

A Smart and Solar-Powered Solid Waste Segregator with Cloud-Based Wireless Monitoring System in a School Campus

Analene Montesines Nagayo¹, Eugene Vega², Omar Rashid Al Maqbali³, Ammar Yousuf Al Farsi⁴

Department of Engineering
Al Musanna College of Technology
Muladdah, Sultanate of Oman

¹analene@act.edu.om, ²eugene@act.edu.om,
³12S12331@act.edu.om, ⁴452S12329@act.edu.om

Rodrigo S. Jamisola Jr.⁵

Mechanical, Energy and Industrial Engineering Department
Botswana International University of Science and Technology
Palapye, Botswana

⁵jamisolar@biust.ac.bw

Abstract— This work presents the design and implementation of a smart and solar-powered solid waste segregation system using Arduino microcontroller interfaced with sensors, actuators, and Particle Photon cloud for wireless monitoring. The materials segregated are metal and non-metal that includes plastic, paper, and glass. Metal detection is done using inductive proximity sensor. Plastic is detected using infrared sensor based on shape and size. Laser and light dependent resistor (LDR) pair is used to detect paper. And lastly, glass bottles are detected using capacitive sensor. The prototype has an average percentage accuracy of 90.67% for sorting 30 assorted waste samples.

Keywords— Waste management, automation, control design, solar energy, cloud-based monitoring, electronic sensors

I. INTRODUCTION

Waste management is one of the concerns that countries needs to address at present due to the high waste generation rates and limited number of waste disposal sites [1]. According to the study conducted by Palanivel and Sulaiman [2], the daily solid waste generated in the municipalities of Oman is around 0.97 Kg/day/person by weight, 3.113×10^{-3} m³/day/person by volume with a density of 311.73 Kg/m³. Based on the data published by Zafar [3], municipalities in Oman generated about 1.6 million tons of solid waste in 2010 and continues to increase over the years. High percentages of these municipality solid wastes are biodegradable and recyclable materials [3]. In solving the problem of waste management and disposal, the initiative of recycling and segregation of waste should begin in homes, school campuses and offices [4].

Recycling is a resource recovery method which involves collection, sorting and reuse of waste materials such as glass bottles, plastic containers, tin cans and papers. One method of recycling is called single-stream recycling wherein all recyclable materials are placed in a single bin for collection, and the sorting is done at a central facility [5]. Recycling is done to reduce energy usage, limit filling up landfills, lessen air and water pollution, minimize greenhouse gas emissions and preserve natural resources for future generations [6],[7]. For these reasons, a solar-powered solid waste segregation system (SWSS) with cloud-based wireless monitoring was designed and implemented.

This research promotes the use of modern engineering technology in waste management to keep a clean and green campus environment. This project allows waste collection and segregation with minimum human intervention for sanitation and health safety. Furthermore, this eco-friendly system is powered up by a renewable energy source in form of solar energy.

In this paper, Section II cites the current developments in the design and implementation of solid waste segregation system. Section III describes the design, set-up and implementation of the solar-powered solid waste segregator with cloud-based wireless monitoring system. In Section IV, the experimental data are presented to show the performance of the designed system in promoting environmental sustainability in Al Musanna College of Technology (ACT) campus. Lastly, Section V concludes the paper and recommends the possible improvements in the designed system for large-scale waste management. A demo video of the system can be seen here: https://youtu.be/qgB_9oPyliY.

II. CURRENT DEVELOPMENTS IN THE WASTE SEGREGATION CONTROL AND MONITORING SYSTEM

The need to automatically control and constantly monitoring segregation system for environmental sustainability is extensively studied. Waste segregation process may be implemented using radio-frequency identification (RFID) [9]-[11], programmable logic controller (PLC) [12]-[14] and microcontroller [15]-[19].

Several RFID and sensor models were developed for smart waste management system, including automatic waste sorting, weight classification and stolen bin identification. [9]-[11]. In an RFID-based segregation system, each waste material has an RFID tag that stores the information about the object which travels on a conveyor belt [12]. Whenever waste comes near the RFID reader, it sends the vital information to the RFID reader. This information is conveyed to the microcontroller for sorting process and releasing the waste material in its proper bin. The drawbacks of this kind of system are as follows: (a) cost of using RFID tag in consumer products and (b) dissipation of toxic and/or valuable substance present in RFID tags [10].

