engineering proceedings

MDPI

Proceedings

IoT-Based Framework for Smart Waste Monitoring and Control System: A Case Study for Smart Cities †

Sani Abba * and Chinaka Ihechukwu Light

Department of Mathematical Sciences (Computer Science), Faculty of Science, Abubakar Tafawa Balewa University (Federal University of Technology), Yelwa campus, Dass road, Private Mail Bag (P.M.B.) 0248, Bauchi state, Nigeria; chinakalight@googlemail.com

* Correspondence: saniabba2004@ieee.org; Tel.: +234-0811-9717-843

† Presented at the 7th Electronic Conference on Sensors and Applications, 15–30 November 2020; Available online: https://ecsa-7.sciforum.net/.

Published: 14 November 2020

Abstract: Environmental sanitation is very essential for healthy living. In our daily livelihood, garbage bins are usually kept without proper monitoring until they are filled to the point of overflowing onto the surroundings and spilling out, resulting in environmental pollution, which has serious health-related issues to human beings and the environment. For smart cities, garbage bins need to be monitored and controlled to ensure a healthy and clean environment. In the present technological advancement, real-time monitoring and control of waste disposal is a challenging area that needs urgent attention by the research community. The traditional approach of monitoring waste in garbage bins placed in strategic locations is a very tedious and inefficient way that consumes time, human effort, and cost, and this is also not in agreement with smart city requirements. This research paper presents the design and implementation of an internet of things (IoT) based Arduino microcontroller working with the ultrasonic sensors that detects the level of waste in the garbage bin placed in garbage locations and constantly at regular intervals display the status information as "filled", "half-filled", or "empty" on an LCD screen, as well as send the content level information at those intervals to a central web-server system that displays the garbage bin levels graphically. This is achieved using a microcontroller, a Wi-Fi module, and ultrasonic sensors. The programming of the Arduino Uno microcontroller was done with an Arduino IDE and embedded C programming language. The communication with the web server was done using the hypertext preprocessor PHP scripting programming language. The prototype was designed and simulated using Proteus 8.0 professional simulation software. This process helps to automate garbage bin monitoring and control. Experimental results demonstrate a promising solution to waste management and control. A number of testing runs were performed to evaluate the device workability in real situations. The measured distances from the garbage bins were transmitted to a website; this web page performs analytic and visualization and displays a bar chart showing the levels of the garbage waste, time, and location in real time for viewing. The proposed prototype is an innovative system that will help to keep the smart cities clean and tidy using ultrasonic sensors.

Keywords: ultrasonic sensors; smart waste monitoring and control; Internet of Things (IoT); smart cities; waste bins

1. Introduction

At the present time, our environment is being polluted by massive deposits of global waste. This will have a catastrophic effect on human life and the surroundings. It was anticipated that the global waste will grow by 70% by 2050 unless immediate necessary measures of monitoring and control are put in place, according to the World Bank report [1]. In addition, due to high increase in global

population and urbanization, the volume of waste produced globally is expected to rise to 3.4 billion tons within the next three decades. The use of modern and innovative technologies will pave the way for a better monitoring and control of waste as compared with the traditional approach, which makes use of human labor, garbage bins, and disposal trucks.

Garbage is an unwanted material, such as rubbish or waste, that is disposed from homes, cities, public centers, schools, markets, industries, etc. It is regarded as waste material that is discarded by humans, mainly due to lack of utility. The rapid increase and buildup of waste in our society has a serious concern, especially when monitoring and control measures are not properly maintained [2].

In smart cities where environmental pollution is supposed to be graciously reduced, sanitation measures are vital, and cleanliness begins with providing garbage bins for waste disposal at strategic locations. The real-time monitoring and control of garbage bins placed in strategic locations and disposal at the final destination is very essential [3].

The high increase in industrialization and human population resulted in higher levels of garbage generated in urban areas. Therefore, the number of garbage bins need to be increased and placed in strategic locations for real-time monitoring and collection to save the environment. Without the proper collection and disposal of the waste, the garbage bins would be filled up or overfilled and spill out onto the surrounding, which can cause health-related problems to human beings and the environment [4].

As the volume of solid waste increases rapidly, waste management is becoming a big challenge to the authorities and governments handling them, and therefore it becomes imperative to tackle the problem using modern technologies to provide the needed solution [5]. This research paper presents an innovative system that will help to keep the cities clean by implementing a system that would monitor and control garbage bins levels, and provide real-time communication between the garbage bins and the garbage collection personnel (truck driver) via an organized web-based system depending on the status of the garbage bins. This approach will help to keep smart cities clean and hygienic for better living.

