An IoT Based Smart Waste Management System with Built-in Segregation Feature

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Abstract:

Many countries, including Kuwait, face significant difficulties in waste management, particularly in achieving effective waste segregation and recycling, which can be intricate and time-consuming. The widespread consequences of irresponsible waste disposal, such as pollution, have extensive impacts on public health and the environment. To tackle these challenges, the Smart Waste Management System (SWMS) has been developed as an innovative solution comprising of multiple stages. The first stage involves the detection of waste based on its type; the second stage involves allocating each waste into a specific chamber based on the type detected; and the third stage involves treating each type in the most effective way. Furthermore, the system creates a clean environment through the insulated chambers and the automatic inlet that locks when the chambers are full. In addition, the system uses IoT to provide vital information related to the system status such as temperature, level, and gas levels inside the chambers and notifies authorities with all this information. Finally, SWMS is a promising project with objectives that are aligned with New Kuwait 2035 vision by achieving sustainability goals.

Keywords: Smart Waste Management, New Kuwait 2035, Sustainability, Internet of Things (IoT)

1. Introduction

Pollution caused by waste is a pervasive issue that significantly impacts the quality of life and the environment. While its effects may not be completely apparent, risks caused by waste are a real presence that are raising flags and concerns from different parties. These risks are threatening the sustainability of the environment including humans, agriculture, animals, water, and air. According to a report by the World Bank, Kuwait's per capita waste generation is more than double the global average with an average of 1.55 kilograms of waste per person per day [1], emphasising the urgency for action to prevent further deterioration of the quality of life and to align with Kuwait's vision for 2035, which places sustainability as one of its primary objectives.

Background:

Kuwait, located on the Arabian Peninsula and bordering the Arabian Gulf, is a small country in the Middle East with an area of 17,818 km² and a population of 4.25 million inhabitants as of 2021 [2]. One-third of the population are Kuwaitis, while the majority are expatriates and foreigners. In 2017, the government of Kuwait has launched a new vision named "New Kuwait 2035" with strategic goals aligned with the UN's 17 SDGs. On of the main objectives is to "Improve standards of living for citizens" while one of the main pillars is to maintain a "Sustainable living environment." However, Kuwait currently faces serious environmental

challenges that act as obstacles for achieving sustainability goals related to maintaining a clean environment. According to the Arab Times Online, Kuwait ranks as the 8th most polluted city globally and the first in the Arab world [3]. The Kuwait News Agency (KUNA) website reported on September 12th, 2019, that plastic waste accounts for 18% of the total solid waste, or around 200,000 tons annually [4]. Like any country worldwide, Kuwait's rapid economic growth, development, and modernization each year is leading to an increase in solid waste generation in all its forms including plastics, electronics, metals, paper, organic, etc... In addition, as Kuwait is a high-income country with high gross domestic product (GDP) and power purchase parity (PPP) this leads as well to an increase in waste production. Therefore, without prompt action, Kuwait will continue to face significant challenges. The World Bank has declared that Kuwait's per capita waste generation ranks it second after UAE in the Gulf region [1].

Kuwait's per capita waste generation is significantly higher than the global average, with a daily output of 1.55 Kg compared to the worldwide rate of 0.74 Kg. Moreover, according to the data report of the Kuwait Central Statistics Office in 2018, Kuwait's solid waste is approximated by 1.7 million tons per year [5]. According to Kuwait's Official Environmental portal BEATONA, almost half of the generated waste in Kuwait is disposed in un-engineered landfills, through the process of backfilling [6]. Waste separation, recycling, and composting are only implemented on a small scale and based on an individual practice. This not only means the loss of great opportunities to benefit from the waste generated, but also has negative effects on our environment. Most of this waste is dumped in landfills which occupy around 45 km^2 and is predicted to increase to 60 km^2 by 2025 [7]. Currently, Kuwait has 18 landfills; 14 sites are permanently closed due to reaching full capacity and 4 are still in operation. However, with the increase of amount of waste being generated, more landfills are expected to open to accommodate this increase in production. These landfills accommodate all kind of mixed wastes including food, industrial, construction, and household waste and are becoming increasingly overcrowded over time, posing a significant issue. Moreover, these landfill sites are located near residential areas, such as Sulaibiyah, Kabed, Al Qurain, Shuaiba, Jleeb Al Shuyoukh, West Yarmouk, and Al Wafra; which raises environmental and health concerns regarding diseases, unpleasant odors, fires, explosions, and toxic gases.

In addition to these concerns, the need for recycling in Kuwait is also a missed financial opportunity. A study conducted in 2014 found that 76% of Kuwait's waste is recyclable. The potential value of the raw materials that could be salvaged from these landfills is estimated to be over KWD 39.88 million annually [7].