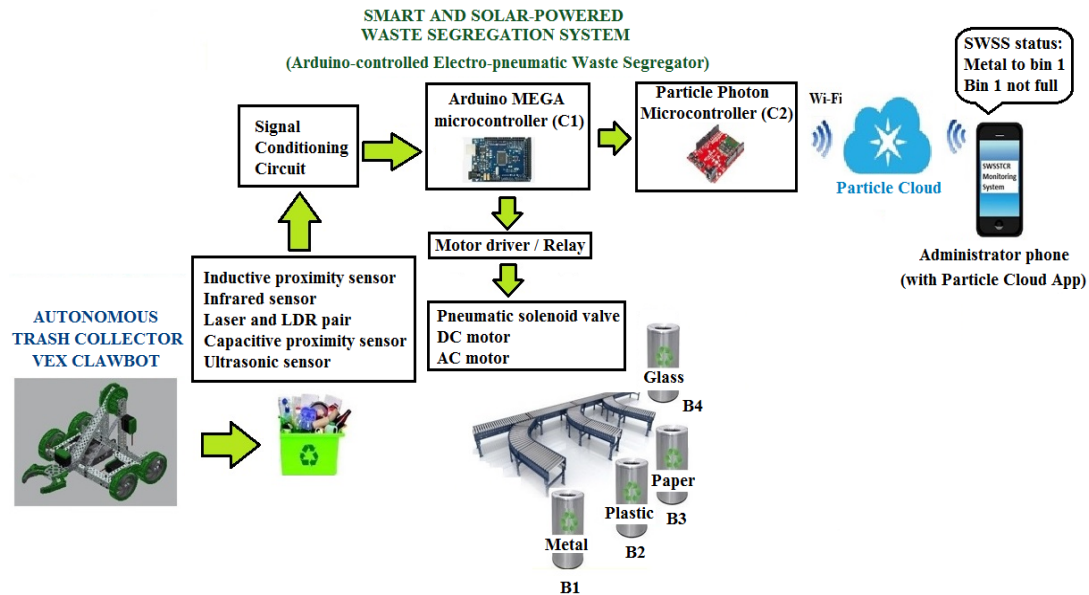


Fig. 1. Over-all block diagram of the solid waste segregation control and monitoring system

A higher level of automation such as industrial and commercial waste segregation process can be designed and implemented using programmable logic controllers (PLC) [12]-[14]. The PLC-based waste segregation system consists of the following: (a) controller which acquires the digital and analog data from an input module and produces an output based on the input conditions in real-time; (b) action performing component such as rotating conveyor belt and pneumatic cylinders which require the application of energy to drop the waste object into its correct bin; and (c) sensors which are used to detect the presence of the object on the conveyor belt, detect the type of object to be sorted, and signal the PLC to start the conveyor [12],[14]. PLC-based systems are reliable, rugged and tough to fit industrial environment. However, it is costly and requires higher power than microcontroller-based system.

In waste segregation system using microcontrollers such as PIC [15],[17], 8051 [16] and Arduino [18],[19], the operation and synchronization of all the subcomponents to sort the waste materials are controlled by the microcontroller [12]. It receives the signals from various sensors, actuates the solenoid valves connected to a door that opens, and distributes the waste to its correct recycle bin [15]-[19]. This type of system has smaller size, low cost and low power requirement.

Wireless monitoring of the sorting activities may be IoT-based [18]-[21], Zigbee-based [22] or GSM-based. Zigbee-based monitoring has limited area of coverage and less secured than IoT-based system. In reducing the cost of monitoring the waste segregation system performance and increasing the system's accessibility, Nagayo and Jamisola [23] recommended the use of Wi-Fi technology and cloud data storage instead of GSM technology.