This research paper aims to overcome the shortcomings of the previously reported works. The previous approaches did not allow for real-time monitoring and control of the garbage bins levels and did not have a central monitoring and control system where the data or information regarding the garbage bin will be sent to for proper decision making by the concerned authorities responsible for waste control and management. Furthermore, this research paper aims to provide a better solution to the stated problem by creating a central system that collects these data and then smartly displays the graphical information of the levels of the garbage bins so that the authorities can make real-time and cost-effective decisions that would be beneficial to all and ultimately keep the environment clean.

This research paper is an innovative system that will help to keep the smart cities clean and tidy. The proposed system monitors garbage bins and informs users about the level of garbage collected in the garbage bins via a web page. The system makes use of ultrasonic sensors placed over the bins to detect the garbage level and compares it with the garbage bin's depth. A web page is built to display the status information to the end users. The web page gives a graphical view of the garbage bins and highlights the garbage collected in color in order to show the level of garbage collected. In addition, a liquid crystal display (LCD) screen displays the status of the garbage level. Thus, this innovative system helps to keep the city clean by informing the end users and authorities concerned about the garbage levels of the bins by providing a graphical image of the bins via a web page.

This study will be of immense importance not just to those whose jobs mainly involve the disposal of refuse bins, but also to the entire public adopting the smart cities guidelines for better living. The implementation of this proposed approach will go a long way in making efficient use of waste disposal in real time as well as the optimal use of resources, and this will also go a long way to improve the living condition of the smart city dwellers. Finally, the design and implementation of the working prototype system will serve as an innovative and informative way of keeping and improving the health condition of smart city dwellers. The salient contributions of this research paper are as follows:

1. A working prototype for the identification of garbage bins so that users can know its location and the efficiency to empty it in real time can be increased.
2. The autonomous monitoring and control of the garbage bins level using ultrasonic sensors.
3. The garbage bins sending data to a web application via a Wi-Fi modem.
4. An LCD screen and light emitting diodes (LEDs) used to display the status of the garbage bins to the end user.
5. A web server and web page interfaces are designed to graphically display the levels of the garbage bins.

2. Related Works

Currently, smart cities are highly populated due to rural migrant inflow to the urban cities. This causes a significant increase in waste disposal and causes harmful effects to human beings and the environment. Due to the lack of proper monitoring and control of waste, the garbage bins mainly appear to be flooded and spilling out onto the surrounding, causing many health-related issues. This situation should be taken into serious consideration by the relevant authorities and the research community so that a solution can be provided in order to manage, monitor, and control waste disposal. The use of an IoT-based solution will help in providing a lasting solution to waste monitoring and control [6].

The authors Padini et al. [7] presented a hardware and software approach to waste management that allows the users to be part of the management process. The proposed system employs the use of IoT technology that constantly monitors the level of waste in garbage bins in real time. The sensed data are stored and processed using a middleware and provides statistical information regarding the status of the waste in the garbage bins. Users can obtain the waste information through a web page or mobile application. A prototype was presented, and a use case evaluation of the approach was demonstrated and validated.

The authors You et al. [8] proposed an informatization scheme that combines multiple technologies to monitor illegal behavior in waste disposal in real time. The scheme provides a means of evaluating the performance of stakeholders involved in the process and strengthening the collaboration among supervisory departments. The authors presented a case study to demonstrate the feasibility and effectiveness of their approach. Results from their system testing indicated that the total sum of illegal cases has significantly reduced from 510 to 89 per annum since the adoption of the new system.

The authors Jaid Jim et al. [9] presented a garbage management system that combines the basic ideas of waste management and the Internet of things technology, namely, Internet of garbage bins (IoGB). The proposal makes use of smart cycle containers that cycle individually after being filled with garbage waste. This approach helps to solve the problem of lack of space of putting the garbage bins in a strategic way. A server-based monitoring system was used to control an autonomous car that collects the waste when needed.

Shi et al. [10] proposed a solution to waste disposal and collection problems in urban areas. The approach modeled a multi-depot vehicle routing problem as a means of collecting waste from the collection centers to reduce the means of transportation. A heuristic technique was adopted to provide a solution to the problem.

