Waste Management System Based on IOT Aware and Cloud Services

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Abstract: Waste management is a challenge for modern cities as it impacts on environmental sustainability and on the level of quality perceived by citizens. In the last few years, several progresses have been made in this direction with the introduction in the city of door-to-door separate waste collection. A key element for the success of such actions is to achieve excellent cooperation from citizens. The Digital Transformation process in this sector will require time other than a careful management of the data associated with the waste collection processes. At this regard, the progress of hardware and software technologies enabling the Internet of Things (IoT) will contribute significantly to accelerate the whole process. Among these innovative solutions, the use of RFID tags with augmented capabilities and cloud-based software architectures capable of properly managing collected data will be crucial to obtain an intelligent and efficient waste management system. In this paper, an innovative system capable of capturing and processing data relating to the door-to-door separate waste collection in the context of future smart cities is presented. In particular, the system includes an innovative RFID sensor-tag equipped with low-cost weight sensors and a Cloud software system capable of managing the collected data and satisfying the various stakeholders' expectations. First results on both functional and performance validation of the overall system are shown

Keywords-Cloud, Embedded system, Internet of Things, Performance, Proof-of-Concept, RFID, Sensor-tag, Waste management

I.INTRODUCTION

Phenomena such as urbanization, industrialization and economic growth have resulted in increased solid waste generation per person. For this reason, waste management is one of the hardest challenges that modern cities have to face. Waste management includes several processes such as collection, transport, processing, disposal, management and monitoring of waste materials. These processes cost a considerable amount of money, time and work. This need perfectly fits with the modern concept of smart city, which is an urban area that uses different types of electronic data collection sensors to supply information useful to efficiently manage assets and resources. This includes data collected from citizens, devices, and assets that is processed and analyzed to monitor, and manage traffic and transportation systems, power plants, water supply networks, waste management, information systems, hospitals, and other community services. The smart city exploits the Information and Communication Technology (ICT) to integrate a plethora of physical devices connected to the network, the so-called Internet of Things (IoT) [1], [2], in order to optimize the efficiency of city operations and services. From a technological point of view, the solutions that are nowadays available for designing and developing new smart systems are innumerable, mainly due to the exponential spread of devices connected to the Internet. Sensors or actuators have acquired a new meaning because of the introduction of computational intelligence on the devices that were previously limited to sensing. Thanks to the development of microcontrollers and microcomputers with an operating system, it is now possible to design integrated systems with their own intelligence (edge-computing) or cloud-based systems over Internet, delegating the computational load to connected machines and reducing the cost. In this perspective, a smart system capable of monitoring the waste disposal process could represent the ideal solution to address the afore mentioned problem. In the field of waste management, several solutions are proposed in the literature, most of these are based on the use of RFID technology and Cloud-computing [3]-[8]. For instance, in [3], authors propose to equip each recyclable object with a RFID tag that stores basic information and helps users to sort waste in a right way. Nevertheless, this approach involves relevant changes, especially in the packaging system. [4] Proposes the use of a RFID card to authenticate the user who takes out waste and to collect some credits points given by the system. Another RFID-based system is shown in [5]. Despite the architecture is not described in detail, this solution allows to recognize users by a passive RFID tag on the garbage bin and to measure the amount of waste by a load cell sensor installed on the arms of the waste collecting vehicle. So, data are collected by a Personal Digital Assistant (PDA)-based RFID reader on the truck and, then, sent to the cloud via Wi-Fi. The system proposed in [6] provides a smart waste management, monitoring the fullness of garbage bins through the use of various types of sensors and technologies, such as Zig Bee, Raspberry and Smart-M3 platform. Furthermore, it allows to plan the best and shorter path followed by garbage trucks and the status of garbage bin are reported on an Android application. In this context, the aim of this paper is the definition and realization of a waste management system that provides several advanced features exploiting RFID technology with sensing capabilities [9]-[16] and Cloud technology [15]. Thanks to an innovative RFID tag applied on the garbage bin, the system allows to recognize and register citizens who make delivers and to detect the weight of the waste disposed by each citizen. Moreover, the system can register the timestamp of the withdrawal and where the waste was disposed. Finally, the dustman can report any anomalies (e.g., an erroneous waste disposal). Information is collected in a Cloud system and provided as a dashboard to users who request it (citizens, municipal authorities, etc.) based on their permissions. Furthermore, all collected data, appropriately anonym zed, can be made available as open data to be used by third-party services. The usage of the proposed system for the door-to-door waste management introduces several advantages that affects different areas: improvement in waste collection and disposal services with a consequent reduction in management costs for local administrations and greater control over the disposal process. In addition, the proposed system could make possible to implement a more precise and fair waste tax calculation system based on the actual number of waste collections. In this way the citizen would be more incentive to select the different types of materials in order to minimize the quantity of waste to be disposed and also contain the relative taxation.