III. SOLAR-POWERED WASTE SEGREGATION CONTROL AND MONITORING SYSTEM DESIGN CONSIDERATIONS

A. Block Diagram of the Solid Waste Segregation Control and Monitoring System

Based on Fig.1, the solid wastes are dumped by a trash collecting robot to the elevator conveyor which will transfer the trash to the electro-pneumatic segregation system. Then, trashes are passed one by one through the sensor array via the horizontal belt conveyor. Inductive proximity sensor is used to identify empty aluminum cans, infrared proximity sensor is used to detect empty plastic bottles, laser-light dependent resistor (LDR) pair is used to detect papers, capacitive proximity sensor is used to detect clear glass bottles and unclassified wastes are dispensed at the end of conveyor belt by the process of elimination. Arduino microcontroller (C1) receives the signals from the sensors, activates the pneumatic solenoid valves connected to a flap door that opens, and dispenses the trash to its appropriate recycle bin. Particle Photon cloud-based wireless monitoring system is also designed to monitor events in the waste segregator. The whole system works on the concept of a renewable energy source which is solar energy.

B. Design and Assembly of the Solid Waste Segregation System (SWSS) Mechanism

The design of the solid waste segregation system is based on the process flowchart shown in Fig. 2. From the flowchart, the necessary components of the system were identified by the researchers.

1) Electro-pneumatic System

Electro-pneumatic systems combine pneumatic and electrical technologies into one system where the control medium is the electrical signal and the working medium is the compressed air [24]. In this system, relays and solenoid valves are used to interface electrical control with pneumatic action. The schematic diagram of the pneumatic system and its components are shown in Fig. 3 and Table I. The components of the pneumatic system are specified in Table I.

TABLE I. COMPONENTS OF THE PNEUMATIC SYSTEM

air compressor	12 V DC, 120 psi with tank
pneumatic cylinder	Single acting spring return 15 mm bore x 75 mm stroke
directional control valves	Pneumatic solenoid 3/2 way, spring return, 24 V DC
working pressure	30 psi

TABLE II. HORIZONTAL BELT CONVEYOR SPECIFICATIONS

Length	1500 mm
Width	100 mm
Roller diameter	65 mm
Motor power	60 W
Speed	30-180 mm/s

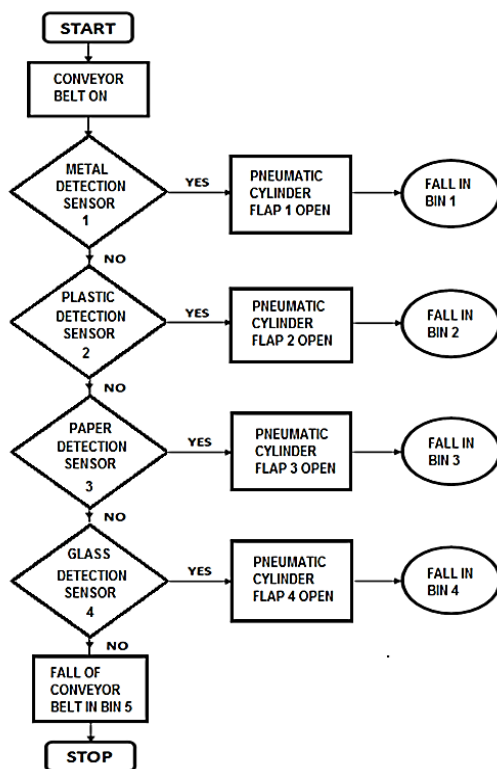


Fig. 2. Solid waste segregation system process flow

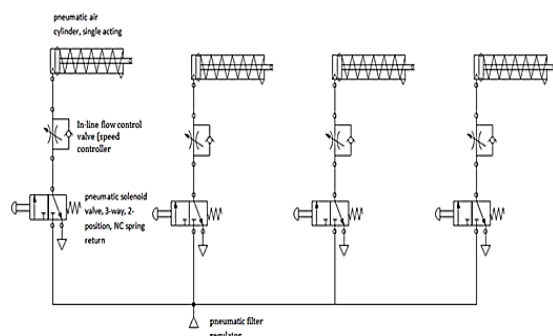


Fig. 3. Schematic diagram of the pneumatic system

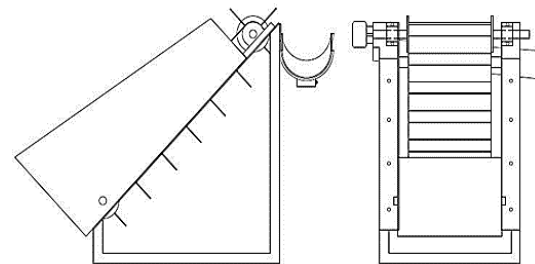


Fig. 4. Design of elevator conveyor with bins and vibrating chute

2) Horizontal Belt Conveyor

The horizontal belt conveyor, installed with swinging pneumatic doors was designed based on the following user requirements:

