MANAGEMENT FRAMEWORK FOR USED COOKING OIL COLLECTION

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SUMMARY

The production of waste pollutants has increased in recent decades at an impressive rate. These pollutants pose a threat to life on our planet, so it is increasingly important to process them correctly. Fortunately, today it is possible to obtain profit through the reuse and recycling of most of these residues, in particular, of vegetable oil, which is especially interesting due to the potential of transforming it into biodiesel. However, this process does present some constraints, mainly related to the operating costs associated with its collection. This paper proposes a new platform that aims to simplify the bureaucracy of the process and optimize the collection routes, thus maximizing the potential profit to be obtained from this business.

Introduction

The production of waste has been increasing in recent decades (AWE Magazine, 2005). This waste usually requires special treatment in order to prevent the pollution of the environment and avoid a global catastrophe (UNEP/GRID-Arendal, 2006; Baker *et al*., s.d.). In 1995 each individual produced an average of 460kg of waste. This value increased to 520kg per person in 2004 and is predicted to rise to as much as 680kg per person in 2020. This represents an increase of ~50% within 25 years (EEA, 2008).

This increase of waste is due, in most part, to the increase in consumption, resulting in a reduction in raw materials. Today, however, the recycling of solid waste (paper, plastic, metal and glass) is a reality because of the investment that has been made in the area, and especially due to the increase in collection points exclusively for this type of waste. However, the recycling of liquid waste, excluding water treatment that has been a reality for a long time (European Commission, 2000), is virtually non-existent.

The processing of used cooking oil (UCO) is a subject that is frequently ignored or overlooked, and does not receive the attention

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PROCEDIMIENTO PARA RECOLECCIÓN DE DESECHOS DE ACEITES COMESTIBLES USADOS

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RESUMEN

La producción de residuos contaminantes ha aumentado en las últimas décadas a un ritmo impresionante. Estos residuos representan una amenaza para la vida en nuestro planeta; por lo tanto, se hace más importante darles un tratamiento apropiado. Hoy en día es, afortunadamente, posible obtener ganancias de la reutilización y el reciclado de la mayor parte de estos residuos, en especial los aceites vegetales, que son particularmente interesantes debido a la posibilidad de su transformación en biodiesel. Sin embargo, este proceso presenta algunas limitaciones, principalmente como resultado de los costos de explotación ligados a su recoleccción. En este trabajo se propone una nueva plataforma que tiene por objeto simplificar la burocracia del proceso y la optimización de rutas de recolección y así maximizar el beneficio en este negocio.

PLATAFORMA PARA ECOLHA DE ÓLEOS VEGETAIS USADOS

André Sousa, José Faria, Ramiro Gonçalves, António Pereira e João Barroso

RESUMO

A produção de resíduos poluentes tem vindo a aumentar nas últimas décadas a um ritmo impressionante. Estes resíduos representam uma ameaça para a vida no nosso planeta, pelo que, se torna premente dar-lhes um tratamento próprio. Hoje felizmente é possível a obtenção de lucro na reutilização e reciclagem da maioria destes resíduos, designadamente, os óleos vegetais usados, que são particularmente interessantes devido à possibilidade de transformação em biodiesel. No entanto este processo apresenta alguns constrangimentos, resultantes sobretudo dos custos operacionais associados à sua recolha. Neste artigo propomos uma nova plataforma que tem como objetivo simplificar a burocracia do processo e otimizar as rotas de recolha e desta forma maximizar o lucro envolvido neste negócio.

it deserves. Often, UCO will end up in the sewage system due to ignorance of the harmful environmental impact, but mostly because people just do not know what to do with it. For convenience it is poured down the sink. Some of the resulting problems of UCO ending up in the sewage system are pipe corrosion and the clogging of the sewage treatment plant filters, but the most important consequence is the contamination of massive quantities of water that come into contact with it due to the difficulty of separating these two fluids.