II. PROPOSED SYSTEM

Due to its environmental impact, effective waste recycling is a more and more discussed topic from both research and industry fields. Despite door-to-door waste collection is spreading and the recycling is consequently increasing, some cost-effective technological improvements could motivate even more citizens to perform a correct and sustainable waste disposal. For this reason, this work aims at designing and experimenting an innovative waste management system for door-to-door collection. The proposed system would make the process more efficient and would allow to gather useful data to support municipalities in increasing citizens' collaboration and their level of satisfaction. The targeted system must be able to:

• Store data about the user delivering the waste. More specifically, the system has to record the weight of the waste disposed by each citizen. In this way, it is possible to make an analysis of the user's behavior in order to calculate, for example, the reduction of taxes on waste.

• Store data about date and time when the dustman performs the waste collection and the position of the garbage bin at the time of collection. In this way the system can detect whether or not a garbage bin is correctly collocated around the associated citizen's address;

• Store information related to anomalies detected by the dustman (e.g., incorrect waste disposal) in order to stimulate interventions towards less virtuous citizens.

• Show summarized information to different stakeholder (citizen, municipality, waste company, etc.);

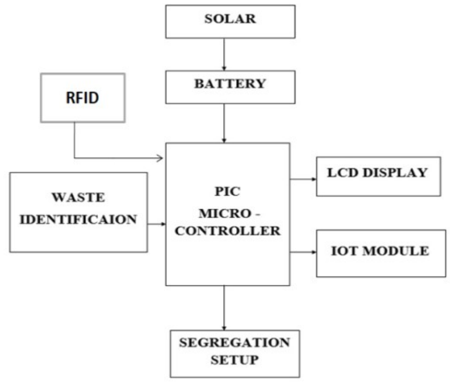
• make available and reusable collected information as Open Data for the creation of additional services useful to improve the management of smart cities. To satisfy such requirements, a specific hardware capable of allowing both bin identification and waste weight at time of collection is needed. This identification strategy leverages on UHF RFID technology augmented with sensing capabilities. Alongside the functional requirements, the system has to satisfy a series of non-functional requirements:

• Data confidentiality through appropriate authentication and authorization mechanisms, so that only registered and authorized users could access the information;

• Data integrity by adequately protecting the communication channel from any unauthorized third parties who attempt to access the channel to alter or subtract information;

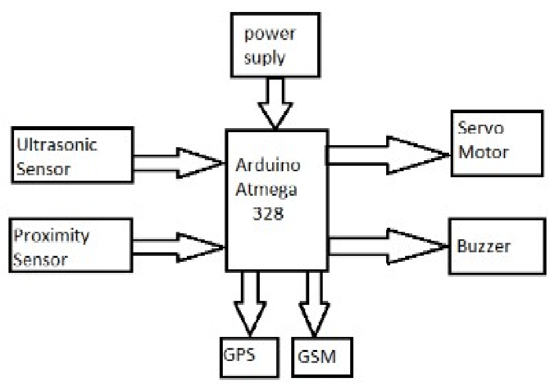
• ability to communicate with RFID readers in order to configure the data acquisition mode, set the power parameters for receiving and transmitting antennas, monitor the correct functioning of the reader, collect and filter events and store these events in Cloud.