- (a) It should carry all wastes with 1.0 kg maximum.
- (b) It should be able to convey common sizes of aluminum soda cans, plastic bottles, glass bottles and tea cups.
- (c) It should have control speed.

The final horizontal belt conveyor specifications are shown in Table II.

3) Elevator Conveyor

The design of the elevator conveyor is shown in the Fig. 4. The width is 500 mm and the total length is 700 mm. The elevator is fitted with belts with ridges that runs over two pulleys. The ridges in the belt will serve to separate the waste one by one with each waste falling horizontally between the ridges. The angle of the belt is 45 degrees. Wastes which will not fall horizontally between the ridges falls back by gravity to the bottom of the bin where they are reoriented by the rotating belt. The pulleys are driven by a 40W low speed geared DC motor. Since the elevator cannot drop the waste directly into the horizontal conveyor and the problem posed by the metal sensor required to be in contact with the waste, a vibrating cylindrical chute is considered which will convey the waste from the elevator to the belt of the segregator.

C. Control System of the Solid Waste Segregator

Referring to Fig.1, the trash collecting robot dumps the wastes in the elevator conveyor which will transfer the trash to the horizontal belt conveyor. Ultrasonic sensor is used to detect the presence of waste in the elevator conveyor. The signal from the sensor allows the Arduino microcontroller (C1) to synchronize the operation time of the conveyors. As the solid waste reaches the electro-pneumatic segregation system one at a time, it passes through various sensors for sorting.

The first sensor that the waste touches is the inductive proximity sensor which determines if the object is metal or not. If the output of the inductive proximity sensor is 0 V, metallic waste like aluminum can is detected. Door 1 (D1) will open and metal can will fall in garbage bin 1 (B1). If it is not a metal, the trash will be transferred by the conveyor belt to second sensor area wherein infrared (IR) sensor is used to detect if the object is a plastic bottle or not. Plastic bottles were detected by the IR sensor based on their size and shape. If IR sensor output ranges from 490 to 520, the trash detected is a plastic bottle. Door 2 (D2) will open and plastic bottle will fall in garbage bin 2 (B2); otherwise, the trash will go to third sensor zone which consists of laser and light dependent resistor (LDR) pair. The LDR will sense the intensity of the light produced by the laser. If the LDR reading is greater than or equal to 3 V, it means paper waste is detected. Consequently, door 3 (D3) will open and paper will fall in garbage bin 3 (B3). For glass waste detected by the capacitive sensor, it will fall in garbage bin 4 (B4). Any unsorted waste item goes to garbage bin 5 (B5) at the end of the conveyor.

The microcontroller C1 generates digital output signals to indicate the status of each door and which trash bin receives the waste. Ultrasonic sensor installed on top of each garbage bins is used to determine if the bin is full or not. If the reading of the ultrasonic sensor is less than 2cm, it means the trash bin is already full. The microcontroller C1 also produces digital output signals to indicate the status of each trash bins.

D. Monitoring System of the Solid Waste Segregator

Particle Photon cloud-based wireless monitoring system is designed to monitor events in the waste segregator and to monitor if the garbage bins are full or not. Particle Photon microcontroller (C2) reads the digital signals generated by Arduino microcontroller (C1) indicating the status of the doors and trash bins. The events in the SWSS are published on the Particle Cloud which the administrator can access using his mobile phone.

