A Smart Waste Management with Self-Describing objects

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***Abstract*—Radio Frequency Identification (RFID) is a pervasive computing technology that can be used to improve waste management by providing early automatic identification of waste at bin level. In this paper, we propose a smart bin application based on information self-contained in tags associated to each waste item. The wastes are tracked by smart bins using a RFID-based system without requiring the support of an external information system. Two crucial features of the selective sorting process can be improved using this approach. First, the user is helped in the application of selective sorting. Second, the smart bin knows its content and can report back to the rest of the recycling chain.**

Keywords-green IT; waste management; recycling chain; RFID; NFC; QR code.

I. INTRODUCTION

Waste management is an important requirement for ecologically sustainable development in many countries. Efficient sorting of waste is a major issue in today's society. In Europe, the consumer society has led to an ever increasing production of waste [1]. This is a consequence of the consumer's behavior, and worsened by packaging. In [2], it is shown, that the production of waste reaches almost 1.2 kg/day/inhabitant in western Europe. Paradoxically, the same consumers who are very sensitive to environmental protection are often reluctant when it comes to have more land-filing or more incinerators. Therefore, waste should be disposed and treated properly to reduce environmental impact.

Waste management services are becoming an important market, for which the waste collection process is a critical aspect for the service providers [3], [4]. The main goals are the following :

1) Reducing waste production
2) Ensuring that wastes are properly disposed
3) Recycling and re-using disposed products

To achieve these goals, regulations and taxes are being implemented to favor virtuous behaviors. In particular, to reduce the production of waste, there is an increasing trend towards individual billing, where people are charged depending on waste quantity disposed.

Selective sorting is another approach, which is often implemented to improve recycling and reduce the environment impact. The importance of resources and energy saving is another argument to manufacture recyclable materials.

The sorting of wastes must be implemented as early as possible in the chain to increase the quantity of valuable recyclable materials. The use of pervasive computing technology such as Radio Frequency Identification (RFID), and sensor networks offer a new way to optimize the waste management systems.

In recent years, we have seen increasing adoption of the radio-frequency identification (RFID) technology in many application domains, such as logistic, inventory, public transportation and security. Essentially, RFID makes it possible to read digital information from one or several objects using a reader at proximity of the objects, enabling automatic identification, tracking, checking of properties, etc. It is predicated that RFID could replace barcode and attached to most products by manufacturers and/or retailers. In this perspective, RFID would be an important opportunity for waste management, as RFID tags could be used to improve current waste management processes.

This paper proposes a method to improve the quality of selective sorting. This approach is based on local interactions to track the waste flow of a city. Each waste is detected by information properties stored in a RFID tag associated to it. At each step where wastes are to be processed the RFID tags are read in order to provide the relevant information. This process improves the sorting quality of recyclable products. We assume organic wastes products are not recycled and hence RFID tags are not attached to it.

Without using an external information system, RFID can improve the selective sorting quality. The information stored in each tag associated to a waste can be used to help the user in the sorting process, and to analyze the content of a bin.

This article is organized as follows. The next section outlines the architecture used to process the waste flow in our waste management system. The third section presents a tagged (or self "describing") waste approach. The fourth section details our RFID system to help the individual sorting of the wastes, while the fifth section discusses some related works. Finally, Section VI concludes the paper.

II. WASTE FLOW AND GLOBAL ARCHITECTURE OF THE WASTE MANAGEMENT SYSTEM

The waste management architecture we consider is built around several elements: waste items, domestic bin, trash bags, collective containers and collecting vehicules. The waste flow

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starts from the waste items and the domestic bin to end in the collecting vehicules. We now describe each of step in the waste flow and how elements interact.

A. Wastes description

The presented management system is based on a self-describing approach of each waste. We propose to associate digital information to each waste to ensure an appropriate treatment of each item. This is a key point of this approach.

