Encouraging citizens for recycling improvement: Results of the STERLING initiative

Diego R. Llanos[a,b], Ester Diego[a], Ivan Carreño[b], and Jose Luis Gay[b]

[a]Dpto. Informática, Universidad de Valladolid, Valladolid, Spain
[b]RDNest, Valladolid, Spain

ABSTRACT

In 2018 we introduced STERLING, a framework designed to encourage citizenship to develop recycling habits. This framework is composed by a low-cost, low-energy sensor installed in recycling containers to measure fill level and other physical parameters, together with a mobile app and an associated web-based server. The sensor is activated magnetically each time the container lid is opened by a user. Instead of directly sending this information to a cloud-based server, our sensor broadcasts a Bluetooth Low Energy (BLE) packet to the surrounding area. An app running in the mobile phone of the user performs two actions: To capture this information, re-sending it to the cloud-based server, and to assign credits to this particular user for having used the recycling container. In this way, users are rewarded for using the container, and the infrastructure benefits from cost-free communications from the container to the server. During the first semester of 2019, we have launched a pilot demonstration of the STERLING solution at different schools of the University of Valladolid. This test included the deployment of ten STERLING recycling containers, making a public presentation to encourage users to improve their recycling habits, and running a rewarding mechanisms consisting on Amazon gift cards. In this paper we describe the experience in detail, showing the advantages and weaknesses of our solution, discussing some interesting lessons learned from this experience, and pointing to further research directions.

Keywords: Waste disposal, recycling, low-cost sensors, low-energy sensors, gamification, IoT

1. INTRODUCTION

Waste disposal and management is a main concern all around the world. In developed countries, many resources are devoted to convince citizenship to separate waste according to their composition and use (plastic bottles, cans, organic waste, etc.) To improve recycling habits among citizenship, some kind of rewarding mechanism can be useful. However, in order to reward citizens for recycling, the first problem is to correctly an unambiguously identify them.

In 2018 we introduced STERLING at the SPIE Remote Sensing Conference.[1] STERLING is a complete solution that, at the same time, monitors the working conditions of recycling containers, and correctly identifies their users. It is important to highlight that STERLING is agnostic with respect to the particular rewarding mechanism chosen. From a technical point of view, STERLING is a framework composed by a low-cost, low-energy sensoring system installed in recycling containers to measure and broadcast fill level and other physical parameters, together with a mobile app and an associated web-based server. The sensor is activated magnetically each time the container lid is opened by a user. Instead of directly sending this information to a cloud-based server, our sensor broadcasts a Bluetooth Low Energy (BLE) packet to the surrounding area. An app running in the mobile phone of the user performs two actions: To capture this information, re- sending it to the cloud-based server, and to assign credits to this particular user for having used the recycling container. In this way, users are rewarded for using the container, and the infrastructure benefits from cost-free communications from the container to the server.

During the first semester of 2019, we have launched a pilot demonstration of the STERLING solution at different schools of the University of Valladolid, Spain. This test included the deployment of ten STERLING

For both technological request and business proposals, please contact Dr. Diego R. Llanos, RDNest, Edificio CTTA, Paseo Belén 9A, 47011 Valladolid, Spain. e-mail: diego@rdnest.com.

recycling containers, making a public presentation to encourage users to improve their recycling habits, and running a rewarding mechanisms consisting on Amazon gift cards. Our results show the effectiveness of rewarding users for recycling, not only to keep the users motivated, but also to motivate their friends and colleagues as well. In this paper we describe the experience in detail, showing the advantages and weaknesses of our solution, discussing some lessons learned from this experience, and pointing to new research directions.

This paper is organized as follows. Section 2 enumerates some related works. Section 3 describes some solutions found in the bibliography, discussing their advantages and weaknesses. Section 4 describes the STERLING architecture. Section 5 shows more details about the STERLING sensoring device, while Sect. 6 describes the STERLING mobile app. Section 7 explains the details of the test pilot conducted and some lessons learned. Finally, Sect. 8 concludes our work.