E. Solar Energy Conversion Station for the Solid Waste Segregation System (SWSS)

The SWSS is powered-up reliably for 8 hours daily. During its operation the horizontal belt conveyor, elevator conveyor, switch-mode power supply and air compressor are activated. With these conditions, the AC power requirement of the SWSS is computed as 402 Watts and the total energy requirement per day after correction factor is 3,344.64 Watt-hours. Considering the calculated solar energy needed daily, two (2) 300 W, 28 V PV panels and two (2) 12V, 200 Ah deep-cycle batteries are utilized, which are designed to be discharged at 25% to extend the battery life. A 30 A, 24 V PWM solar charge controller is used to match the ratings of the batteries. To provide a 220

Vrms AC output, a 1000 W inverter with 24 V DC input is utilized for the system. According to A.M. Nagayo and R. Jamisola [23], the inverter power rating should be 25% to 30% greater than total wattage of the load and its DC input voltage should match the voltage of the battery bank. The connection diagram for the solar energy conversion station of the SWSS is shown in Fig. 5.

IV. EXPERIMENTAL DATA AND ANALYSIS OF RESULTS FOR THE SOLAR-POWERED SOLID WASTE SEGREGATION SYSTEM

A. Experimental Set-up and Test Results of the Control and Monitoring System for the Solid Waste Segregation System

Prior to the actual testing, the sensors attached to the microcontrollers of SWSS such as inductive proximity sensor, infrared sensor, LDR, capacitive proximity sensor and ultrasonic sensor were calibrated to perform task precisely. To determine the optimum speed of the horizontal belt conveyor, the response time and reliability of SWSS in sorting thirty (30) assorted waste materials were noted down in Table III for five (5) different speed settings (S1 to S5). Based on the results, the designed waste segregator has an average percentage accuracy of 90.67% for sorting 30 assorted waste samples. The optimal speed of the horizontal belt conveyor with minimal failure rate is S4.

The ability of the elevator conveyor to separate the wastes and feed into the SWSS one by one is tested by dumping the wastes together in the bin of the elevator and recording how many wastes are separated accordingly. The results are as shown in Table IV with a 100% success rate for separating metals, 89% success rates for separating plastic and paper wastes, and 78% success rate for separating glass bottles. The failure rates were due to the position of wastes as they are dumped into the bin, as well as the size and weight of the waste materials.

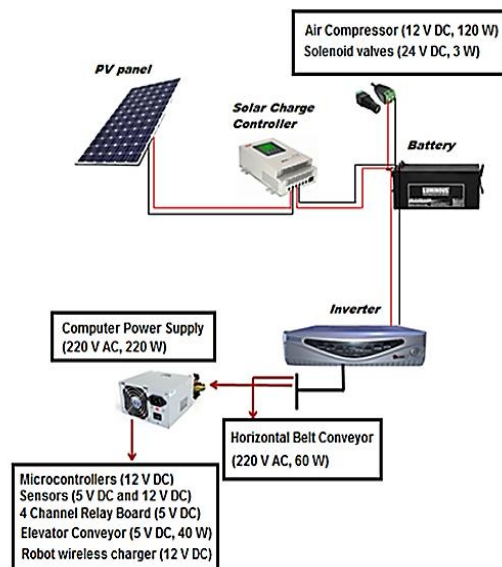


Fig. 5. Connection diagram of the solar energy conversion station of the solid waste segregation system

The reliability and response time of the SWSS in sorting the trash properly with the horizontal belt conveyor speed set at S4 are shown in Table V. The smart solid waste segregation system completed the task of sorting 30 assorted waste materials in a time of 1 minute and 45 seconds with a sorting success percentage of 96.67%. Based on the observations, the common causes of errors in the sorting process are as follows: (a) friction between the object and the conveyor belt, (b) the material is stuck at the door due to its size or position, (c) timing synchronization, and (d) glass wastes material is not a transparent glass which is one of the limitation of the system. The actual waste segregation system and its sorting process is shown in Fig. 6 and Fig. 7.

For monitoring purpose, the events or occurrences happening in the SWSS are published in the Particle Cloud. The administrator can access the data anytime using mobile phone by logging in to his/her Particle Cloud account. Fig. 8 shows a sample published events for SWSS in the Particle Cloud.