BLOCK DIAGRAM



III-DESCRIPTION OF SYSTEM ARCHITECTURE

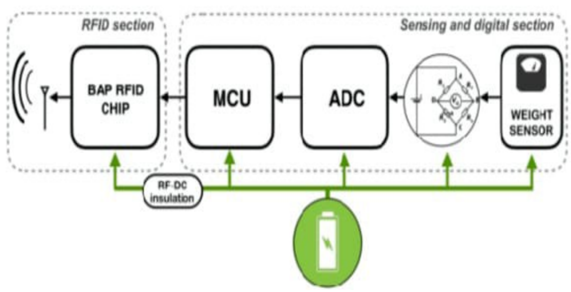
The proposed waste management system aims to manage the entire process of waste collection. Through a specifically designed RFID tag with weight-sensing capabilities, it permits to detect the amount of the urban waste produced by every citizen. As shown in Fig. 1, the system architecture consists of four main components: (i) an innovative RFID tag with augmented capabilities, (ii) a wearable RFID reader, (iii) a Cloud server, and (iv) a Web application. The RFID tag, placed on the garbage bin, is equipped with a sensor able to detect the weight of the waste. More detail about the RFID tag are reported in Section IV. The wearable RFID reader is responsible for collecting tag readings and for sending them to the Cloud server. The RFID reader communicates with the Cloud server through GPRS technology and it is able to store information in its EEPROM ifGPRS signal is temporary not available.



The Cloud server is in charge of storing and processing data coming from RFID reader and Web app. All information is stored in a relational database and queried through APIs. The database is mapped in the business logic through Object Relational Mapping (ORM) files. Moreover, business logic module manages data stream and also formats APIs requests and responses. Finally, the Web application provides users with dashboards summarizing data stored in the Cloud server. The Web application interacts with the Cloud server through an API module, getting all data required for business logic operations.

IV. DESIGN OF THE INNOVATIVE RFID SENSOR

The main feature of the sensor tag is the ability to sense the waste weight by using a weight sensor located on the bottom of the garbage bin. According to the previously stated requirements, a block diagram of the proposed BAP UHF RFID sensor tag architecture is shown in Fig. 2. The system architecture is composed of an RFID section, featured by a proper augmented RFID BAP chip, driven by a specifically designed sensing and data processing unit equipped with Microcontroller (MCU) and an analog weight sensor. The analog weight sensor information is digitalized through an Analog-to-Digital Converter (ADC) featured by a Wheatstone bridge front-end. The MCU manages the digital data, elaborates the related information, and transfers the data to the RFID chip through an SPI bus. The adopted RFID chip provides a double choice for memory access: the wireless standard access, and a wired access for MCU connection. In this way sensor data are directly accessible through a standard RFID reader by means of the antenna front-end. As for the implementation of the designed Sensor-Tag, the ADC model HX711 from Avia Semiconductor [18], which is a precision 24-bit ADC conceived for weight scale applications, has been selected. The ADC is interfaced with a Wheatstone bridge realized by using three SMD resistors of 330Ω each. If compared with a direct sensor-to-ADC connection, this approach improves the sensitivity of the sensor since, as well known, a slight current variation (produced by a weight difference) generates an appreciable voltage level at the Wheatstone bridge arms. The digital section of the novel RFID Sensor-Tag includes the 16-bit MSP430G2553 MCU from Texas Instruments [19] and the related external control circuitry. This ultra-low power microcontroller can run up to 16 MHz and supports a supply voltage range from 1.8 V to 3.6 V with a current consumption A at 1 MHz in Active Mode. The microcontroller



Sensor-Tag architecture

supports all the serial interfaces (SPI, UART and I2C) useful to interface a dual-access RFID chip. In this case, the EM4325 from EM Microelectronic [20] has been selected. It is particularly suitable for the proposed design due to its cost effectiveness and its reduced power consumption in BAP mode. To complete the design specific unbalanced RFID antenna designed to achieve the conjugate impedance matching with the selected unbalanced RFID chip has been designed. More in detail, a meandered PIFA antenna (Planar Inverted-F Antenna) has been optimized in terms of efficiency, return loss and radiation pattern at 866 MHz. In addition, a quarter-wave microstrip impedance transformer has been designed to insulate the antenna from the DC power supply section. This microstrip line (connected between RFID chip and battery) allows DC signal to pass while blocking higher frequencies. For the sake of completeness, Fig. 3 shows both top and bottom sides of the r = 4.7,εnovel RFID Sensor-Tag designed on a FR4 substrate (thickness of 1.52 mm) in CST Microwave Studio Environment, and Fig. 4 shows the detail of the designed digital section including the RF-DC insulation micro strip line. Fig. 5 shows the designed RFID PIFA antenna with the related dimensional parameters obtained after a CST Microwave Studio simulation and optimization to work in the European dedicated RFID band of 866MHz. Finally, a specific firmware has been designed to smartly alternate active and sleep periods according to the presence/absence of the electromagnetic field emitted by an RFID reader. Once designed the proposed Sensor-Tag has been also realized and connected to the external ADC and weight Sensor as shown in Fig. 6. Details about RFID Tag validation will be provided later on in the Results Section along with simulated and measured performance.