Fortunately, there is great potential in the recycling of UCO, which increases interest in the collection process, particularly for the production of biodiesel. By recycling UCO into biodiesel it is possible to create a huge income source and simultaneously reduce environmental pollution and fossil fuel dependence (Wang *et al*., 2006; Zheng *et al*., 2006; Phan and Phan, 2008). The use of biodiesel as a biofuel has already been foreseen in the European Union energy policies, specifically in Directive No. 2009/28/EC of European Parliament and the Council of 23 April.

The biggest challenge of recycling this type of waste is its collection, mainly due to the high logistical costs. For a company or a local administrative unit that wishes to make the collection it is extremely difficult to do so through standard waste collection methods. Generally, either the containers are not full or have already reached the maximum filling level, meaning that the quantity would have been greater had it been collected earlier. This last problem causes further difficulties if the containers are public oil (UCO) containers because they could overflow. These kinds of situations also happen in normal solid waste collection and are also very common, but in the case of liquids and especially with UCO, these situations need to be treated more carefully.

This paper presents a framework for building an intelligent system that allows the efficient and optimal collection of UCO.

In the preceeding introductory section a rough outline of the problem has been provided. In the next section the context to the problem is presented along with a review of the state of the art in the collection process. In the following section the proposed framework for the collection system, with all the modules of the system including software and hardware is described in detail. Thereafter are described the results of a test carried out together with FiltaPorto, a Portuguese company with a great deal of experience in the oil collection business. The paper concludes with the current state of the system and the future work to be carried out, and the changes needed based on the results of the field test are the subject of final examination.

Contextualization

Technological evolution leads to an increase in the consumption of energy sources. This increase, together with the scarcity of fossil fuels, results in an increase in prices (Levy-Carciente *et al*., 2004), and that creates an imperative to discover new solutions to counter this inflation (Bolivar *et al*., 2006). Some of these solutions include the use of renewable energy sources (solar, wind, sea and rivers) or even nuclear, but recently more solutions based on the reutilization of waste to produce alternative energy sources, such as biodiesel (Bula and Cujia, 2008) have become viable. These new forms of energy source are considered to be the next step in the use of renewable energy as an alternative (Laine, 2008).

Biodiesel production from used cooking oil (UCO) is, today, a commercial process with numerous production facilities across several countries. The biggest challenge in this industry is the collection, both in domestic and industrial environments.

In Portugal the amount of UCO waste production is estimated at between 43×10^3 and 63×10^3ton/year, of which more than 60% is produced by households and the remainder produced by hotels and restaurants (HORECA). Given UCO's potential for recycling and the impossibility of storing it in landfill sites, as the European Council Directive 1999/31/CE of April 26 1999 that regulates waste depositing in landfill sites forbids it, it was necessary to regulate UCO collection. In Portugal, a regulation was also published that makes local administrative units responsible for domestic UCO collection (PEM, 2009), since the collection at HORECA was already compulsory by law and was previously being conducted by dedicated companies.

Usually, the UCO collection process in restaurants is based on statistical data generated from previous pickups or, in special cases, when the client (UCO producer) calls and asks for a single pickup. Difficulties start to arise when the collection is made and the containers are not full, as this reduces the waste collection company's revenue. The opposite may also happen, the container may be full sooner than expected and remain full until the next collection, also reducing revenue. The collection of domestic UCO is even more difficult because the individual households produce small amounts of UCO. This makes the individual collection of UCO in the domestic environment unprofitable. Public UCO containers where household members can deposit their UCO are a possible solution, as long as the collection is made on time and measures are taken to avoid spills.

In both cases (domestic and industrial) the problem is in the difficulty of knowing when the containers are full or at least with enough UCO to justify their collection. With this kind of information the companies in this sector could increase the amount of oil collected and reduce the operational costs of collection, thereby increasing revenues (Li *et al*., 2006).

