Smart Waste Collection System in the Context of Smart Cities

Alexandros Boubaris[*], Fanourios Kantounias[*], George Kyriazidis[*], Vasilios Dasteridis[†], Nick Rigogiannis[*], Nick Papanikolaou[*], Georgios Sirakoulis[*]

[*]*Department of Electrical and Computer Engineering, Democritus University of Thrace,* Xanthi, Greece
Email: aboumbar@ee.duth.gr, fanokant@ee.duth.gr, georkyri7@ee.duth.gr, nrigogia@ee.duth.gr, npapanik@ee.duth.gr, gsirak@ee.duth.gr
[†] *Dasteri Systems S.A.,* Alexandroupolis, Greece
Email: vdasteridis@dasteri.gr

***Abstract*—This paper presents the development of a smart bin application, aiming at the upgrade of conventional, already in use bins, transforming them into a vital component of the smart city concept. Special attention has been paid in the cost-effectiveness of the proposed solution, in order to become sustainable. In this context, the use of a popular and low-cost high-performance microcontroller has been employed. Moreover, by means of a touchscreen, a friendly user interface is established, along with the interconnection with the smart city waste management infrastructure; therefore, the optimal route planning for municipality vehicles becomes possible, reducing so the associated costs whereas improving the environmental footprint. In addition, temperature, gas/fire, weight and ultrasonic sensors are also incorporated in the proposed solution, so as to prevent hazards, as well as to provide useful data to the citizens/users. Last but not least, the smart bin is equipped with an energy harvesting system, becoming so a zero-energy solution.**

Keywords—energy harvesting, microcontroller, sensors, smart city, waste collection

I. Introduction

Nowadays, human population is growing increasingly, mainly due to the rapid developments in science and technology, worsening the problem of overpopulation, especially in large urban centers. Hence, the exponential growth in waste amounts (either recyclable or not) is inevitable. Conventional waste collection and management methods seem insufficient to face this phenomenon [1] - [5].

However, modern smart systems and technological trends, such as sophisticated microcontroller units (MCU) and microprocessors, smart applications, cloud infrastructures, Internet of Things (IoT), data analytics, digital twins, artificial intelligence etc. may become a part of the solution, so as to address the aforementioned waste growth problem. In addition, the above smart systems contribute to the development of the Smart City concept, which has been proposed over the last few years [6], [7]. In more detail, the development of cloud infrastructures with superior performance, along with the flexible interconnectivity that IoT offers, provide an efficient use of big data, enhancing smart systems' scalability and flexibility. Moreover, recent advances on semiconductor materials and chip construction, lead to miniature-sized chips and sensors, increasing their adaptability and appropriateness for smart applications.

In this context, this work focuses on a smart waste collection application, which constitutes a critical part of the Smart City Concept [6], [7]. The design of a smart bin is presented, based on a common low-cost and high performance MCU (i.e., Raspberry Pi 4), whereas by the aid of a touchscreen display a friendly user interface is developed, on a conventional waste bin. Furthermore, a 3D light detection and ranging (LiDAR) depth camera is employed, accommodating simple visualization techniques, in order to estimate accurately the waste volume and consequently the bin filling rate. Therefore, the waste collection command occurs when the container is full.

In addition, many sensors are incorporated into the smart bin, collecting real-time data and sending them to a central information / control center. The data are stored and analyzed, so as to plan an optimal route for the municipal garbage trucks, reducing so both transportation costs and greenhouse gas emissions (e.g., CO_2, NO_x). Other sensors, e.g., temperature, humidity, gas / fire, weight, ultrasonic are also installed, in order to provide essential information and emergency commands, in case of dangerous conditions. Moreover, for equipment safety, an automatic electromagnetic lock is utilized. Last, but not least, the proposed smart bin system constitutes an energy autonomous solution, as it incorporates photovoltaic (PV) energy harvesting, along with a battery bank, so as to supply the necessary electronic circuits.