Hussain et al. [11] presented an IoT-based smart bin by employing a machine and deep learning model to tackle the problem of waste disposal and to provide information based on the forecast of air pollution associated with the garbage bin in the environment. An IoT-based server was interfaced with the garbage bin. The Google cloud server provides the computation needed to report the status of the bin and to provide the real-time forecasting information on the status of the air quality surrounding the garbage bins in real time. The benefit of the proposed approach in terms of an improved accuracy using machine learning was demonstrated.

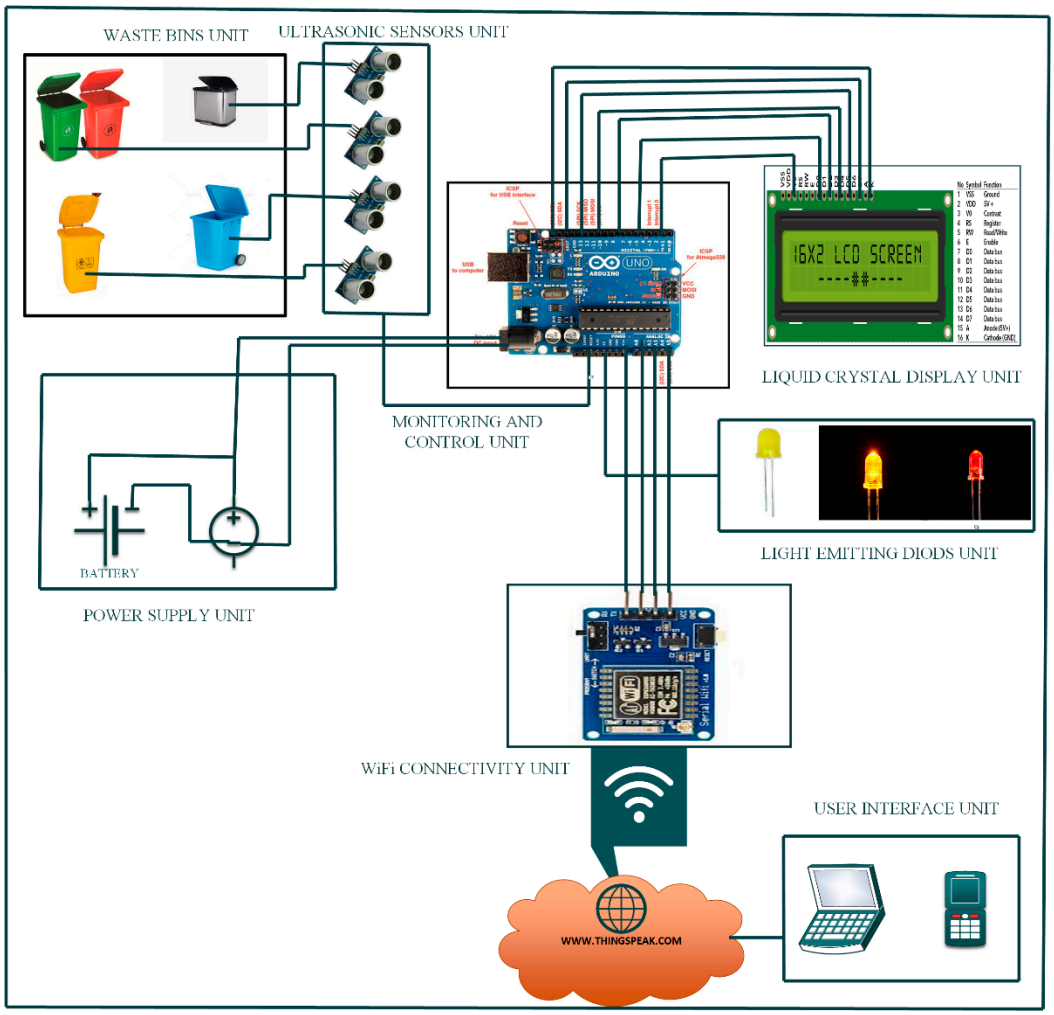
Laurieri et al. [12] presented a survey based on residents' habit in generating and managing recycle waste as well as the financial cost and environmental impacts of the adopted door-to-door waste collection scheme in Altamura, Italy. The authors proposed a weekly garbage bin collection

scheme to provide an efficient and waste collection service to the people living in the town. This approach was an aim to design a smart device to assist people in the proper handling of waste management.