In the selective sorting process, the type of a waste item is identified by its main component. For example, a plastic bottle is identified as a plastic waste, and a cardboard box is identified as a cardboard waste. In the presented approach, each self-describing waste carried digital information about its type. Other properties of the waste are interesting for the collection process of the wastes. For example, the weight of each wastes can be used to estimate if a bin is full, or empty. Without using measurement sensors, the weight data of a waste item can be stored in digital information attached to it, making itself describing.

B. Wastes identification

The user is the principal element of the selective sorting process. Based on this observation, our waste management system proposes some pervasive assistance for the selective sorting process. Then, the waste flow presented in Figure 1, begins at the user level where the trash is generated. As it is shown on the top of Figure 1, we propose to favor a behavior of the users: by indicating the appropriate bin for a waste, or more directly, by opening the lid of the bin corresponding to the type of the waste.

C. Trash bag

To ensure an appropiate treatment, the knowledge of the type of wastes contained in a trash bag is crucial. As for the wastes, it is also possible to associate several properties of each trash bag: for example, the owner of the trash bag, and the number of items in the trash bag can also be considered. In the prototype presented in the next sections, some digital information about the total weight of the trash bag, its content and the number of items contained in the trash bag are physically associated to each trash bag. In this prototype, some digital information is also associated to identify the owner of a trash bag: the interest is to identify the waste production of each consumer. This information defines an analysis report associated to each trash bag.

The analysis report stores some important information for the selective sorting process. The information stored in the analysis report is to determine whether the trash bag could be accepted. In Figure 1, this analysis report is transmitted to the collective container, when a user brings a new trash bag.

D. Collective container

In our waste management system, each collective container is associated to an embedded computing system which processes the data of the analysis report of each trash bag, making it a smart bin. When a new trash bag is added in a collective container, the analysis report is read.

Considering the type of wastes contained in a trash bag, a collective container determines whether it could accept a trash bag or not. For example, a collective container collecting only plastic wastes can stay closed when a user brings a trash bag containing the cardboard objects: it would only be opened for a bag of plastic wastes. If the trash bag is accepted, the smart bin stores some information about the content and about the owner of each trash bag. Then, the content of a collective container is iteratively updated as a new trash bag is added. The information stored by the collective container is transmitted to the truck during the collection by using a local connection, as it is presented on the bottom of Figure 1. At this step, the errors of the selective process can get transmitted. Among the collection of wastes, the highly polluting wastes which are not placed in the appropriate container, are detected: for example, it becomes possible to detect a battery placed in the container dedicated to plastic waste.