2. RELATED WORK

Internet of Things (IoT) technologies[2] is playing an important role in all fields of manufacturing, deployment and use of goods and services. In the field of waste disposal and recycling, IoT devices are used to monitor the fill level and working conditions (temperature, humidity, etc.) of recycling containers. Giacobbe *et al.*[3] presents a comprehensive state of the art on the use of IoT technologies for smart waste recycling. Lindström *et al.*[4] analyze a case study about optimizing recycling management in terms of emptying containers holding, for instance, glass, paper, plastics or metal waste collected, thus supporting sustainability of natural resources and the circular economy. Chin *et al.*[5] have discussed the need for a new household waste management system and presents a comprehensive literature review of research that concerns the production of high-tech refuse bins. Gattim *et al.*[6] have recently proposed to augment solid waste containers with sensors that measure their working conditions and send this information to the Internet. Measurements not only include fill level, but also the level of potentially-hazardous gases produced by the waste being stored. Other uses of IoT technologies include the use of special sensors to store dry and wet waste in their corresponding underground containers.[7]

Gamification techniques[8] are techniques that aim to involve people in certain tasks as if they were a game, taking advantage of emotional and/or physical rewarding. Regarding gamification techniques to encourage recycling, González-Briones *et al.*[9] have recently proposed a multi agent-based system that encourages citizen participation, using tax reductions as incentives. Other proposals related to waste management include to reward citizens with emoticons and sounds[10] , and to use gamification techniques to improve environmental knowledge and behavior[11] .

3. CURRENT SOLUTIONS AND THEIR LIMITATIONS

As we mentioned in the previous section, there exist several solutions that aim to use IoT technologies to improve the quality of the recycling process. These solutions usually consist of adding small, battery-powered sensoring devices to recycling containers, in order to collect their working conditions (temperature, humidity, fill level, presence of potentially-hazardous gas, etc.) and to send this information to the Internet. This approach allows the recycling infrastructure manager to know the state of their containers. However, this approach has two disadvantages.

The first one is relative to power consumption. Although different network infrastructures has been proposed in these days to handle IoT communications, such as 5G,[12] or Narrow Band IoT (NB-IoT),[13] most commercially-available solutions today rely on 3G communications. 3G modems, such as the SIM800, are reliable and inexpensive. However, they need a variable amount of current to establish communication, depending on the local 3G coverage, with peak currents up to 2A during short intervals. Considering that a typical sensoring device consumes a few mA during operation, and in sleep mode the current is in the order of some μA, such peaks greatly reduce the autonomy of the system, requiring more frequent battery changes. To mitigate this problem, sensoring systems installed in recycling containers do not transmit each time the container is used, but once a day at most.

The second problem of 3G modems is that somebody should pay for the communication costs. 3G SIM cards requires to pay a minimum monthly fee of around two euros, even for IoT devices that only transmit a few Mb