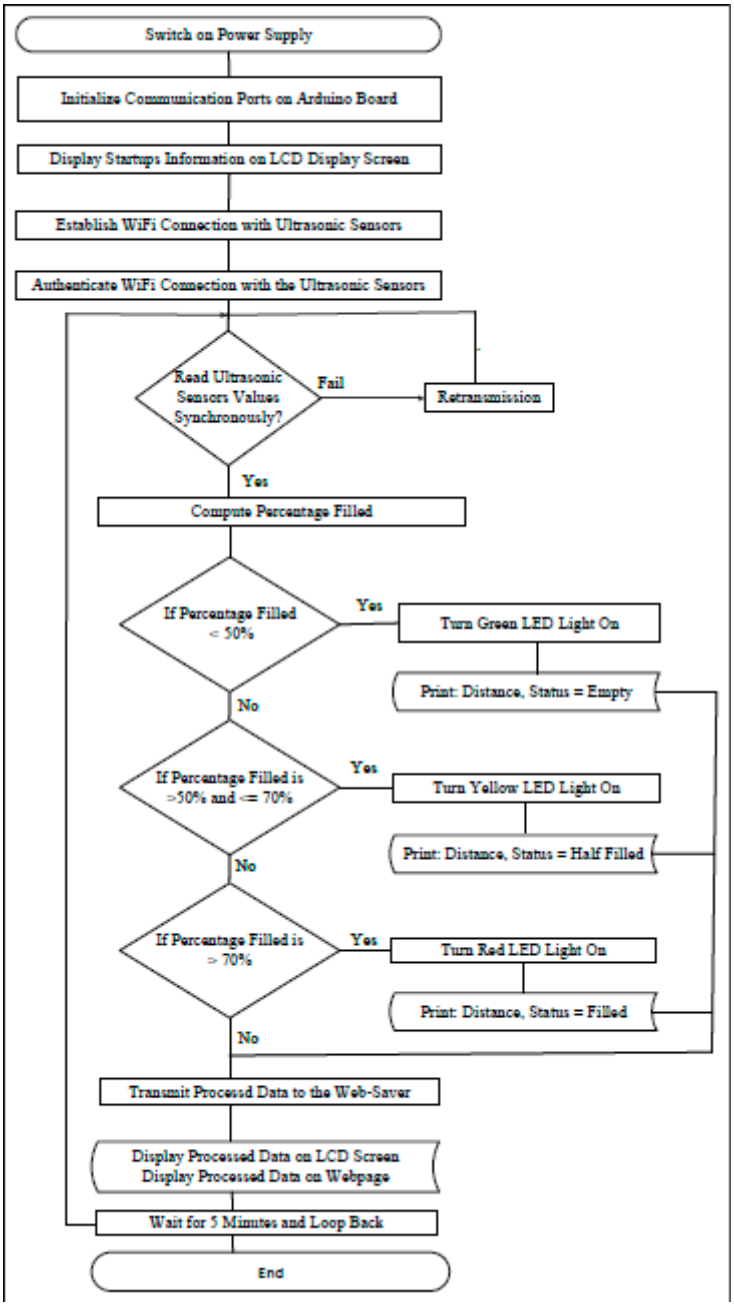
Moreschi et al. [13] presented a study based on a case study of a city in Italy namely, Genoa. This is as a result of the closure of the Scarpino landfill that was preserved for the disposal of garbage waste in the municipality. The study provided a multiobjective tool that can be used for long-term planning and scheduling of daily activities. A decision support system for waste management was presented. The effectiveness in long-term targets in relation to the total cost, the amount of emissions produced by the garbage waste transportation, and the utilization of an individual plant for sustainable development was demonstrated. Finally, other interesting approaches that employed the use of IoT-based technologies for monitoring and control applications were provided in our previous works [14–18].