Current Practice

Until recently, due to the novelty of UCO collection processes, pickup management systems have mostly been manual or adapted from solid waste collection management systems. These systems are, by default, based on statistics, being characterized by an initial period where there is no data input and collection is made randomly. In a second period, collection is made by estimation, with all the previously described related issues.

As time goes by, companies have been adopting some solutions such as asking the client about the current state of the container, or waiting until the client takes the initiative to request a pickup. These solutions present some drawbacks, mainly in route planning since by the time the client requests pickup the container is usually already full and requires immediate collection. From the economic point of view, route planning is essential to maximize profit and, in this sense, the current solutions are inadequate.

For this reason, in most cases UCO collection companies use production statistics to estimate pickup timings, which is not the most effective way, but the one that presents the minimal collection costs. This system only achieves basic accuracy after massive data collection based on the used oil production levels of each client. Different periods of the year typically translate into different quantities of used oil. This is also a variable to be taken into account when estimating the oil levels of the containers and it increases the overall complexity of the system and decreases the accuracy.

From these considerations, the major problem can be expressed as the difficulty to assess when and where a specific container is ready for pickup, or even more specifically, when the container collection is economically viable. Achieving this input would allow for efficient route planning, creating a reasonable time window from when the alert is triggered (around 75% of maximum container capacity) and the maximum filling capacity of the container.

Overview of the Management Framework

The proposed UCO framework aims to optimize the processes involved in the collection of the used oil. This framework is intended to create a system that allows the collection company to accurately know when and where the containers are filled with enough UCO to be collected. The concept of 'smart containers' for the collection of used cooking oils consists of building active containers to collect highly hazardous waste, like cooking oil, which alert the collection company that the container is ready for pickup. This information is received and processed automatically.

When using these active containers, which are responsible for measuring their own waste level, the user only needs to store the UCO. The company responsible for its treatment will automatically know when it is the best time to collect it. After the notification is sent to the collecting entity it will be automatically processed and added to the database. Then, using these stored notifications, daily/weekly collection route plans will be generated, increasing efficiency and lowering costs. In order to optimize the collection procedure, a mobile application was developed to identify the container and automatically update the management system with the container's status.

This proposed system was awarded with the first place in the 2008 Portuguese Imagine Cup and with the fourth place in the 2008 International Imagine Cup in the Software Development category organized by Microsoft (Microsoft Corporation, 2008: Microsoft Portugal, 2008). The initial version of the project was published as a paper at CISTI 2009 (Sousa *et al*., 2009). The project's development is currently being funded by the *Quadro de Referência Estratégica Nacional* (QREN), Portugal, in co-promotion with a UCO collection company.

Framework Description

The framework proposed in this paper is based on the low cost active containers that allow the optimization of the collection procedure. The active container is a standalone unit that measures the amount of residue in the recipient and notifies the collecting company when the predefined threshold amount is reached.

The management system receives and processes the notifications, creates the optimized collection routes and provides a graphic visualization of the containers on a map.

Figure 1 shows the UCO collection process as designed and implemented in the prototype testing. The process starts with the recipient full notification sent from the active container (A in Figure 1). The container is equipped with the proper sensors to detect the residue level, oil in this case. When the pre-programmed level of waste is reached, the notification is sent over SMS using a GSM module.

The management system (B in Figure 1) receives the information through the notification monitoring system and adds it to the database. This is a fully automated