V. DETAILS ON SOFTWARE ARCHITECTURE

This Section provides a detailed description of the software components

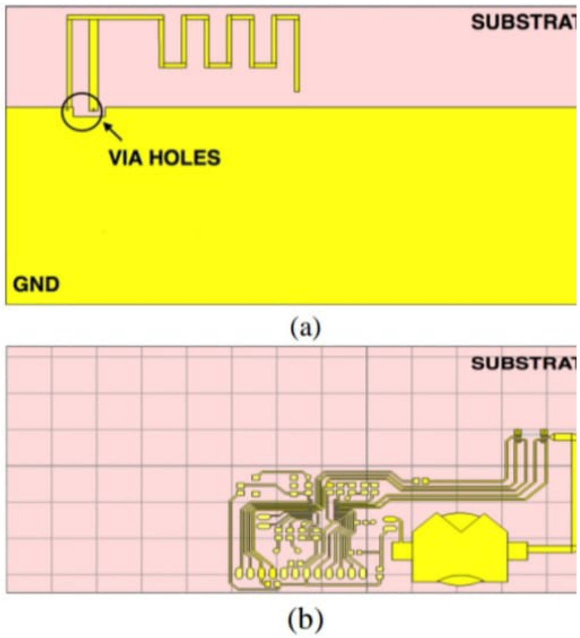


Fig3: Top (a) and bottom (b) layers of the proposed BAP tag. Dimensions: 13.3 x 6.8 x 0.438 cm3 (with battery-slot).

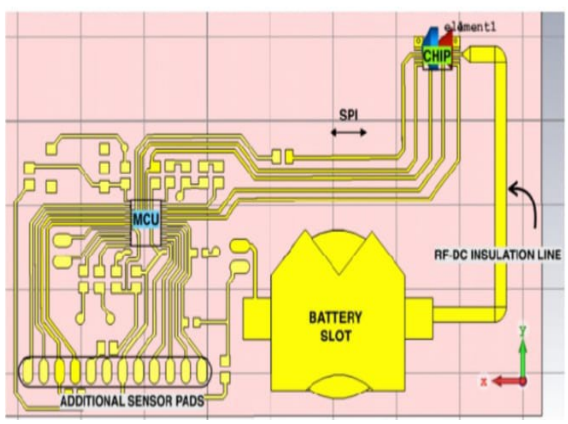


Fig4. Detail of the digital section of the novel RFID Sen’s

A .Cloud Server

The Cloud server has been developed using spring framework, through the Spring Boot project [21]. Spring Boot provides an effective way to set up, configure, and run web based applications. The entire server is deployed on the Cloud server provider Hurok [22] and its main modules are:

• Database. My SQL has been chosen as Database Management System (DBMS). The choice to use a relational database, instead of a non-relational database as No SQL, has been made because it guarantees Atomicity, Consistency, Isolation, Durability (ACID) properties, but also because the system requires a structured database to store data. Database schema consists of several tables and relationships. The Many-to-Many relationship between Reader and Garbage bin entities generates the main entity Reading that stores data coming from RFID reader, such as garbage bin ID and weight, but also anomalies and alerts. Database is mapped into the Cloud server exploiting Hibernate [23], an Object Relational Mapping (ORM) tool. In Fig. 7, the Entity-Relationship diagram shows the relationships of entity sets stored in the database.