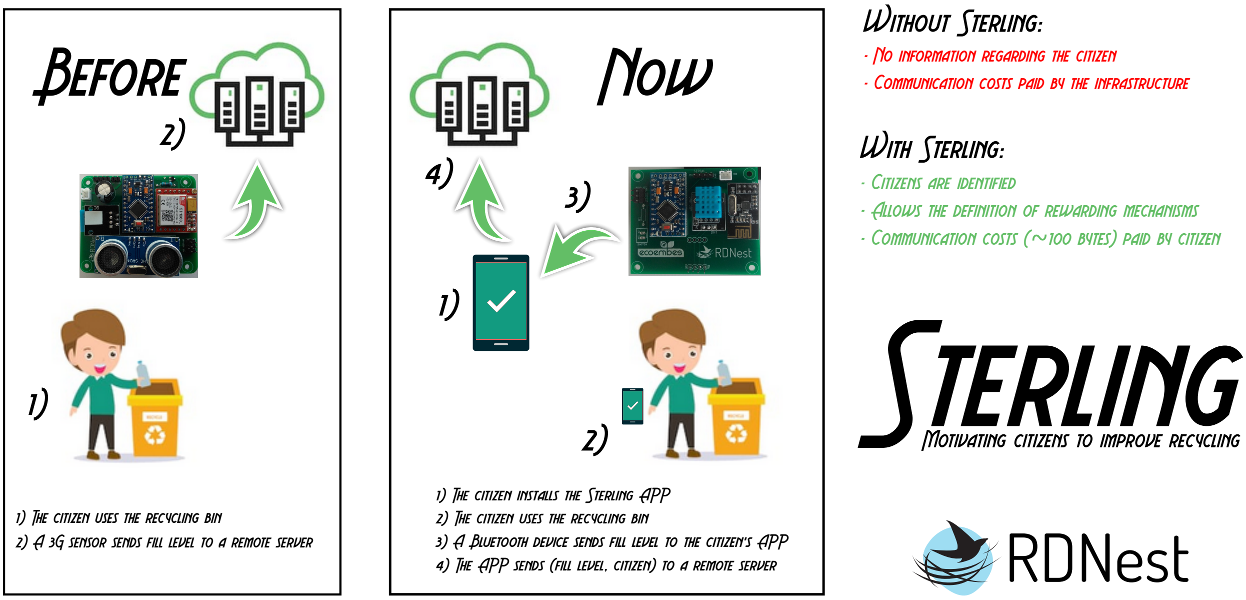

Figure 1. STERLING proposed architecture, compared with previous solutions

per month. It may seems that the cost is negligible, but some recycling companies manage tens or hundred of thousands of containers.

Besides these problems, 3G-based sensoring devices work without taking the user into account. They simply measure some physical magnitudes periodically, sending them to a cloud-based server. In order to improve recycling habits, it would be desirable to identify the particular user, rewarding his/her for his/her compromise with the environment preservation.

As we will see in the following section, the STERLING initiative solves all the limitations described above.

4. STERLING INITIATIVE OVERVIEW

The STERLING initiative is based on the STERLING sensoring system. It is a modified version of a conventional 3G sensor, that replaces the 3G modem with a Bluetooth emitter. Instead of transmitting the collected information directly to a cloud-based server, the STERLING sensor broadcasts the same information in a Bluetooth packet, with a local coverage of around 30 meters. Of course, this is not enough to make the information reach the server. To make it happen, users of the recycling container should have the STERLING app installed in their phones. This app captures the Bluetooth packet, signs it with the user identifier, and retransmits it to the cloud-based server. See Fig. 1.

This proposal solves all the limitations described in the previous section. Regarding power consumption, Bluetooth emitters, such as the NRF24L01, only consume around 10 mA in operation, several orders of magnitude lower than the peak consumption of 3G modems. This eliminates the need of transmitting the information once a day, allowing to send a data packet each time the container lid is opened, and still extending the battery life. Regarding running costs, to broadcast Bluetooth packets is not subject to a monthly fee. The user is now in charge of retransmitting the information to the server. The marginal cost of this transmission is negligible for the user, because the data package sent after a single container usage is composed by just some hundreds bytes.

From an operational point of view, these advantages are relevant. However, the main advantage of our solution is that we are finally able to identify the particular user of the recycling container, allowing the creation of rewarding mechanisms of many different kinds.

5. THE STERLING SENSORING DEVICE

The STERLING sensor includes the following components:

- A low-power CMOS 8-bit microcontroller (ATmega328/P).
- A distance sensor used to measure distance between the waste level and the ceiling of the container (HC-SR04).
- A sensor to measure temperature and humidity (DHT11).
- A Reed-type, magnetic switch to detect when the container lid has been opened.
- A Bluetooth serial wireless module, based on the nRF24L01+ single chip 2.4GHz transceiver.
- Auxiliary electronics to avoid sensors to consume power when the microcontroller is in sleep mode.

Other digital sensors and devices can be integrated as well, including a GPS module, in case the position of the container should be periodically checked, or tilt sensors to detect vandalism.