3. System Architecture

Figure 1a illustrates the block diagram of the architecture of the proposed system. The IoT-based smart waste monitoring and control system consists of seven units. This prototype device consists of the waste bin unit, an ultrasonic sensor unit, a power supply unit, a monitoring and control unit, a liquid crystal display (LCD) unit, a light-emitting diode (LED) unit, a Wi-Fi connectivity unit, and a user interface unit. The overall system operation is controlled by a single microcontroller (monitoring and control unit). This unit is programmed based on how other peripherals and components of the system behave. The ultrasonic sensors are used to detect the garbage distance inside the garbage bin. The ultrasonic sensor poses the capabilities to measure the distance to or from an object by using sound waves. The sensor determines and measures the distance by transmitting a sound wave at a particular frequency and by listening to the sound wave to bounce back. In order to determine the distance between the sonar and the object, the time difference between when the sound wave is transmitted and when the wave is bounced back is computed. However, it is essential to know that some objects may not be detected by ultrasonic sensors [19]. The sensed data from the sensors are monitored and controlled in the monitoring and control unit. The light-emitting diode unit provides status information on the levels of garbage in the garbage bins. If the level is less than 50%, the green LED will turn on; the status message “emptied” will be displayed, as well as the measured distance. If the level is greater than 50% and less than 70%, the yellow LED will turn on, and the status message “half-filled” will be displayed, as well as the measured distance. If the level is above 70% the red LED will turn on, and the status message “filled” will be displayed, as well as the measured distance. The processed data will be displayed on the LCD screen and also sent to the remote server via the Wi-Fi module, which would store the information in a database. A web application was designed and implemented using PHP programming language to query the data from the database through Wi-Fi connectivity and display the information onto a web page for remote viewing and monitoring. Users can access the garbage status or level information through the website. The website can be accessed with the use of electronic gadget such as a laptop, desktop, and smartphone devices. The sensed data will be uploaded to the data log file and updated continuously. The displayed data on the web page will be updated in every 5 min. Figure 1b illustrates the proposed system flowchart.


WASTE BINS UNIT
ULTRASONIC SENSORS UNIT
16X2 LCD SCREEN
LIQUID CRYSTAL DISPLAY UNIT
MONITORING AND CONTROL UNIT
BATTERY
POWER SUPPLY UNIT
LIGHT EMITTING DIODS UNIT
WiFi CONNECTIVITY UNIT
USER INTERFACE UNIT
WWW.THINGSPEAK.COM

(**a**)



(**b**)

Figure 1. (**a**) System architecture block diagram. (**b**) Proposed system flowchart.

3.1. System Simulation and Design

Figure 2 illustrates the schematic diagram of the simulated system using the Proteus professional 8.0 design environment [20]. The major goal of this research paper is the creation of a firmware program in embedded C programming language that monitors and controls the sensors and other peripheral devices. This is because the microcontroller controls all the processes in the entire system. The programming of the Arduino Uno was done with Arduino IDE [21].

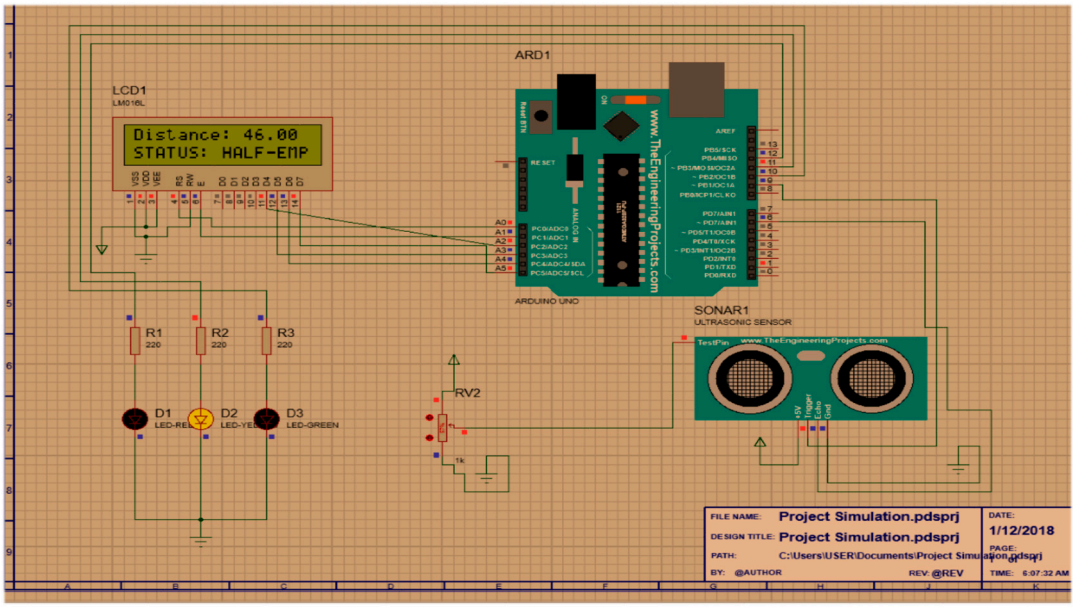


Figure 2. Simulation schematic block diagram.