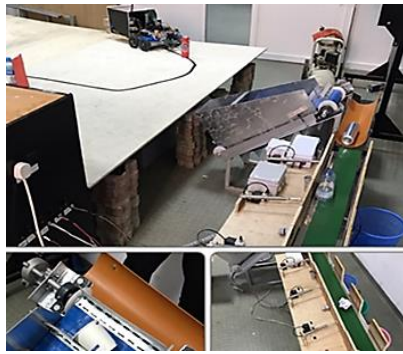


Fig. 6. Actual set-up of the solid waste segregation system

TABLE III. RESPONSE TIME AND RELIABILITY OF SWSS FOR FIVE (5) DIFFERENT SPEED SETTINGS

Speed setting	Total Number of Solid Waste Materials	Total Number of Items Sorted Successfully	Total Time to Complete the Segregation Process in seconds	Sorting Success Percentage
S1	30	25	2 min and 32 sec	83.33%
S2	30	26	2 min and 16 sec	86.67%
S3	30	28	1 min and 59 sec	93.33%
S4	30	29	1 min and 45 sec	96.67%
S5	30	28	1 min and 31 sec	93.33%

TABLE IV. DATA AND RESULTS FOR THE ELEVATOR CONVEYOR

Type of waste	Trial	No. of waste	Total Number of Items Separated Successfully	Success Rate %	Total success rate %
Plastic water bottle	1	3	2	67	89
	2	3	3	100	
	3	3	3	100	
Paper tea cup	1	3	3	100	89
	2	3	2	67	
	3	3	3	100	
Soda can	1	3	3	100	100
	2	3	3	100	
	3	3	3	100	
Glass bottle	1	3	2	67	78
	2	3	2	67	
	3	3	3	100	

TABLE V. DATA AND RESULTS FOR THE SWSS WITH HORIZONTAL BELT CONVEYOR SPEED SET AT S4

SN	Solid Waste Items	Total Number of Solid Waste Materials	Total Number of Items Sorted successfully
1	metal	7	7
2	plastic	9	9
3	paper	9	9
4	glass bottle	5	4



Fig. 7. Sorting process of the solid waste segregation system

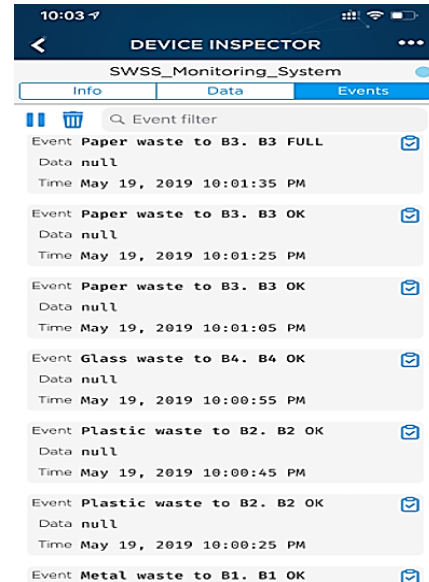


Fig. 8. Sample published events for SWSS in the Particle cloud

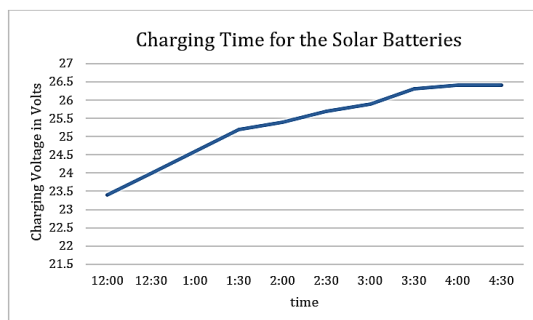


Fig. 9. Charging time of the deep-cycle batteries



Fig. 10. Solar power conversion system for the solid waste segregator

B. Experimental Set-up and Test Results of the Solar Energy Conversion Station

For testing the deep-cycle batteries, the solar panel was connected to charge controller, then the charging time of the deep-cycle batteries were taken as seen in Fig. 9. The actual Solar Power Conversion System for the Solid Waste Segregator is shown in Fig. 10. With the solar energy conversion system design, the SWSS operates continuously for more than 8 hours daily.