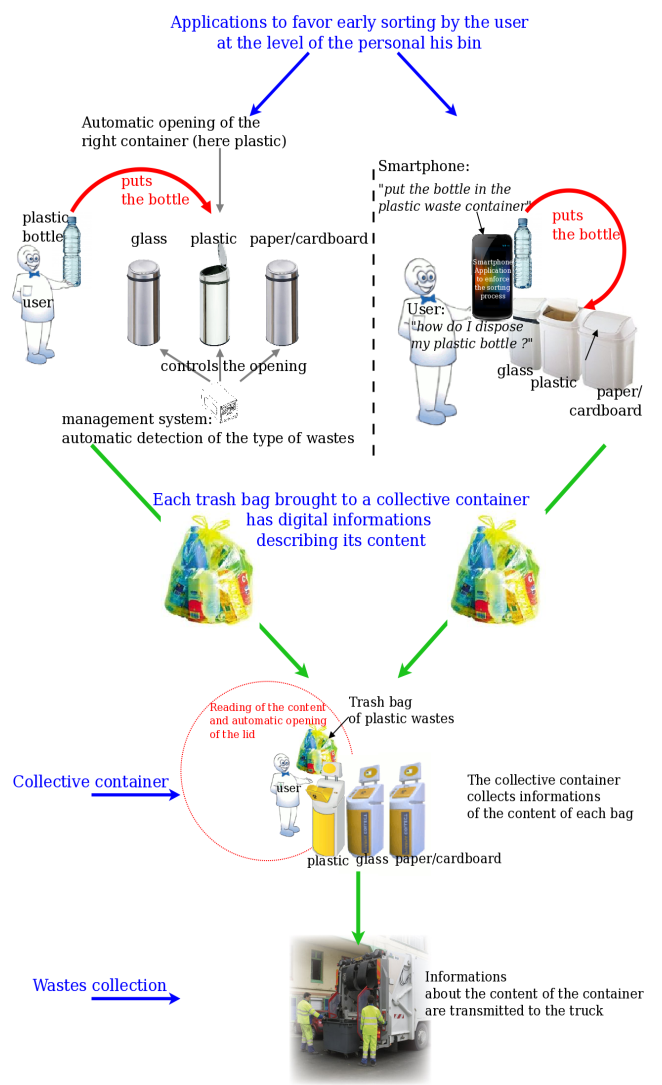

Figure 1. Waste flow and global architecture of the system.

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Considering this waste flow, we now present a system based on RFID technology to implement this waste sorting process.

III. A SMART WASTE APPROACH

The *smart waste approach* consists of associating a physical waste with digital information. In our approach, information associated to a waste can be stored in a QR code or in a RFID tag memory. Using QR codes does not introduce an additional cost. However, QR code requires the object to be in line of sight. Unlike this technology, the RFID tags can be read without requiring a precise position relative to the reader during the reading operation. The UHF tags, are used increasingly in the supply chain management and can be easily read at a distance of five meters from the reader antenna. In this context it is easy to envisage a widespread deployement of the RFID tags on each manufactured product. This is an important advantage for using RFID technology in the waste management domain.

The tagged waste concept uses the data banks memory of a tag to store information about each waste associated to the tag. The tag memory is not used to store an identifer of the waste in an external database, but the information describing the associated waste is directly stored in the associated tag. A connection to an external database is not required to have some information about the smarte wastes. Only a RFID reader is required to read the information of a smart waste. Figure 2 presents a smart waste composed of a plastic bottle associated to a RFID tag which stores the data describing the bottle as a plastic object.

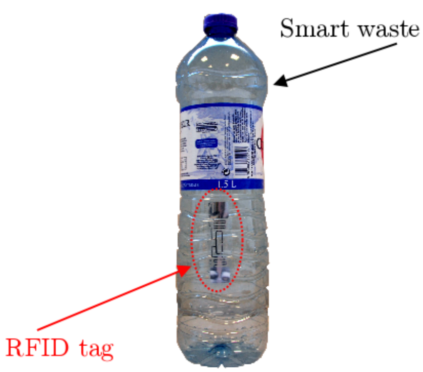

Figure 2. An example of a smart waste.

A RFID tag contains data banks for the users applications. The memory size of data banks is limited. For example, an UHF tag ALIEN ALN-9640 Squiggle shown in Figure 3 can store 512 bits of information.

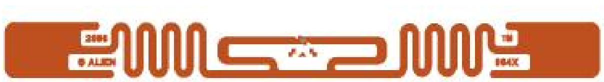

Figure 3. The ALN-9640 Squiggle Alien tag.

In [5], the classification of type of wastes is proposed. In this classification, each type of waste is associated to an identification number. Taking examples from everyday life:

- the cardboard is associated to the reference 200101,
- the glass is associated to the reference 200102,
- the plastic is associated to the reference 200139.

The smart waste concept proposes to use the classification [5], to store the reference number representing the type of the waste in memory blocks of each tag associated to a waste. As it is shown in Figure 4, our prototype also saves in the tag memory of each smart waste, the weight (represented by a measure in grams, encoded in hexadecimal) of the waste associated to the tag.