4. Experimental Results

Several experiments were conducted using the designed device prototype. The results are obtained from the outputs that were taken from the sensor reading stored in the website (http://www.garbage-iot.herokuapp). Several rounds of testing were performed to evaluate the device workability in real situations. The measured distance from the garbage bin was transmitted to the website. This web page performs analysis and visualization, and it displays a bar chart showing the levels of the garbage waste, time, and location in real time for viewing. It is essential to monitor and control the garbage height and distance parameters in order to track the level of the garbage in the bins. This would ensure that the values displayed by the central server system are accurate and reliable to be used by the smart city dwellers.

Figure 3a–c illustrate the garbage waste level indicators. The red LED light on the LED light unit will illuminate to indicate that the garbage bin is almost filled up (i.e., the status is "filled"), and this will be displayed in the red bar chart graph as shown in Figure 3a. When the status of the garbage bin is "half-filled", the yellow LED light will illuminate, and the result will be displayed in the yellow bar chart as illustrated in Figure 3b. When the garbage bin is almost empty (i.e., the status is "empty"), the green LED light illuminates, and the green bar chart is displayed as illustrated in Figure 3c.

In a highly populated city, this will help to keep the cities clean and tidy. In addition, this will ensure enormous advances in technology, most especially in this present age where there is a tremendous advancement in creativity and in using technology to better the lives of smart city dwellers and the environment.

Figure 3. (**a**) The garbage bin is almost full and is due for collection; the status is "filled". (**b**) The garbage bin is half-filled; the status is also "half-filled". (**c**) The garbage bin is almost empty; the status is "empty".

5. Conclusions

This research paper presented an innovative approach to facilitate the process of keeping the environment clean, tidy, and conducive for living. The proposed approach presented the design and implementation methodology to strategically monitor and control the rate at which garbage bins are filled and can eventually help prevent overflow, which in most cases leads to environmental pollution. The research paper presents the design and implementation of an IoT-based Arduino microcontroller working with ultrasonic sensors that detects the level of waste in the garbage bin placed in garbage locations and constantly at regular intervals display the status information as "filled", "half-filled", or "empty" on an LCD screen, as well as send the content level information at those intervals to a central web-server system that displays the garbage bin levels graphically. This is achieved using a microcontroller, a Wi-Fi module, and ultrasonic sensors. The programming of the Arduino Uno microcontroller was done with an Arduino IDE and embedded C programming language. The communication with the web-server was done using the hypertext preprocessor PHP scripting programming language. The prototype was designed and simulated using Proteus 8.0 professional simulation software. This process helps to automate garbage bin monitoring and control. Experimental results demonstrated a promising solution to waste management and control. Future work will consider the use of a field programmable gate array (FPGA) to provide high performance real-time computing capabilities compared with the Arduino microcontroller. The proposed system can be extended to monitor and control waste in remote locations for sustainable development.