The behavior of the sensoring system is simple. Each time the container lid is opened, the magnetic switch raises an interrupt that wakes up the microcontroller. The microcontroller waits a few seconds (to allow the user to deposit the waste), and then measures the distance between the container ceiling and the waste level, temperature and humidity, and any other physical magnitude that may be desirable. Then, instead of sending the information to a cloud-based server using a 3G modem, the STERLING system broadcasts a Bluetooth Low Energy packet using the Eddystone protocol. The operational range can be determined by adjusting the intensity of the signal being broadcasted, and ranges between 30 and 50 meters. The information broadcasted includes a timestamp, an unique identification of the container, the information acquired by the sensors, the voltage level measured in the microcontroller (to allow preventive maintenance if the battery is low), and the number of times the lid has been opened since the container was originally installed.

The opening counter is an useful feature that allows the recycling organization to acquire knowledge about the use of the container. This counter not only allows to know how frequently the lid is opened, but also allows to estimate the penetration rate of the STERLING app, an issue discussed in the following section.

6. THE STERLING APP

The second component of the STERLING framework is its app. This app allows a user to sign up, asking for a valid e-mail address, and includes a background service that listens for BLE packets coming from recycling containers. Once such a packet is received, the app simply retransmits this information to a cloud-based server. The information sent includes all the information gathered from the recycling container, such as sensor data, timestamp, container identifier, current voltage and the value of the opening counter; an unique code assigned to this particular user; and the physical intensity of the signal received from the container. This information allows the server to associate this user with this particular container usage event.

The intensity of the signal received can be used as a method to distinguish between different STERLING users that can receive the same packet from the container. If several STERLING apps running on different phones retransmit the same packet, the cloud-based server might assign the usage of the container to the user that has received the packet with the highest intensity, that is, the nearest one. For simplicity, in these cases the first version of our solution simply divides the reward among all the users that retransmit the same packet.

The opening counter, that takes account of the number of times the container lid has been opened, is an useful value for several reasons. First, it gives an estimation of the average volume of the waste being disposed, simply by dividing the capacity of the container by the number of times the container lid has been opened between two consecutive emptyings. Note that it is not necessary to reset the STERLING device when emptying the container, since the following measure will then return a greater distance between the ceiling and the waste level.

An additional usage of the opening counter is to estimate the penetration of the STERLING app among citizenship. In many cases the Bluetooth packet emitted by the container will be simply lost, because the user

Figure 2. STERLING recycling containers installed at different buildings of the Universidad de Valladolid.

is not participating in the STERLING initiative and there will be nobody with a STERLING app within its operational range. By including the value of the opening counter, it is possible to estimate the number of packets being lost, thus obtaining an estimation of the usage of the STERLING app by their final users.

7. PILOT TEST OF THE STERLING INITIATIVE

In order to test the entire STERLING framework, we have conducted a pilot test during the first semester of 2019. With the support of the Innovation and Economic Development Agency of the Valladolid City Hall, the University of Valladolid, and Ecoembes (the organization that cares for the environment through recycling and the eco-design of packaging in Spain), we have built ten STERLING recycling containers that have been installed in ten different buildings of the University of Valladolid (Fig. 2). Each container includes a poster with step-by-step instructions to participate in the initiative: (a) Download the app using the QR code provided; (b) register as a STERLING user; and (c) start using the container. One STERLING point was assigned to the user each time the user introduces a can or bottle into the container. The rewarding mechanism chosen was a draw of Amazon Cards among the registered users that have used the service at least five times during each fortnight. To avoid misuse, once the container was used, the system does not assign additional points to the same user during the following half an hour. Each user was allowed to collect up to two points per day. As explained above, if several smartphones running the STERLING app detect and retransmit the same Bluetooth packet, the point associated to this particular usage event was equally distributed among all the owners of that smartphones.