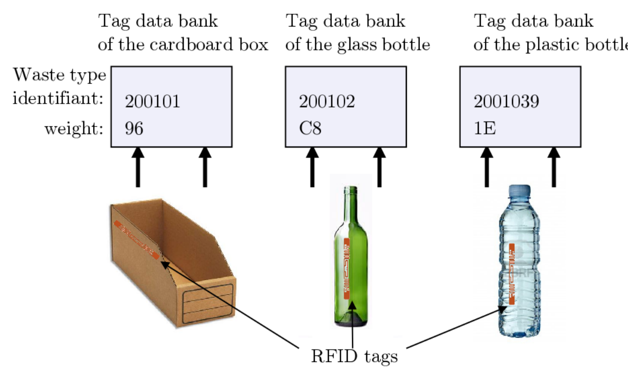

Figure 4. Representation of the information in the tag memory.

The weight encryption presented in Figure 4 is a way to store directly the description of each waste directly in the associated tag.

IV. A RFID WASTE SORTING SYSTEM

In this section, we describe the step of the domestic collection of the wastes. The presented approach proposed a smart bin which produces smart trash bags. At the end of this waste flow, the collective smart bin is presented.

A. Individual smart bins

At the first step of our waste sorting system, the information contained in the RFID tag associated to each smart waste is used to help the people discarding an object in the appropriate container. Here, the main goal is to reduce the sorting errors when someone does not know which is the right container, or mistakenly discards the object in the wrong one. It is also help people to learn the selective sorting rules applied locally. The smart bin system uses the self-describing approach of smart wastes to improve the selective sorting quality.

The description of smart wastes is stored in a RFID tag physically associated to each smart waste. Using a RFID reader, the smart bin reads the RFID tag attached to each smart waste to determine the appropiate treatment. Let's consider the example of someone who wants to discard a plastic bottle in a bin. He puts the bottle near a smart bin as it is shown on Figure 5. When the plastic bottle is in the antenna area, the

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tag associated to the bottle is detected. The data stored in the tag is read to determine the appropriate procedure to discard the bottle. If the bin accepts plastic objects, then the system opens the lid of the bin. Otherwise, the system keeps closed the lid of the bin.

Note that it is also possible to control the opening of several containers using a single RFID reader. Figure 5 presents a prototype of a selective bin. In this approach, a management system connected to a RFID reader uses the data stored on waste tags to open the correct containers. In this example, when someone want to discard a pastic bottle, the container for the plastic wastes is opened by the management system. On Figure 5, only the lid of plastic container will be opened, all other lids will remain closed.

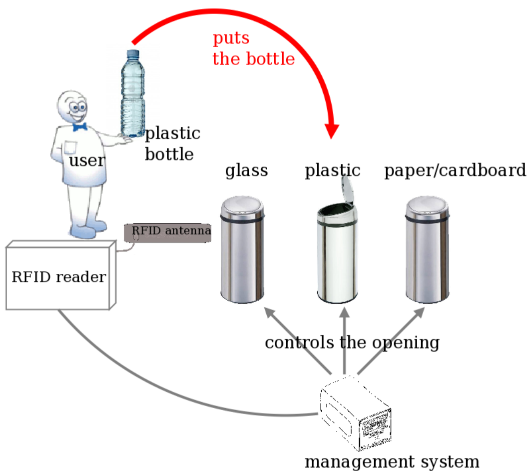

Figure 5. A RFID based selective bin.

This approach assumes that the management system tracks the information of the wastes that are discarded in each container of a selective bin. When a waste is discarded in the container, the management system updates the memory inventory for this type of waste. In this way, undesirable wastes for a given container are either rejected or tracked, depending on the choosen policy for handling undesirable wastes.

The scanning of products is done itemwise to ensure a complete reliable reading process.

Figure 6 presents a prototype of a smart bin based on UHF RFID tags and a UHF RFID reader which implements this approach.