II. System Description

The proposed system is presented in the schematic diagram of **Fig. 1**. The central control unit of the smart bin system is based on the well-established Raspberry Pi 4 model B MCU, equipped with a powerful quad-core Cortex-A72 (ARM v8) 64-bit processor at 1.5 GHz, 8 GB of RAM, USB 2.0, USB 3.0, USB-C and micro-HDMI connectivity, and fast networking via 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE and gigabit Ethernet. The MCU is interconnected as a node to the IoT, by means of wireless connectivity, exploiting the cellular network (4G or 5G) [8].

In addition, a friendly user interface is utilized via a 7-inch touchscreen display, which provides waste placement guidelines, e.g., whether there is enough capacity, according to waste dimensions and container filling rate, and waste type (i.e., recyclable or non-recyclable). Measured data of gas / smoke, humidity and temperature sensors are collected and analyzed, in order to ensure valid estimations for hazardous conditions, e.g., in case of fire. Additionally, a tilt sensor is incorporated, so as to secure the smart bin correct position.

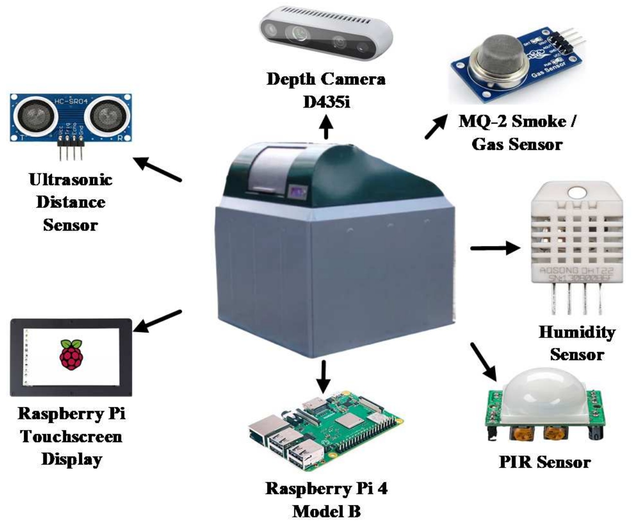


Fig. 1. Schematic diagram of the overall smart bin system, incorporating the Raspberry Pi 4 MCU and the necessary sensors.

The presence of a user is detected by means of an ultrasonic sensor in the front side of the container. When both distance and time interval criteria are satisfied, the MCU goes from "idle" mode to "full activated" mode. Moreover an innovative container mapping and waste volume calculation method is introduced, based on a 3D LiDAR depth camera, which utilizes high resolution imaging and depth sensing technology. Finally, the simplified energy harvesting system is illustrated in **Fig. 2**, where the Raspberry Pi and all sensors are supplied by means of a PV / battery system, connected in an energy harvesting module.

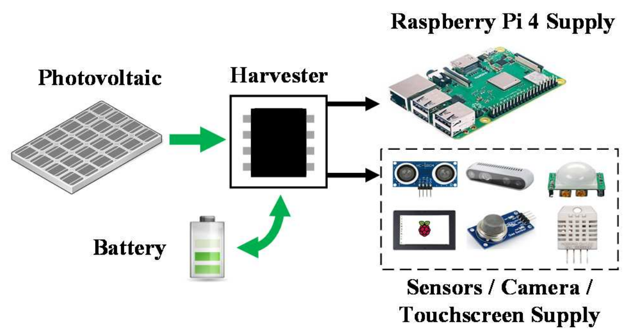


Fig. 2. Simplified block diagram of the energy harvesting system.

III. Operating Principles

A. General Operating Scheme

Fig. 3 presents the flowchart of the operating principle of the developed smart bin. In more detail, the ultrasonic sensors continuously perform the detection of possible users; upon person detection, the MCU is activated and the LCD screen provides waste placing information. This is through an interactive process, in order to determine whether the waste is either recyclable or not. In parallel, by the aid the LiDAR 3D camera, the waste-bin filling rate is provided, and so it is possible for the MCU to estimate whether there is enough space for the new coming waste amount. In case that the bin is full, no more waste is acceptable and a report signal is transmitted (by means of IoT or even through a simple e-mail) to the waste management center for further programming of waste collection. Otherwise, access is provided for the new coming waste deposit.