In the light of the above, and in alignment with the New Kuwait 2035 Vision, there is an urgent need to consider solutions that can segregate and treat waste on a small individual scale as well as through government support. Waste segregation is important because it can help the country efficiently manage its waste and reduce the environmental impact of its waste disposal practices. By implementing a smart waste management system that eases the process of waste segregation, Kuwait can save time and money in managing its waste and reduce the amount of waste sent to landfills. This can also help to reduce the environmental impact of waste disposals, such as air and water pollution, and mitigate the risks associated with the release of hazardous materials into the environment. This means that recyclable materials will already be sorted, making processing easier and more efficient. Additionally, it will reduce the need for manual labour and minimize the risk of contamination during the recycling process, resulting in a higher quality of recycled materials. With the ease of recycling, Kuwait can reduce its reliance on raw materials, conserve energy, and reduce greenhouse gas emissions [7]. This will

contribute to the country's sustainability goals and help to preserve its natural resources for future generations.

Problem Statement:

Our environment is at risk of contamination from pollutants, often caused by the irresponsible disposal of waste. The consequences of pollution are far-reaching, including the spread of diseases, fire hazards, unpleasant odors, and harm to various species, with significant and lasting impacts on our planet. The depletion of natural resources, soil contamination, and climate change resulting in rising sea levels and the disappearance of entire countries are some of the consequences of unchecked pollution.

Proposed Solution:

Waste management is the optimal solution that can help in partially solving the problem of waste generation in Kuwait. On the other hand, the process of waste management is a significant challenge for many countries, including Kuwait, where effective waste segregation and recycling can be complex and time-consuming. Therefore, a Smart Waste Management System (SWMS) offers an innovative solution to this problem and makes the process of waste management easier, efficient, and less time consuming. The SWMS is designed to make waste segregation and recycling more efficient, as the system segregates the waste at the beginning and then treats the waste based on the type of the waste detected which includes resizing and compression. Additionally, the SWMS is designed to motivate people to dispose waste responsibly, as it operates differently from traditional dumpsters, reducing bad odors and unsightly appearances.

The SWMS is also designed to create a hygienic environment, featuring insulated chambers and a closed port to input waste, reducing the risk of contamination from waste and improving overall cleanliness. The system is cost and time saving, as no labour is required to operate in the segregation process. Moreover, the system is IoT based which enables involved authorities to receive continuous vital information about the status of the system including the level of waste in the bins. In addition, it optimizes routes for waste collection and eliminates unnecessary visits to dumpsters that are not full. Accordingly, this has its positive impact on the environment as it reduces the amount of fuel being spend on unnecessary trips.

Furthermore, data collected from the SWMS and transmitted over the Internet through an application featuring the usage of IoT can provide information related to waste based on locations. This can improve waste management practices in the country, leading to a cleaner and more sustainable environment.

In summary, the SWMS offers an innovative and efficient solution to waste management in Kuwait, addressing the challenges of waste segregation and recycling while also creating a hygienic and sustainable environment. The system's capabilities to treat waste, motivate responsible disposal, optimize routes, and provide data insights makes it a promising solution for the future of waste management in Kuwait.

The Research Importance:

The importance of this research lies in the fact that pollution is a global issue that affects every living being on this planet. With the increasing population and urbanisation, the amount of waste generated is also increasing, directly impacting the environment. Implementing the SWMS can help reduce the negative effects of waste on the environment and improve public

health by promoting responsible waste disposal practices including recycling. Additionally, the system can provide cost and time-saving benefits, optimizing waste collection routes and reducing the number of emissions released from collection vehicles. Ultimately, the research aims to contribute to creating a sustainable future and preserving the environment for future generations.

Aims and Objectives:

This project aims to design and implement a fully automated state-of-the-art dumpster that can segregate the waste thrown into it. The system will automatically compress the waste after segregation, freeing up more space and sending a notification to the relevant authorities for collection. An IoT application will be used to monitor waste levels in each chamber, with temperature and humidity levels displayed, and the system will send an alert if a fire hazard is detected.

The objectives set within this project are firstly, to design and develop a fully automated dumpster that can segregate waste based on its type. Second, to develop a waste treating system that can compress the waste after segregation, allowing for more efficient use of space. Third, to create an application that can monitor the waste level in each chamber and the temperature and humidity levels inside the dumpster. Fourth, to promote waste segregation and motivate people to throw their waste in the designated place through creating a visually attractive design for the dumpster. Fifth, to create a hygienic and odor-free environment for waste disposal. Finally, to reduce the negative impact of waste on the environment by promoting recycling and efficient waste management.