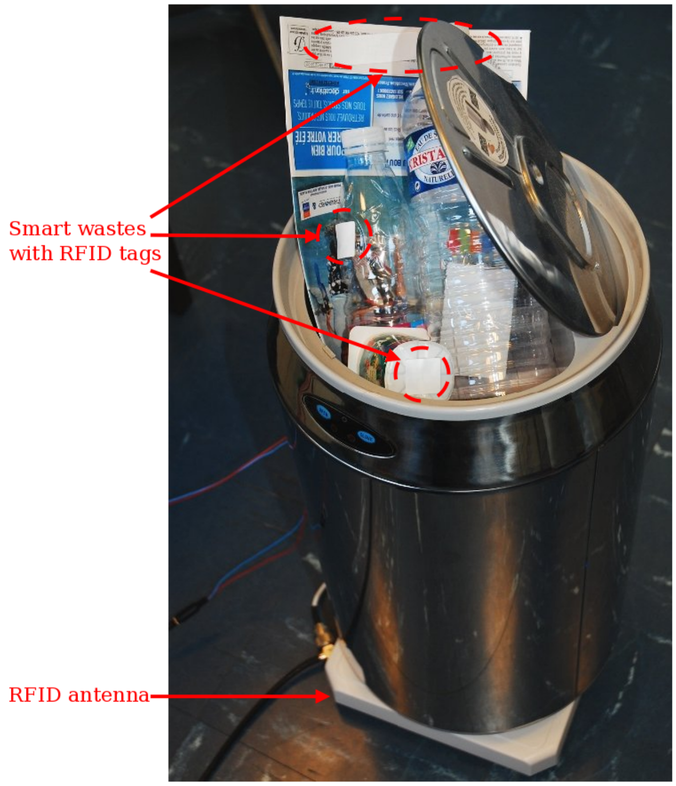

Figure 6. An individual bin using the RFID technology.

UHF RFID technology is already used in the supply chain management systems. In this context, a UHF tag is placed on the packaging of each product at the begining of its lifecycle. Since the UHF tag is already attached on the packaging of each product for the supply chain management process, we are interested to reuse the tag and its technology in our smart bin approach.

B. Use of QR codes technology for a cheaper approach

The passive UHF RFID tags are very cheap, ranging from \$0.25 to \$0.40 per tag. However, the price of a UHF RFID reader is still expensive (around \$2000). The current cost of the RFID reader can be a important issue for widespread deployment of the RFID technology in the smart bins of the households. We introduce here a cheaper solution using QR codes technology that would allow an early adoption of some of the concepts and applications presented previously. This approach is based on the NFC sensor embedded in the smartphone of the users.

This alternative approach assumes that every waste is associated to a QR code describing its type. The mobile application maintains in its memory the current inventory for each type of collected wastes (for example, 3 inventories if there are 3 types of collected waste). Waste disposal would require users to scan each item, allowing the mobile application to update the current inventory for this type of waste in phone's memory. Some other waste properties, such as weight, could also be collected at this step.

A smartphone is a small, low-cost, mobile computer. Moreover, most smartphones now embedd a camera enabling them to read bar codes or 2-dimensional QR codes (also known as “flash codes”). A first step in the solution would consist to scan a QR code (or bar code) associated to a product, and to use this information for giving a sorting instruction to the smartphone of the user. As in the approach of the individual RFID bin presented in section IV-A, it is also important to report the actions of the user to the waste collecting chain.

On figure 7, a user wants to drop a plastic bottle. He scans the QR code associated to bottle. The properties associated to the bottle are added to the inventory of the plastic container that is stored in the smartphone’s memory.

Figure 7. Reading of a QR code associated to a waste.

Obviously, reading QR code is less convenient than RFID reading. In addition, in this approach the opening of the lid is also not controlled by an automatic system. However, this approach allows the deployment of the rest of the chain without requiring the smart bins presented in secion IV-A inside each home. Beside being cheaper, the mobile application also provides helpful support to the user regarding the selective sorting rules in application.

Like the individual bin presented in section IV-A, the management system of the collective bin tracks wastes properties as they are disposed. When a smart trash bag associated to a RFID tag is dropped in the collective container, the management system updates the collective inventory according to the new bag’s content. Prevention of sorting errors is also possible, provided that the user actually fills his trash bags according to what he scans.