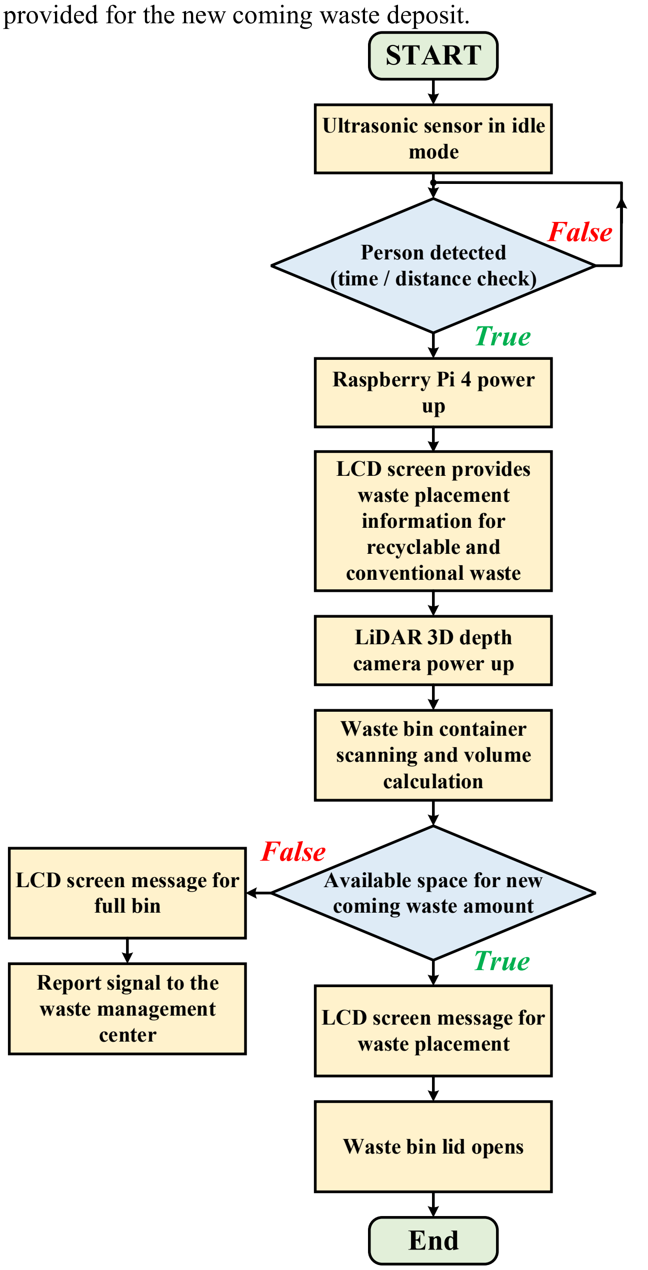


Fig. 3. Flowchart presenting the basic operating principle of the smart bin system.

B. Emergency Conditions Management

As it is illustrated in the flowchart of **Fig. 4**, the smart bin is internally inspected continuously in order to detect any emergency circumstance. In this context, a variety of sensors can be employed for smoke / gas detection, as well as humidity and temperature measurement. The final selection lies upon the available budget for the installation of the smart bin kit. In any case, the MCU manages all those sensors and in case of an emergency condition the waste management center is directly informed. In addition, the electromagnetic lock is activated and a buzzer warns about the emergency condition. It is worth noting that the specific MCU provides the desired flexibility to install various sensors, in order to protect the smart bin and the general public.