• Business Logic Module. It has multiple roles. Firstly, it processes all data coming from both database and API module and provides a bidirectional communication between these blocks. In fact, this layer formats API response resulting from the query to the database. Moreover, it manages Authentication and Authorization processes, thanks to the implementation of JSON Web Token (JWT) and roles.

• API module. It provides public interfaces through which it is possible to retrieve data. In particular, this module handles the HTTP protocol through REST paradigm, allowing GET / PUT / POST / DELETE methods. The

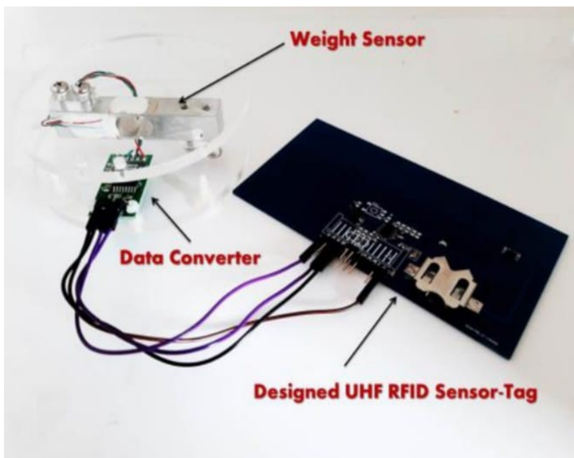


Fig.6. Realized RFID Sensor tag: connection with weight sensor.

REST ful APIs are reachable via URL endpoints. Fig. 8 shows a sequence diagram relating to the management of anomalies at the request of a registered municipality. All collected data has been also published in re-usable machine-readable formats (XML, JSON).

B. Web Application

The Web application has been developed using Angular framework [24], which allows the creation of scalable applications. In addition, it is a reliable framework with an extensive support community. The Web application consists of several modules: • API module. This module contains Angular Services for managing RESTful APIs provided by the Cloud server. This module manipulates JavaScript Object Notation (JSON) responses coming from the backend. • Business Logic Module. This module includes all the Angular components logic. It is in charge of processing and visualizing data through graphs and tables, but it also handles routing among pages. Furthermore, it manages Authentication and Authorization processes, through the implementation of Guards and Interceptors handling the tokens from server. • Views. Except for the login, each application page is restricted to authorized users. Once logged in, Municipality, Citizen and Waste Company can display the same section with different data. Dashboard is the main page that summarizes in form of graphs the amount of collected waste, sorted by typologies (e.g., organic, plastic, metal, etc.) and by month, week and day. The application also allows for searching and filtering the tag readings showing detailed reports of the weight of waste produced by citizen or collected by the dustman. Graphs are created support community. The Web application consists of several modules:

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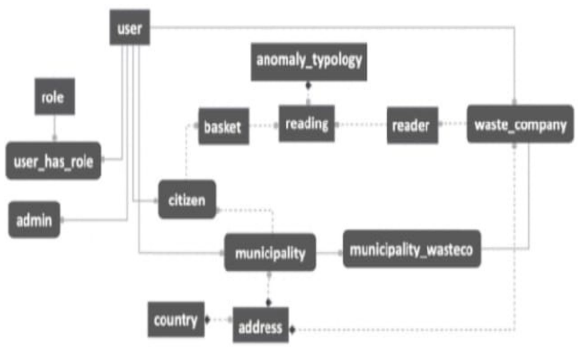


Fig. 7. Designed Entity-Relationship diagram.

The proposed cloud-based infrastructure reflects the IoT modern architectures, respecting all the requirements needed to obtain an efficient, flexible and scalable architecture. In particular, a 3-tier architecture has been developed consisting of: (i) Presentation layer, (ii) Application layer (server), (iii) Database Server. The Application layer between the user and the DBMS is responsible for communicating the user's requests to the DBMS system and send the response from the DBMS to the user. It also processes functional logic, constraints, and rules before passing data to the user or down to the DBMS.