We don’t rely a network connection on the bin instead it is the waste bag itself which will store the waste inventory. As we will see in next section.

C. *Smart trash bag*

In the individual selective sorting point like a smart bin in the kitchen of a user, the wastes are not directly deposited in the container of the bin. Every user uses a trash bag, which will be dropped to a collective container, or put at the entry of every households for being collected by the service provider.

The *smart trash bag concept* is smart in the sense that the waste management infrastructure (bin, truck) will be able to check its contents. A smart trash bag is a trash bag associated to a RFID tag, as it is shown in Figure 8. The tag associated to a smart trash bag, offers a memory space to store some information about the contents of the trash bag: type of wastes, number of items. The RFID tag associated to the smart trash bag also stores some information about its owner: name, adress, etc.

Figure 8. A smart trash bag.

Writing data in the tag associated to the smart trash bag about its content is very simple: for each new waste added, it is identified by reading the waste tag; then, the trash bag content is updated by writing in the trash bag’s tag with the updated information about its content. This approach enables the tracking of trash bag content. Various information can be reported: the type and quantity of wastes contained in the bag, total weight of the content, and the interactions between the wastes. In this approach, it is assumed that the management system ensures that all the wastes of a container belong to the same type. Then, it is just necessary to store the expected type of wastes in the analysis report. The weight of the smart bag is estimated by considering the weight of each smart waste contained in it. When a smart waste is added, its weight is read in the tag memory of the smart waste. The weight of the smart trash bag is refreshed by adding the weight of this smart waste to its current weight. The weight is computed when a smart waste is added. This iterative process uses the information stored in the tag associated to each smart waste. This approach is totally autonomous and based on the information stored in the tags associated to each smart waste. A connection to an external information system is not required to obtain the information associated to each waste.

As it is illustred in Figure 9, the information stored in the tag associated to the smart trash bag, are encoded by a

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sequence of bytes. The storage of the identifier of the owner uses three bytes. Using the classification of wastes [5], the type of wastes is stored on six hexadecimal digit: three bytes. The number of waste items is stored on one byte. The weight (in gram) of the content is stored on two bytes. Without require to an external database, the description of trash bags content is direcly carried by the tag associated to the trash bag.

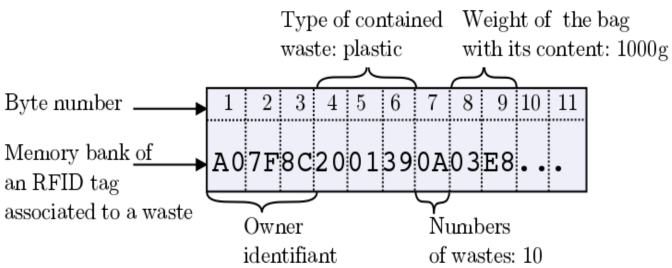

Figure 9. Data memory structuration of a smart trash bag.

The individual smart bin approach presented in Section IV-A assumes that the management system tracks the information of the wastes that are discarded in each container of a selective bin. To this end, the management system updates the analysis report of a container when a smart waste is added in the container. The whole report is stored locally in the memory of a tag associated to the smart trash bags. In the prototype in Figure 6, the analysis report stores the information about the owner of the smart trash bag, the type of the content, the number of wastes, and the weight of the content, using the data representations shown in Figure 9.

We have also developed an application to store the analysis report of the content of a trash bag for the cheaper solution using QR codes technology presented in Section IV-B. In our prototype, the NFC technology provides this second step of the solution: NFC-enabled smartphones can interact in close proximity: in particular, they can read some RFID tags and also emulate the response of some tags. It is in the former functionality that we are interested, as it allows a user to write the required information in a trash bag's tag using only an NFC smartphone.

Figure 10. Writing analysis report operation with a smartphone.