V. CONCLUSION

The current developments in the design and implementation of waste segregation system are presented in this paper with one common goal which is to sort recyclable waste to its appropriate bins to achieve a clean and green campus environment with minimum human intervention. A smart and solar-powered solid waste segregation system (SWSS) was designed and implemented to sort out four (4) different types of solid waste materials, then distribute each trash to its proper recycle bin. With the sensor-based segregation method, the spacing, position and size of the wastes passing through the horizontal conveyor belt plays an important part in determining the accuracy of the system. With respect to the transferring of wastes from the elevator conveyor to the SWSS area,

singulation of the waste materials plays a critical part in controlling the flow of waste to the sensor array. Based on the results, the maximum sorting percentage of the system is 96.67% with a time of 1 minute and 45 seconds to complete the task of sorting 30 assorted waste items. Internet of things (IoT) technology and cloud data storage are utilized instead of GSM to reduce the cost of monitoring of the SWSS and increase accessibility to the system's activities. The solar power conversion set-up supplies electricity to the SWSS within the specified operating hours even when all loads are turned on.

For a large-scale waste facility, the following may be done as future directives: (a) use of alternative sorting methods such as image processing or X-ray imaging as suggested by H. Jiu et al. [25]; (b) modifications in the design of elevator and horizontal conveyors, as well as additional sensors may be added as future directive for better timing synchronization, better singulation and faster sorting process while maintaining a high sorting percentage.; (c) integrate wet and food waste sorting using moisture sensor, methane sensor and other gas sensors [17]; and, (d) incorporate waste to electrical energy generation method in the system [17].

ACKNOWLEDGMENT

Special thanks to Al Musanna College of Technology (ACT) for the full support given to this multi-disciplinary project, and The Research Council (TRC) of Oman for funding major part of this project. Thanks to SWSSTCR team members: Cesar Mendoza, Bindu P.V., Mazna Said Hamdan Al Saidi, Ali Khamis Ali Al Kharusi, Ammar Said Al Hosni, Tasnim Khasif Al Mughaizwi, Raja Muhammed Al Rawahi, Emanuel Rances, Jefferson Zason, Rolando Cabais, Alex Boral, Jorge Ramos, Ericson Recamata for all their support and cooperation.

REFERENCES

- [1] L.A. Guerrero, G. Maas, W. Hogland, "Solid waste management challenges for cities in developing countries," *Journal of Waste Management*, 33(1), 220-232, 2013
- [2] T.M. Palanivel and H. Sulaiman, "Generation and Composition of Municipal Solid Waste (MSW) in Muscat, Sultanate of Oman," *APCBEE Procedia*, Vol. 10, Pages 96-102, 2014
- [3] Zafar, S. (2014). *Waste Management Scenario in Oman*. [Online] Available: <http://www.bioenergyconsult.com/waste-oman> [Accessed: March 2, 2016]
- [4] Shammass, M. E. *The Report of the Sultanate of Oman on Solid Waste Management*. [Online] Available: <http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-17/oman2.asp> [Accessed: March 3, 2016]
- [5] Lakhan, C., "A Comparison of Single and Multi-Stream Recycling Systems in Ontario, Canada," *Resources* 2015, 4(2), 384-397, 17 June 2015
- [6] R.P.Bagozzi and P.A.Dabholkar, "Consumer recycling goals and their effect on decisions to recycle: A means-end chain analysis," *Psychology & Marketing*, 11(4), 313-340, 1994
- [7] J. Heimbuch (2011). *Trash Sorting Robot Could Reduce Waste Going to Landfill by 50%*. [Online] Available: <http://www.treehugger.com/clean-technology/trash-sorting-robot-could-reduce-waste-going-to-landfill-by-50.html> [Accessed: June 4, 2015]