A total of 276 users have taken part in the initiative. The containers have been used 8 197 times, and the users have collected 2 478 points. Table 1 summarizes the usage of each container during the pilot test. The difference between total uses and points collected is explained by the fact that containers have also been used by non-STERLING users. In these cases, the Bluetooth packets sent by the containers were simply lost. We know

Container	Total uses	Points rewarded	Percentage
1. Informática	2426	968	39.90%
2. Telecomunicación	1352	648	47.93%
3. Educación	465	130	27.96%
4. Ciencias	603	188	31.18%
5. Aulario Ciencias	385	102	26.49%
6. Biblioteca	294	61	20.75%
7. LUCIA	277	126	45.49%
8. Económicas	376	57	15.16%
9. Aulario Cauce	1626	107	6.58%
10. Derecho	396	91	23.16%
Total	**8197**	**2478**	**30.23%**

Table 1. Statistics of usage of STERLING containers.

the total number of usages because each sensoring device keeps track of this number, sending it as a part of the Bluetooth packet being broadcasted.

Regarding the age and gender of the registered users, their distribution can be seen in Fig. 3. Both distributions match the expectations. In the case of the gender, it can be seen that more men that women have participated in the initiative. This is explained by the fact that most of the users comes from the Informatics and Telecommunications buildings, where there are many more male students.

We did not experience any major problem during the test pilot. Our main concern was to get some sensoring devices damaged due to vandalism. This was not the case: All devices were conveniently hidden and locked inside the containers and all of them remained in place during the test. Battery consumption was negligible, allowing us to forecast a battery duration of more than two years.

Regarding the STERLING app, we have discovered that the management of background services related to the Bluetooth interface varies greatly with the Android version, as well as the behavior of the notification system associate to the app. This is a problem hard to detect before the release, because to do so the developers should have access to different Android devices with different operating system versions. After releasing some updates, the app ran smoothly.

Regarding users' behavior, we were able to confirm the interest of the university community in the initiative, not only because of the prizes themselves, but because the STERLING initiative finally recognizes their efforts in maintaining good recycling habits. The STERLING initiative also allowed the community to better know what kind of packages went to the yellow container, and to apply this knowledge and the new acquired habits at home.

8. CONCLUSIONS AND FUTURE WORK

The pilot test conducted at the University of Valladolid have demonstrated that STERLING is a valid method to encourage recycling. We have test all the framework components (mobile app, sensoring software, cloud-based service) in a real environment with excellent results, both in terms of users involved and technical reliability. Our future work include to extend the STERLING initiative at a bigger scale, running a second pilot test in a small village, and to add new sensors, such as a tilt sensor to detect vandalism and GPS to periodically check the exact position of the recycling container.

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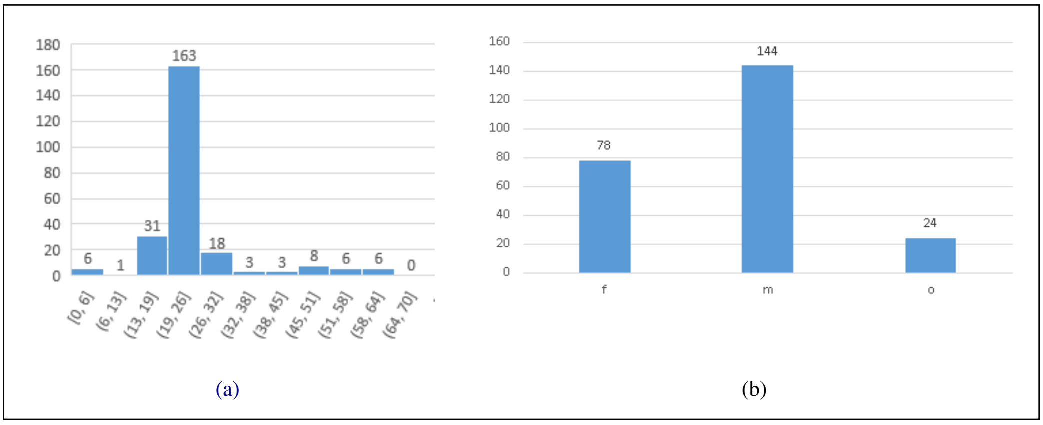

Figure 3. Age (a), and gender (b) (female, male, opt-out) of the users registered in the STERLING pilot test.

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