When the bag for a given type is full, the mobile application is used to write the inventory in the RFID tag attached to the trash bag (figure 10). The smartphone uses its NFC reader/writer for this operation. Then the user closes his trash bag of plastic wastes. Now, he uses his smartphones application to write the inventory of the trash bag, in an NFC tag associated to the bag.

D. *Collective smart bins*

The *collective smart bin* collects the smart trash bags produces by the users. Here, we consider a scenario for the collective smart bins, which can be placed in a condominium of several apartments or in a street. Using the self-describing approach of the smart trash bag, the collective smart bin monitors the flow of wastes, and it detects the alerts: fire, mistake of sorting, detection of undesirable objects. The information about its content is transmitted by an ambient network or local Bluetooth connection during the collection, according to the type of information. As for the individual bin approach for helping the sorting process, it is possible to open a container only when objects of the correct type is brought by a user. The RFID inventories cannot ensure that all the tags have been detected in antenna area of a reader, meaning that missing tags are unnoticed. Considering this limitation, we propose an "incremental" approach, where the global content of the collective container is updated each time a bag is disposed.

The analysis report of the content of a trash bag presented in Section IV-A is used to update content of the collective bin. This approach is based on the self-describing concept of the content of a container. As the same way that the individual container stores knowledge about the wastes, the collective container stores knowledge about the smart trash bags. It is a new way to measure the state of a container without require to the classical use of several sensors. For example, the weight of content, the size, or the type can be measured by using the information store in the tag of each waste of a container, without use one specific type of sensor for a specific property. For example, the total weight of the wastes of a collective container can be estimated by incrementally adding the weigth of each smart trash bag brought to the collective container. The information stored in the tag of the smart trash bag is only needed. This autonomous approach facilitates a large scale deployment of the smart bins.

Figure 11 shows a user in a garbage room. He presents his trash in reading area, where the trash bag's tag is read.

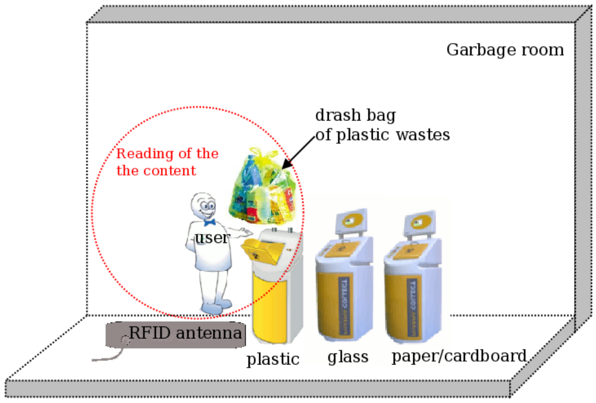

Figure 11. An individual bin using the RFID technology.

The analysis report of the content of the trash bag is transmitted by the reader to the container's controller. The controller can then determine the appropriate action, depending on the bag's content and the local policy. For example, it could reject the bag if it contains an inappropriate item (container remains closed), explaining the cause of rejection to the user (such as "glass is not accepted in this container"). Implementing this policy is a way to avoid that a sorted container is contaminated by undesirable material. For example, it becomes impossible to polluted a container for the plastic wastes with the metal cap of a plastic bottle.

V. Related works

Some other approaches using the RFID technology for waste management systems have already been proposed. In [6], the author discusses about several applications of the RFID in the process of collecting wastes. The identification of each bin associated to a RFID tag is principally mentioned. The storage in a tag associated to each product some information about the end-of-life management process of the product, is also evoked in the paper.

These approaches propose to identify each bin using an identifier stored in a RFID tag associated to the container. In [7], [8], using this identifier, the author proposes to associate in an external database each container with the address of the household owning the container. The volume of wastes estimate the quantity of waste produced by each household. It is not an information based approach but a physical measurement approach using sensor. The estimation of the volume of waste is computed using an image analysis from a picture of the content of the bin (when the lid of the container is opened). The data are transferred using a GPRS connection to an external database.