- [8] M. Joubert (2013). *National Strategy for Waste Management*. [Online] Available: <http://omanobserver.om/national-strategy-for-waste-management> [Accessed: March 2, 2016]
- [9] M. Arebey, M. A. Hannan, H. Basri, R. A. Begum and H. Abdullah, "Solid waste monitoring system integration based on RFID, GPS and camera," *2010 International Conference on Intelligent and Advanced Systems*, Manila, 2010, pp. 1-5.
- [10] S. Abdoli, "RFID Application in Municipal Solid Waste Management System," *International Journal of Environmental Research*, 3(3), 447-454, 2009
- [11] B. Chowdhury and M. U. Chowdhury, "RFID-based real-time smart waste management system," *2007 Australasian Telecommunication Networks and Applications Conference*, Christchurch, 2007, pp. 175-180.
- [12] S. Dwivedi, M. Fernandes and R. D'souza, "A Review on PLC based Automatic Waste Segregator," *International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)*, vol.5, no. 2, 280-285, 2016
- [13] P. Elamurugan, K. Vinobresnav, D. Abirami, K.G. Suardham, "Automatic Material Segregation Using PLC," *International Journal of Engineering and Technology*, 7(2.24), 376-380, 2018
- [14] R. M. Kittali and A. Sutagundar, "Automation of Waste Segregation System using PLC," *International Journal on Emerging Technologies*, 7(2), 265-268, 2016
- [15] F. G. Ang, M.K.A. Gabriel, J. Sy, J. J. O. Tan and A. C. Abad, "An Automated Waste Sorter with Mobile Delivery Waste System," presented at 2013 DLSU Research Congress. DLSU, Manila, 2013
- [16] M. K. Pushpa, A. Gupta, S. M. Shaikh, S. Jha, S. V., "Microcontroller Based Automatic Waste Segregator," *International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering*, vol. 3, no. 5, 104-108, 2015
- [17] R. Rajkamal, V. Anitha, P. G. Nayaki, K. Ramya and E. Kayalvizhi, "A novel approach for waste segregation at source level for effective generation of electricity — GREENBIN," *2014 International Conference on Science Engineering and Management Research (ICSEMR)*, Chennai, 2014, pp. 1-4.
- [18] S. Suryawanshi, R. Bhuse, M. Gite and D. Hande, "Waste Management System Based on IoT," *International Research Journal of Engineering and Technology*, 5(3), 1835-1837, 2018
- [19] A.M. Nagayo, M. S. H. Al Saidi, O. R. Al Maqbali, A. Y. Al Farsi, A. K. Al Kharusi, A. S. Al Hosni, T. K. Al Mughazwi, R. M. Al Rawahi, "A Smart Solar-powered Waste Segregation System with Integrated Self-driving Robot Collector towards Environmental Sustainability in School Campus," presented at the National Research Forum, TRC, Sultanate of Oman, December 2017, unpublished.
- [20] V. S., P. S., & S. H. J. R., "Smart Waste Segregation and Monitoring System using IoT," *International Research Journal of Multidisciplinary Technovation*, 1(3), 1-10, 2019
- [21] I. Hong, S. Park, B. Lee, J. Lee, D. Jeong, and S. Park, "IoT-Based Smart Garbage System for Efficient Food Waste Management," *The Scientific World Journal*, vol. 2014, Article ID 646953, 13 pages, 2014
- [22] V. M. Kantila and A. P. Lakhani, "Zigbee based Wireless Monitoring and controlling of Automation System using PLC & SCADA," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 3(1), 6768-6775, 2014
- [23] A. M. Nagayo & R. Jamisola, "Cloud-based Wireless Monitoring System and Control of a Smart Solar-Powered Aquaponics Greenhouse to Promote Sustainable Agriculture and Fishery in an Arid Region," *2017 BIUST Research & Innovation Symposium (RDAIS)*, Palapye, Botswana, 2017, pp. 144-151
- [24] *Electro-Pneumatic System in Action*. [Online] Available: <http://www.library.automationdirect.com> [Accessed: October 1, 2016]
- [25] J. Huang, T. Pretz and Z. Bian, "Intelligent solid waste processing using optical sensor based sorting technology," *2010 3rd International Congress on Image and Signal Processing*, Yantai, 2010, pp. 1657-1661A.
- [26] B. R. S. Kumar, N. Varalakshmi, S. S. Lokeshwari, K. Rohit, Manjunath and D. N. Sahana, "Eco-friendly IOT based waste segregation and management," *2017 International Conference on Electrical, Electronics, Communication, Computer, and Optimization Techniques (ICEECOT)*, Mysuru, 2017, pp. 297-299.