The Expected Outcomes:

The proposed project SWMS aims to address the challenges faced by Kuwait's waste management system through developing a fully automated dumpster, capable of segregating and treating waste, and alerting authorities for timely collection. Overall, the proposed SWMS offers an innovative and efficient solution to waste management in Kuwait, which can lead to a cleaner and more sustainable environment, improved public health, and cost savings.

2. Methodology

The main idea of the SWMS proposed design is to integrate sensors used for detection of waste along with electromechanical actuators used for creating the mechanical movement needed in compression, sliding, opening of inlets. All these sensors and actuators are integrated with a microcontroller that stores the program required to implement the whole process. Moreover, an application is designed to receive the data collected from sensors.

System Hardware:

The body of the hardware is metallic with an inlet at the middle top face which accommodates the waste at the first level. The front face is made purposely of glass to enable users to see the process of segregation and treatment. Inside the system there are four bins each for paper, metal, plastic, and other. Each bin will only receive the waste based on the sensors' detection. The four bins lay on a sliding conveyor that aligns the designated bin exactly with the entry inlet based on the detected waste. On the top of every bin excluding the "Other Waste" bin has a vertical sliding plate that is used for compression. Only the "Plastic" bin is equipped with a fire gun that is used to reshape the plastic waste before compression. Figure 1 shows the interior and exterior layout of the SWMS prototype.

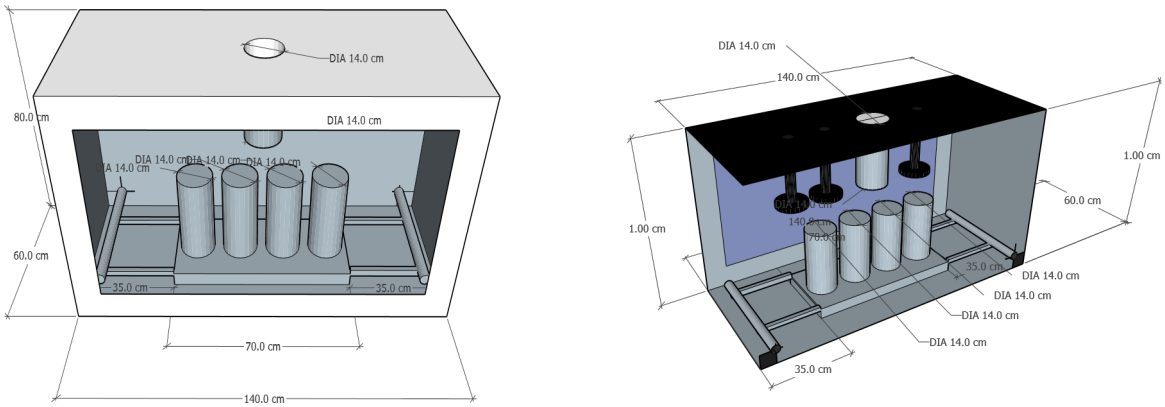

Figure 1: SWMS Layout

Waste Detection:

Initially, waste is inserted through the upper inlet. The waste initially goes into the stage of metal detection. A metal detector operated by one 9-volt alkaline battery with a coil that has a pre-set sensitivity level detects whether the waste is metal or not. If the metal detection is true, a powerful bipolar stepper motor of type 57STH56-2804B - 1.8 Degree – 2.8A - 77:1 Gearbox with a rear shaft and a gearbox that has a 0.023° step angle and 240 kg.cm of torque at low speeds, is used to move the track of a sliding conveyor that has the 4 chambers attached to it. The motor receives an order from the microcontroller to rotate with a specific angle that aligns the "Metal" bin with the top inlet tube. Accordingly, the bottom face of the inlet tube opens to allow the metallic waste to drop through the "Metal" bin. The mechanism of opening the top face and bottom face of the inlet tube happens through 2 stepper motors of type 42STH381684B - 1.8 Degree – 1.68A - 27:1 Gearbox. If the metal detection is false, a laser of output power 5mW, wavelength of approximately 650nm (red), and operating voltage between 3.3V to 5.0 V current < 40 mA is activated to identify if the object (waste) is of a paper source or plastic. After the waste is exposed to a laser light, photo-resistors (LDR) are placed in the opposite side to capture the amount of light passing from the object. Hence, the LDR will be activated to differentiate whether an object is plastic, paper, or other waste, as the detection of these components is light dependent. The laser light can pass objects that are transparent which indicates that the object is either plastic or glass and not paper. Accordingly, if a minimal amount of light is detected the object is determined as paper. If a high amount of light is detected, then a force sensor is activated to complete the identification process between plastic and glass or other waste. A strain gauge acting as a force sensor is activated at this point to obtain the final stage of detection. This strain gauge can convert up to 20 kg of pressure (force) into an electrical signal. Depending on the strain applied to the bar, each load cell may detect changes in electrical resistance that are proportionate to and responsive to that strain. To determine whether the item being tested is glass or plastic, the sensor is placed against the object using a DC motor. Accordingly, pushing the sensor against plastic items will detect less force as compared to glass or other objects.