VI. RESULTS

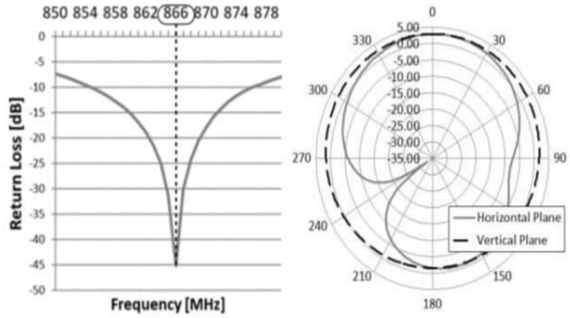
A. Setup test Environment

A specific experimental setup has been used to carry out the performance evaluation of the designed sensor tag in terms of tag sensitivity and maximum reading distance. It is based on a programmable RFID reader, the Thing Magic Mercury 6e (M6e), which is connected to a circularly polarized antenna with known gain (5.1 dBi). The system, deeply discussed in [26] and enhanced in [27], can vary both emitted power (up to 31.5 dBm) and frequency (in the range 860-960 MHz). In this way, for each interested frequency, the tag characterization system automatically evaluates the power threshold at the reader stage, which is the minimum power emitted by the reader obtained, as well as a maximum directivity of 2.267 dBi

Fig. 9. The Discovery Mobile UHF device, a wearable RFID reader by Sensor ID Company.

Besides the electromagnetic performance evaluation of the proposed sensor-tag, a further analysis has been performed to estimate the power consumption of the whole sensing solution. Since the tag is battery-assisted by a cell coin battery, a model to estimate the tag battery lifetime in a realistic use case has been developed. This power consumption model takes into account the maximum power that a single component dissipates for each working profile: active mode and standby mode. Being the components powered by the same supply source, at a fixed voltage of 3 V, currents have been considered instead of powers. The current consumption has been measured for each component by using a low-value shunt resistor of 1 Ω, in series with the component under test, connected to the probe of a digital oscilloscope. Obtained results are in very good agreement with those declared on the related datasheets. Results show that the EM4325 RFID chip supports an average current A in active mode. Thea in sleep mode and of 6.2 of 1.8 MSP430G2553 MCU exhibits a current consumption of A in standby mode.µA at 1 MHz in active mode and 0.55 µ246 The HX711 ADC exhibits a current consumption of about A in standby mode.µ1.6 mA in normal operation and of about 1 By considering a realistic reading profile of a few seconds (about 15 seconds for each reading session) and assuming to perform the tag reading twice a day (active mode), the Table I illustrates the estimated battery lifetime for cell coin batteries with similar physical size and different capacity.

Registered in the system has been carried out. For each tag reading, the RFID reader sends data to the Cloud Server by GPRS module. The Cloud server checks every new event and verifies the correspondence between tag ID and position (latitude and longitude) where the reading has been performed. In particular, the position is provided by the GPS module embedded in the wearable RFID reader. Since each tag ID corresponds to a specific citizen and consequently to a specific location, the Cloud server checks if reader's coordinates are into a region near citizen's house location. If not, an alert is notified to the system in order to prevent the theft of garbage bins. Data store in the Cloud server are properly processed and shown to different authorized users through



(a) (b)

TABLE I
BATTERY LIFETIME MODEL BUILT CONSIDERING BATTERIES WITH DIFFERENT CAPACITIES

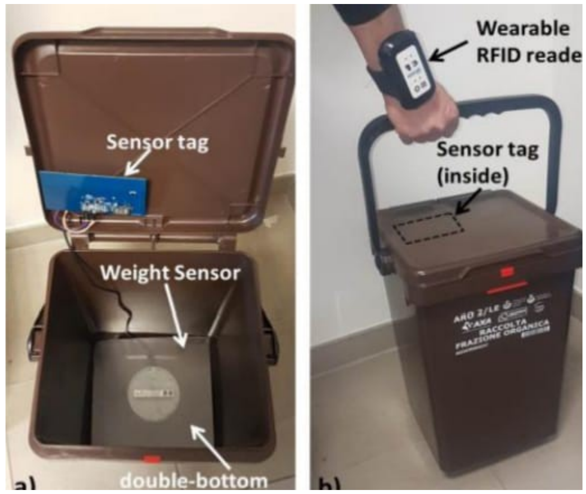
Product	Typical capacity	Lifetime
CR2032	220 mAh	> 6 years
CR2032 energizer	240 mAh	> 7 years
CR3032	500 mAh	15 years

