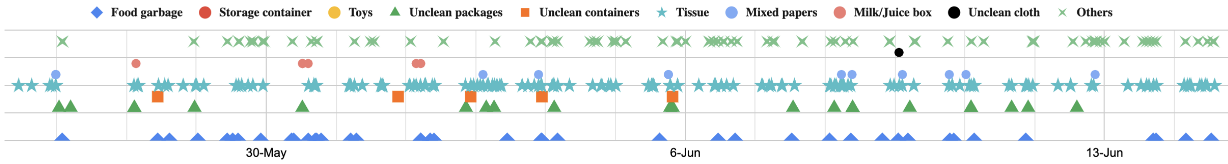

Fig. 16. Identified garbage contents in household three

D. Technical challenges

- **Power problem:** During the experiment, we faced a power supply problem. The used solar panel battery could not achieve the power supply for 29 days as it was approximated by our energy saving algorithm, unsteady it only supplied power to the smart garbage bin half of the expected only 13 days. Additionally, we also experienced some short circuits caused by the design of the circuit on a breadboard.
- **Network connectivity:** Although the used sigfox antenna showed good area coverage. Still, we experienced a message delay problem to our server, which persisted for some hours and sometimes changed the transmission interval from 10 minutes as pre-defined in the SGBS to 20 minutes time interval minutes. These technical challenges led to missing some data points in the households and also disturbed sensor readings.

V. Conclusion

This study aims to understand households' garbage disposal behaviour and further identify the type of garbage contents disposed. It is vital to learn the household behaviour on garbage disposal and identify the type of content and routine of disposing such garbage contents to influence behaviour change, provide healthier life, and improve garbage management operational efficiency. This study designed and developed the SGBS to tracking garbage amounts and identify the contents of garbage disposed. The observations from our initial study reveal that the amount of garbage has a strong relationship with human activities, including households eating and cooking habits. The study showed that households' garbage disposal behaviour depends on the amount and contents of garbage and the routine of disposing of such garbage content. Moreover, the categorization of garbage content helped identify an important type of garbage content for each household. Further, the study realized the household disposes a specific type of garbage contents more often than other garbage. In future, we will build a garbage content estimation model for households and further predict future garbage growth behaviour.

References

[1] S. Faye, F. Melakessou, and W. Mtalaa, "Swam: A novel smart waste management approach for businesses using iot," in *Proceedings of the 1st ACM International Workshop on Technology Enablers and Innovative Applications for Smart Cities and Communities*, 2019, pp. 38–45.

[2] J. Ferrer and E. Alba, "Bin-ct: Urban waste collection based on predicting the container fill level," *Biosystems*, vol. 186, p. 103962, 2019.

[3] S. Kristanto, T. Yashiro, and Koshizuka, "Dynamic polling algorithm for low energy garbage level measurement in smart trash bin," in *Proceedings of the Second International Conference on IoT in Urban Space*, 2016, pp. 92–94.

[4] M. A. Hossain, I. Ahmedy, M. Z. M. Harith, and M. Y. Idris, "Route optimization by using dijkstra's algorithm for the waste management system," in *Proceedings of the 2020 The 3rd International Conference on Information Science and System*, 2020, pp. 110–114.

[5] S. Idwan, I. Mahmood, J. A. Zubairi, and I. Matar, "Optimal management of solid waste in smart cities using internet of things," *Wireless Personal Communications*, vol. 110, no. 1, pp. 485–501, 2020.

[6] S. K. Memon, A. R. Memon, and A. A. Memon, "Smart garbage bin: An iot platform for smart waste management system in pakistan," in *2020 3rd International Conference on Computing, Mathematics and Engineering Technologies (iCoMET)*. IEEE, 2020, pp. 1–5.

[7] A. Lavric, A. I. Petrariu, and V. Popa, "Long range sigfox communication protocol scalability analysis under large-scale, high-density conditions," *IEEE Access*, vol. 7, pp. 35 816–35 825, 2019.

[8] E. Likotiko, Y. Matsuda, and K. Yasumoto, "Smart garbage bin: Garbage growth behavior prediction," *The 28th Multimedia Communication and Distributed Processing System Workshop (DPSWS '20)*, pp. 27–33, 2020.