Waste Treatment:

After the detection of the waste based on its type whether metal, paper, plastic or other waste including glass, each type of waste is dumped in the designated bin by the movement of the sliding track. At this stage, the treatment process is activated. Three relay modules are being used as an electrical switch to control three motors. The relay modules are connected to the Arduino microcontroller of type Mega. Based on the output signals from the sensors in the waste detection process, the designated motor is activated to start the treatment process through

the 4-channel module that requires simple wiring, uses less space and is cheaper. Each motor will use two relays making a total of eight relays that are used for the motors. The heater used in the plastic chamber/bin will require one relay. The motor in the metal, paper, and plastic chamber will activate a vertical top face that exerts force on the object leading to its compression in size. Only the plastic bin will have a heater activated to dimmish the size of the object prior to its compression.

Monitoring and Display:

The process of waste management inside the SWMS prototype is continuously monitored using temperature, humidity, level, and gas sensors inside the chambers. A DHT11 humidity and temperature sensor is used to detect whether there is fire (high temperature levels) or excess liquids (high humidity levels). Moreover, the gas sensor of type MQ135 is used to detect as well whether there is fire eliminating the chances of sending false fire alarms caused by only increased high temperatures. In addition, an ultrasonic sensor of type HC-SR04 is used to detect whether the chamber is full of waste.

All the data collected from these sensors is processed through the Arduino Mega microcontroller and displayed through two mediums. First, an LCD screen with I2C connector is used to display the data continuously. The LCD screen is mounted on the front face of the prototype. Second, the data is transmitted through an Arduino WiFi shield which allows the Arduino microcontroller board to connect to the Internet using the 802.11 wireless specification (WiFi). An application is designed to display the data for the user of these applications who can monitor the data remotely.

3. Results

After testing the prototype, the results were promising. Figure 2 shows the interior mechanism of the prototype. Figure 3 shows the vertical sliding plates used for compression in each chamber. Also, Figure 3 shows the sliding track that allows the movement of the bins/chambers to be aligned with the inlet tube. Figure 4 shows the body of the prototype and the back of it which is used to open the dumpster for emptying the bins. Figure 5 shows how an android application is used to display the data received from the SWMS.