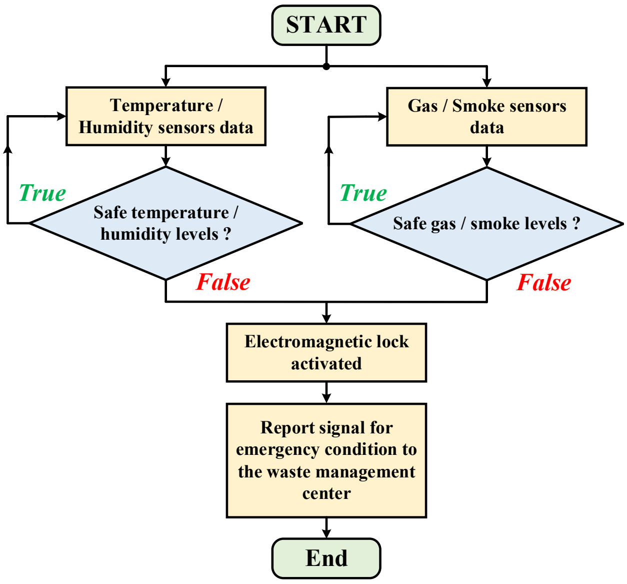


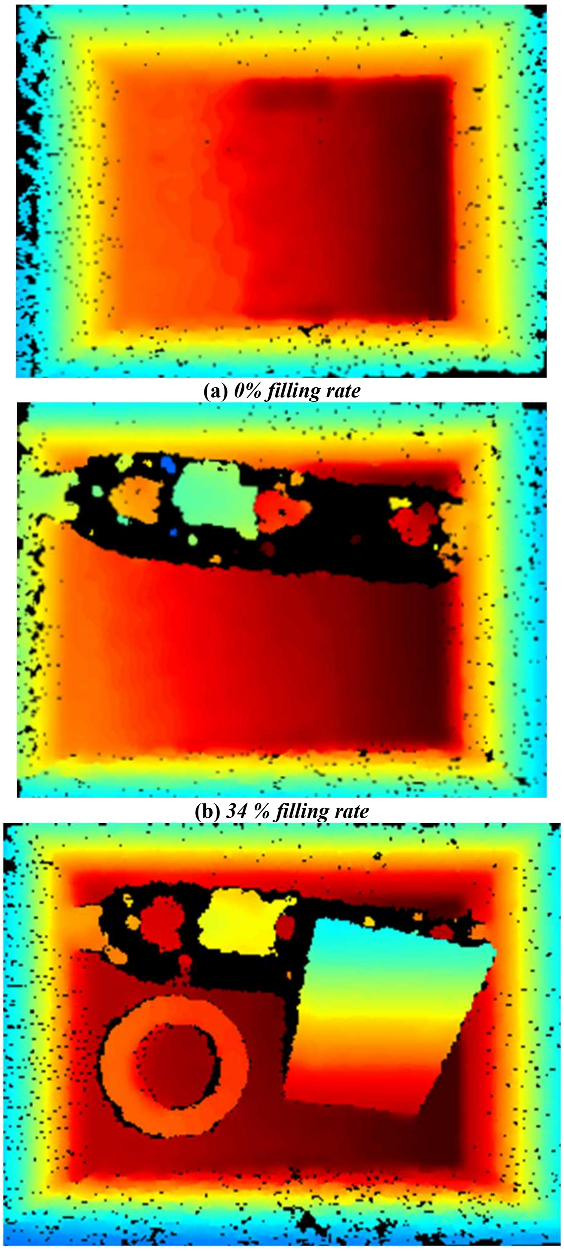
Fig. 4. Flowchart for the inspection and the emergency conditions management of the smart bin system.

IV. Preliminary Tests

The preliminary tests and presented results regard the container volume calculation, through the LiDAR 3D depth camera and the developed graphical user interface (GUI). Initially, the volume calculation was set at a small box, in order to verify the camera functionality. **Fig. 5(a)** depicts the mapping of the empty box; **Fig. 5(b)** depicts the mapping of the box, after the placement of a plastic water bottle. Finally, **Fig. 5(c)** depicts the mapping of the box, after the placement of several objects (of various sizes and shapes). Those results validate the functionality of the volume calculation feature; the container filling rate has been successfully calculated at 0%, 34% and 52%, respectively, providing so useful information to the end-user.