The idea developped in [9] is also very close to this approach. In [9], a sensor measures the weight of the bin placed on the truck which collects the bins. It differs to our approach which proposes to use a self-describing approach of wastes to compute the weight of a container. At each collection operation, the truck saves the weight of each bin. The RFID tags are used to store an identifier in a external database of the owner of each container. This approach is not autonous, but using a Wifi connection, the external database of waste production is updated for each household. It becomes easy to track the waste production of each household. In [10], the author presents a real deployment of a system using an approach similar to the approach proposed in [9].

The concept developed in [11] rewards consumers for recycling empty packaging. The consumers are identified by a RFID tag associated to their bin. Also based on a weight measurement of their recycling packaging, the consumer can log into his personal account to view how much they have recycled, as well as statistics such as the number of trees saved by their effort. Every month, the consumers are also rewarded financially.

Actually, selective sorting is not the priority of these applications. RFID is used by the container to identify its owner. To ensure the selective sorting, it is track waste at the item level. This is why item level RFID tagging can have an important role to play in the selective sorting, provided that the tag contain information about the components of the waste.

In [12], the presented approach also considers that each product is associated to an RFID tags from the begining of its cycle of life. The information stored in the RFID tags is not used to help the user in the selecting selective process. The authors use the RFID technology at another level of the selective sorting process. The RFID tags associated to each product is used to help the service provider of recycling to decide of the appropriate treatment of a product. In this approach, the data stored in the RFID tags are used to access to the information of products in several databases from a single identifer of each product. This approach of the usability of the RFID technology in the recycling process is not autonomous. A major difficulty is then to shared some conformable information about a product accross several databases, and during all the life cycle of the product.

The main goal developed in [13] is to bring out the environmental impact of RFID used in everyday life. The author discusses RFID for the waste management: a system of discounts and fees to stimulate responsible behavior of users in the selective sorting process, is also discussed. The idea of a bin which collects some information about the wastes is mentioned, although its implementation is not discussed. More generally, in [14], the author predicts an important development of RFID applications in the product recycling chains.

The approach that we propose is innovative in its information processing architecture: the properties are directly attached to physical objects (waste, bags) and data are "moved" and processed along with the physical flow of wastes. Several systems for encoding the waste description are discussed. The most simple way is to encode the component of each waste in plain text. A more advanced approach is described inn [15], where an ontology for waste is used. Class definitions enable fine sorting decision to be taken, based on the waste composition. For example, a bin may accept only items containing at least 90% of plastic. The interest of this method is to select the best bin considering all the components of a waste bring by

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a user. For example, all the wastes which contains more than 80% of glass, can be bring to a bin for recycling the glass. This idea could be combined with the approach proposed in this paper to provide a smarter sorting solution.

VI. Conclusion

In this paper, we propose a new solution to enhance waste collection efficiency using the RFID technology. Fully relying on digital information attached to waste items, this approach does not require any sensor, nor external information system support, enabling high scalability and availability. The presented system helps the user in correctly sorting and disposing wastes.

Regarding the waste sorting support, the user is oriented to the correct container to dispose the waste, and is helped in case of errors. Another contribution of this system is to be able to report the content of a bin. This information is useful to waste processing operators, for example to optimize waste collection scheduling, or to set up a special handling when an undesirable product is detected somewhere.

The reported information about the content of each bin is also a way to compute statistics of each type of waste in the recycling process. The smart bins can precisely determine the quantity of each type of waste produces by a household. It should help people to contribute to a more efficient sorting of waste, and reuse valuable materials. By considering the value of wastes produced by each household, it becomes possible to make a retributive incentive system to encourage each user to make the selective sorting of its wastes.

This approach can also help to better plan waste collection and special intervention by operators in case of anormal conditions. The latter feature is based on an ambient communication infrastructure, which we do not describe here. An energy efficient protocol for long life operation such as waste containers is presented in [16].

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