Author Contributions: Conceptualization, S.A.; data curation, C.I.L.; formal analysis, S.A. and C.I.L.; funding acquisition, S.A.; investigation, S.A. and C.I.L.; methodology, S.A. and C.I.L.; project administration, S.A.; resources, C.I.L.; software, S.A. and C.I.L.; supervision, S.A.; validation, S.A. and C.I.L; visualization, S.A. and C.I.L.; writing—original draft, S.A.; writing—review and editing, S.A. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: Special thanks are given to Maria Liz Crespo of the Abdussalam International Centre for Theoretical Physics (ICTP), Trieste, Italy, and Iain Darby of the International Atomic Energy Agency (IAEA), Vienna, Austria, for the ICTP workshop/seminar, smr: 3143, "Joint ICTP-IAEA School on Zynq-7000 SoC and its Applications for Nuclear and Related Instrumentation", 21 Aug.–15 Sep., 2017, Trieste, Italy.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Bank Report, Washington September 20, 2018. Available online: https://www.worldbank.org/en/news/press-release/2018/09/20/global-waste-to-grow-by-70-percent-by-2050-unless-urgent-action-is-taken-world-bank-report, (accessed on 12 August 2020).
2. Wikipedia Online Encyclopedia. Available online: https://en.wikipedia.org/wiki/Garbage (accessed on 12 August 2020).
3. Giffinger, R. Smart cities Ranking of European medium sized cities. *Cent. Reg. Sci. Vienna Univ. Technol*. **2017**, *16*, 13–18.
4. Akhil, R.N.; Valarmathie, P.N. IoT Based Waste Management System for Smart Cities. *Int. J. Adv. Res. Ideas Innov. Technol.* **2017**, *3*.
2. Sonal, C.; Priya, K.; Shruti, S.; Prajakta, P.; Snehal, S.; Shweta, M. Real Time Smart City Garbage Collection and Monitoring System Using GSM and GPS. *Int. Res. J. Eng. Technol.* **2017**, *4*, 126–129.
3. Ruhin, M.S.; Drishya, G.; Harish, K.S.; Mohammed, S.N.; Lakshmi, S. A Survey on Smart Garbage Management in Cities using IoT. *Int. J. Eng. Comput. Sci.* **2016**, *5*, 18749–18754, ISSN: 2319-7242.
4. Pardini, K.; Rodrigues, J.J.; Diallo, O.; Das, A.K.; de Albuquerque, V.H.C.; Kozlov, S.A. A Smart Waste Management Solution Geared towards Citizens . *Sensors* **2020**, *20*, 2380.
5. You, Z.; Wu, C.; Zheng, L.; Feng, L. An Informatization Scheme for Construction and Demolition Waste Supervision and Management in China. *Sustainability* **2020**, *12*, 1672.
6. Jaid Jim, A.A.; Kadir, R.; Mamun, M.A.A.; Nahid, A.-A.; Ali, M.Y. A Noble Proposal for Internet of Garbage Bins (IoGB). *Smart Cities* **2019**, *2*, 214–229.
7. Shi, Y.; Lv, L.; Hu, F.; Han, Q. A Heuristic Solution Method for Multi-Depot Vehicle Routing-Based Waste Collection Problems. *Appl. Sci*. **2020**, *10*, 2403.
8. Hussain, A.; Draz, U.; Ali, T.; Tariq, S.; Irfan, M.; Glowacz, A.; Antonino Daviu, J.A.; Yasin, S.; Rahman, S. Waste Management and Prediction of Air Pollutants Using IoT and Machine Learning Approach. *Energies* **2020**, *13*, 3930.
9. Laurieri, N.; Lucchese, A.; Marino, A.; Digiesi, S. A Door-to-Door Waste Collection System Case Study: A Survey on its Sustainability and Effectiveness. *Sustainability* **2020**, *12*, 5520.
10. Moreschi, L.; Del Borghi, A.; Taramasso, A.C.; Gallo, M. Waste Management under Emergency Conditions: Life-Cycle Multicriteria Analysis as Decision Support System. *Resources* **2020**, *9*, 82.
11. Abba, S.; Wadumi, N.J.; Lee, J.A.; Liz Crespo, M. Design and Performance Evaluation of a Low-Cost Autonomous Sensor Interface for a Smart IoT-Based Irrigation Monitoring and Control System. *Sensors* **2019**, *19*, 3643.
12. Abba, S.; Garba, A.M. An IoT-Based Smart Framework for a Human Heartbeat Rate Monitoring and Control System. *Proceedings* **2020**, *42*, 36.
13. Abba, S.; Lee, J.A. FPGA-Based Design of an Intelligent On-Chip Sensor Network Monitoring and Control Using Dynamically Reconfigurable Autonomous Sensor Agents. *Int. J. Distrib. Sens. Netw*. **2016**, *29*, 4246596.
14. Sani, A.; Itse, M.N. Design and Evaluation of a Low-Cost and Flexible Data Acquisition System Using Sensor Network for Smart Homes. *Sens. Transducers* **2018**, *227*, 73–81.
15. Sani, A.; Beauty, P.E. Smart Framework for Environmental Pollution Monitoring and Control System Using IoT-Based Technology. *Sens. Transducers* **2019**, *229*, 84–93.
16. Ashima, B.; Sumanth, R. Garbage Monitoring System Using IOT. *Int. J. Pure Appl. Math.* **2017**, *114*, 155–161. Available online: http://acadpubl.eu/jsi/2017-114-7-ICPCIT-2017/articles/12/18.pdf (accessed on 8 June 2020).

17. Lab-center Electronics Ltd. Proteus Design Suite 8.5 Professional. Available online: http://www.labcenter.com (accessed on 10 June 2020).
18. Arduino Integrated Design Environment. Available online: http://www.arduino.cc (accessed on 8 June 2020).