Next, the LiDAR depth camera has been integrated into an actual waste bin. **Fig. 6(a)** presents the mapping of the bin container, highlighting the fact that it is fully effective in the real application, whereas in **Fig. 6(b)** presents the bin volume reproduction in the PC application.

The installed smart kit is presented in **Fig. 7** and **Fig. 8**, into the container and at the front side of the bin, respectively. The volume estimation can be implemented, either by using the in-depth camera, or by the aid of ultrasonics sensors (as it is depicted in **Fig. 7**); the latter one constitutes a more cost-effective solution. The potential placement of all the required sensors (i.e., ultrasonic, temperature / humidity, gas) and components (i.e., battery, PV energy harvesting circuit) is shown in the preliminary container prototype of **Fig. 7**. In addition, as it is depicted in **Fig. 8**, the PV module is placed at the top of the bin, whereas the touchscreen display and the RF card reader are placed at the front. The aforementioned RF card reader is utilized, so as to facilitate the operation of the garbage collection staff. Finally, in cases of neighborhoods or small communities the touchscreen display can be omitted (leading to a lower cost solution), whereas the RF card reader will recognize only the local residents ID.



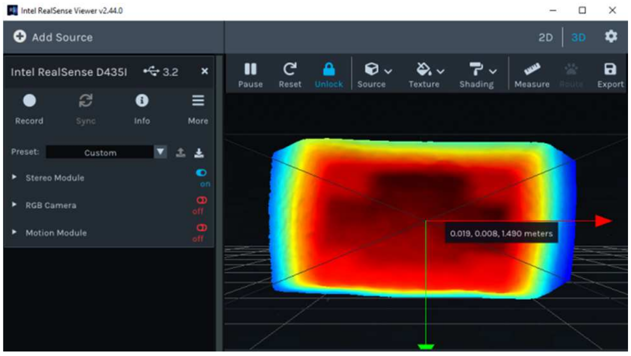
(a) *0% filling rate*

(b) *34 % filling rate*

(c) *52 % filling rate*

Fig. 5. Mapping of a small box for volume calculation, by the aid of the LiDAR depth camera, (a) empty box (0% filling rate), (b) one object (34% filling rate), (c) several objects (52% filling rate).

(a)



(b)

Fig. 6. Mapping of the actual waste bin container, (a) LiDAR depth camera image, (b) the container volume representation.

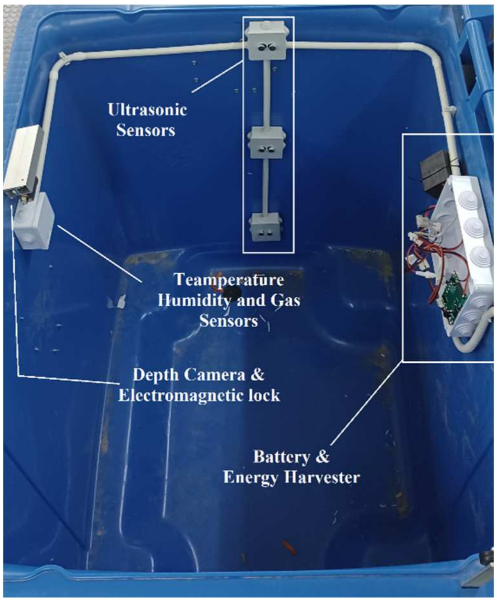


Fig. 7. Installation of the smart kit into a conventional recycling bin container.

Fig. 8. Front view of the installed smart kit, at a conventional recycling bin.

V. Conclusion

A smart bin kit has been presented in the present work, being a low-cost and flexible solution for the upgrade of conventional waste bins, converting them into an essential component of the Smart City Concept. Thanks to the use of Raspberry Pi 4 Model B, a variety of sensors can be employed (in a selectable manner), depending on the available budget. Moreover, effective volumetric estimations are provided and the necessary information is communicated, contributing to the effective central waste management. Last but not least, the end-users are supported by a friendly GUI, presenting useful information and messages on a touchscreen display, developed on the selected MCU.

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