• read the RFID tag, if no anomalies are detected;

• signal to the Cloud server the presence of an anomaly (e.g., the citizen has carried out an incorrect waste disposal). In this case, the dustman sets the reader in the “Anomaly

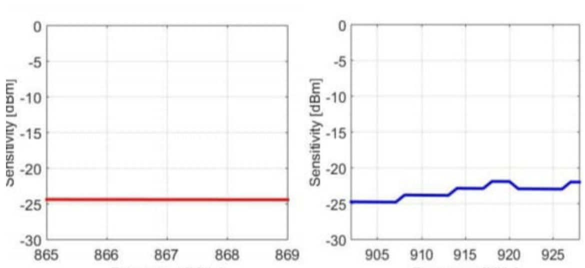
Mode” by pressing for 3 seconds the button programmed to the detected anomaly. In particular, during the second day (Tuesday), an anomaly due to an incorrect disposal has been simulated by pressing the appropriate button on the RFID reader whereas, during the fourth day (Thursday), a reading of a garbage bin placed away from the position in which it was registered in the system has been carried out.

OUTPUT



In particulars the software system is composed of a Cloud Server and a Web Application. The former includes a SQL database module, a business logic module and provides authentication functions. The latter includes dashboards and interfaces allowing users like Municipalities, Citizens and Waste Companies to summarize, in form of graphs or tables, the amount of collected waste and other statistical data sorted by typologies. The proposed platform highlights optimum performance in terms of Sen maintenance, with a very long duration

B. Performance Analysis of the proposed RFID Sensor-Tag In this paragraph, the RFID Sensor-Tag, presented in Section IV, is validated from the electromagnetic point of view. All the simulated outcomes have been performed by using CST Microwaves studio, whilst measurement results have been obtained by using the dedicated measurement setup described in the previous sub-section. In particular, Fig. 10 shows the final results achieved from the simulations in terms of antenna return loss and radiation pattern. A return loss lower than -45 dB has been obtained at the desired frequency of 866 MHz with a bandwidth ranging between 855 and 876 MHz The radiation pattern exhibits a -3dB angular width of 102° on the horizontal plane and of 90° on the vertical one. Finally, an appreciable simulated antenna radiation efficiency of -1.2 dB has been obtained, as well as a maximum directivity of 2.267 dBi. As for the measured results, Fig. 11 shows both planes of the antenna radiation pattern evaluated at 866 MHz The very good agreement with the simulated radiation pattern of Fig 8-b can be appreciated thus confirming the suitability of the realization process. In addition, the tag sensitivity has been also evaluated. As clear from Fig. 12, at the desired frequency of 866 MHz a tag sensitivity of -24.38 dBm has been measured. This sensitivity value corresponds to an estimated maximum reading range of about 16 m when a power of 2 ERP is used at the reader stage. It is important to observe that in the waste management system, this relatively appreciable sensitivity value allows the dustman to minimize the power emitted by the portable reader, thus increasing the battery life. This last aspect is crucial even to realize more and more compact and comfortable wearable readers while reducing the emitted power.



(a) (b)

Fig. 12. (a) Measured Tag Sensitivity at 866 MHz centered band, (b) Measured Tag Sensitivity at 915 MHz centered band.

VII. CONCLUSION

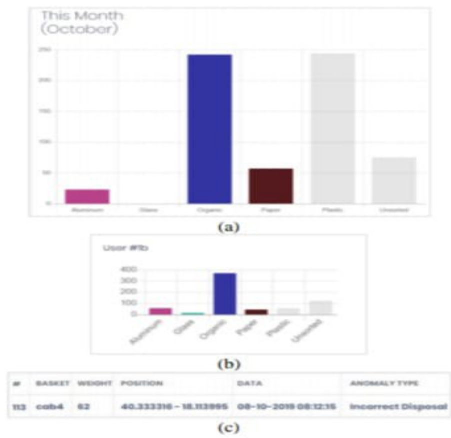


Fig. 15. A detail of the Citizen view (a), a detail of the Municipality view: waste disposal performed by a Citizen (b), and Example of an anomaly reported by the system (c).

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