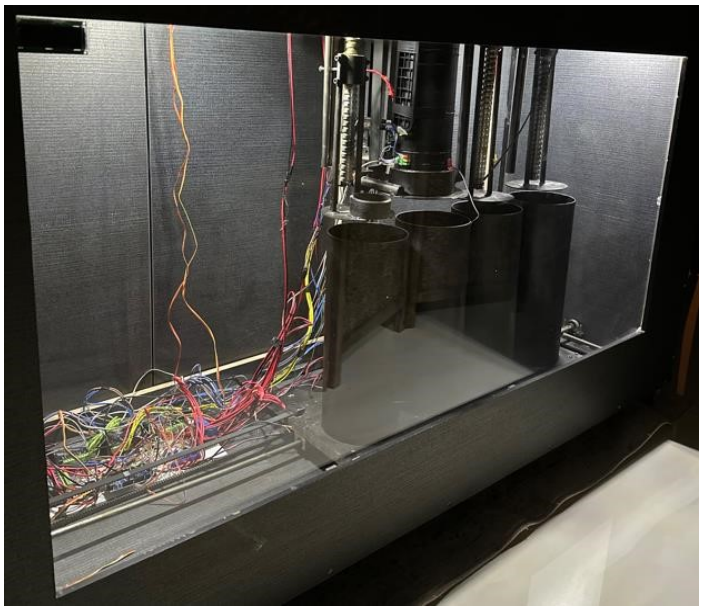

Figure 2: Interior Mechanism of SWMS

Figure 3: Compression Plates

Figure 4: Back of SWMS

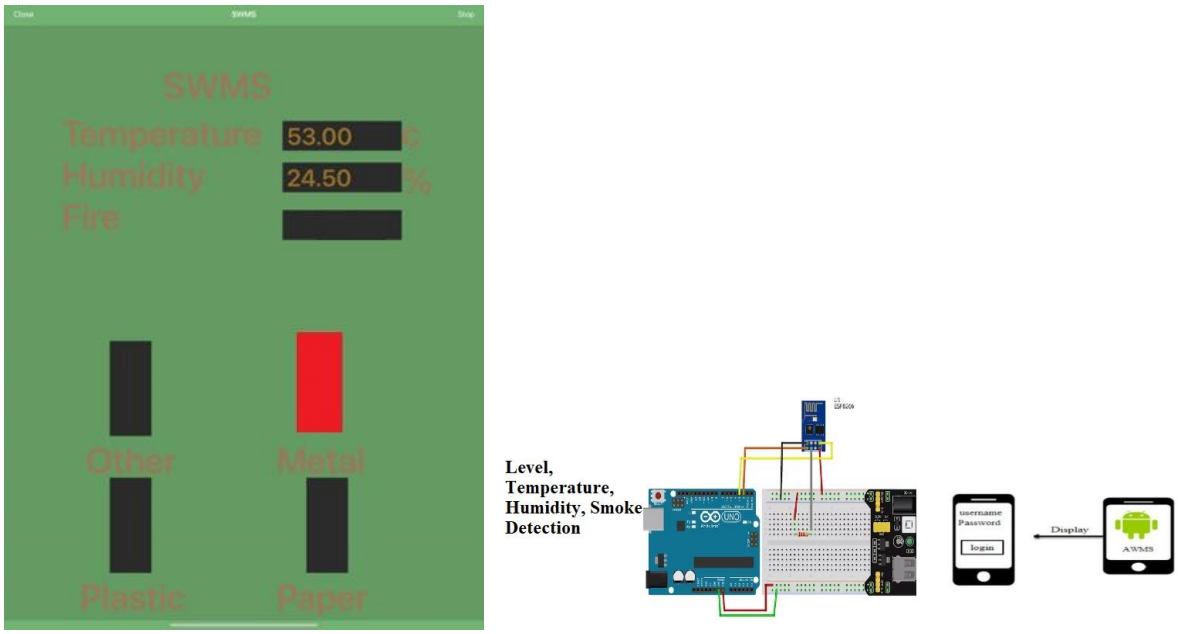

Figure 5: Application of SWMS

4. Conclusion

Waste management is a significant challenge for many countries, including Kuwait, where effective waste segregation and treating can be complex and time-consuming. The consequences of pollution resulting from irresponsible waste disposal are far-reaching and impact public health and the environment. The Smart Waste Management System (SWMS) is an innovative solution designed to address the challenges of waste management by treating different types of wastes through heating, and compression. Moreover, the system motivates people to dispose waste responsibly. The SWMS also creates a hygienic environment, featuring insulated chambers and a closed port to input waste, reducing the risk of contamination from waste and improving overall cleanliness. The system is cost and time-saving, optimizing routes for waste collection by notifying authorities when the chambers are full, reducing fuel usage, and lowering emissions. Data collected from the SWMS can provide insights into waste management practices, improving waste management practices in the country, leading to a cleaner and more sustainable environment. The proposed design is a fully automated dumpster that can segregate waste based on its type, treat the waste after segregation, and notify the relevant department when the dumpster needs to be emptied. Additionally, the proposed design creates an application that can monitor the waste level in each chamber, temperature, and humidity levels inside the dumpster, and includes a fire hazard detection system that alerts the relevant authorities if a fire hazard is detected. Moreover, the creative design of SWMS aims to motivate people to dispose waste responsibly, create a hygienic and odor-free environment for waste disposal, and reduce the negative impact of waste on the environment by promoting recycling and efficient waste management.

The proposed SWMS offers an innovative and efficient solution to waste management in Kuwait, leading to a cleaner and more sustainable environment, improved public health, and cost savings. The outcomes of this project can contribute to creating a sustainable future aligned with the New Kuwait 2035 sustainability goals and preserving the environment for future generations. By addressing the challenges of waste management in Kuwait, the proposed SWMS can serve as a model for other countries facing similar waste management challenges.

5. Limitations and Future Work

The proposed work has limitations that are yet to be looked at. This includes the type of waste being segregated. SWMS can detect plastic, metal, and paper while the rest of waste is dumped in a fourth bin which requires further segregation. Moreover, the system has been implemented on a small scale and more research and testing will be required in case the prototype is used to a large scale. Moreover, the system is powered through the grid; accordingly adding solar panels to the system can turn the prototype to be less dependent on the system power grid or completely off-grid. These limitations can be looked at in future work which may include as well multiple recommendations such as storing all the data into Cloud and make use of machine learning to predict the future of waste in Kuwait. **References**

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