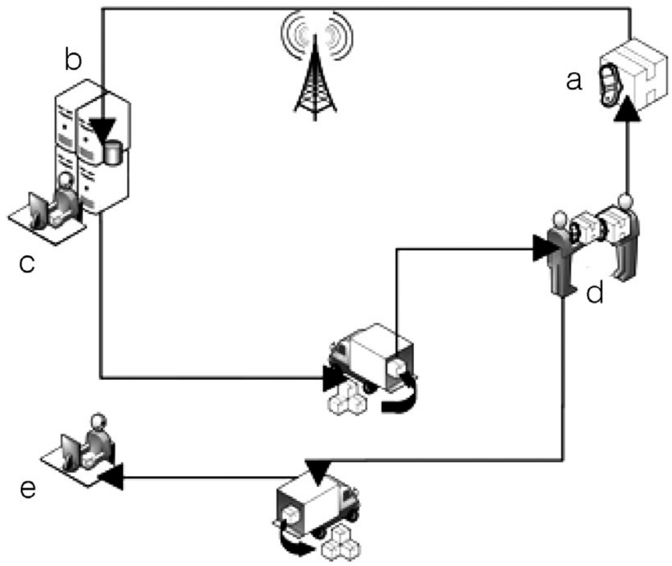

Figure 1. GreenBox framework architecture.

process, without any user interaction.

The employee responsible for collection routes in the collection company (C in Figure 1) issues the instruction, through the management system interface, to generate a route and associates it with an employee responsible for the collection of the full containers. That information will then be uploaded to the employee's mobile device (Smartphone or tablet). If the collection company doesn't have the support for mobile devices, a report with the route is printed instead. The management system can also manage employees, vehicles and containers, and generates reports using stored data.

After receiving the list of containers to be collected, the employee follows the route and updates the status of each location on the mobile device. To make the procedure easier, each container has an RFID tag or barcode that can be read by the mobile device, allowing the operator to fill most of the required information in the report just by reading the serial number of the container (D in Figure 1); if the mobile device isn't available, the same report is filled in by hand. Following its arrival at the company, the UCO is filtered and prepared to be converted into biodiesel, the recipients are cleaned and stored for later usage and the data is synchronized automatically, if the mobile application is used, or updated manually if it isn't (E in Figure 1).

The UCO collection system is composed of three main modules: 1) detection module, consisting of the container and respective instrumentation; 2) management module, consisting of the computer system that provides support and management of the logistics involved in the UCO collection; and 3) collection module, consisting of the mobile device and the respective mobile application.

Detection module

The detection module analyses the amount of waste in the recipient and generates a notification when a predefined amount is reached. These active containers are key to enabling the optimized collection.

The detection module consists of a sensor or collection of sensors, a microcontroller to process the sensor data and generate the notifications, a GSM module to provide communications, and a power supply. The microcontroller is programmed to take periodic samples of the amount of waste present in the container and, when the threshold amount has been reached, to generate a suitable report based on the waste type, amount and communication protocol of the management module. When developing this module the goals were reliability, low cost and minimal maintenance.

In the detection module, the sensors provide data to the microcontroller regarding the amount of residue present in the recipient. This data can be precise or only indicate if the threshold has been reached. This last method was implemented in the prototype. Two detection systems were developed for the initial tests, one based on a switch that indicates whether the threshold has been reached, and a detection system based on load cells, which allows for a precise measurement of the amount of waste present at any given moment.

The recipients were equipped with a switch (2 in Figure 2) with a floating device attached (1 in Figure 2). The threshold is defined by the location at which the switch and floating device are attached. This method is of a very low cost and, as the switch can be used to power the system only when needed, it is very power efficient.

The switch is waterproof, allowing for the switch and floating device to be submerged in either water or oil without compromising their operation. The floating device can be made of any kind of material, as long as the resulting object is less dense than the residue in the container and the materials can withstand the nature of the waste.

When a more accurate reading of the amount of oil or other waste is required, this can be measured by the weight present in the recipient. An instrumented base is used with the recipient on top (Figure 3). The only difference between this method and the above described method is in the way the waste is measured; in the first method the threshold is detected when the waste rises enough to actuate the switch through the buoy, in the latter a load cell is used to measure the weight of the container as often as required and, if necessary, with great accuracy. When a different recipient is used, the base needs to be programmed for the new capacity and desired notification thresholds. These sensors are more expensive and the implementation more complex, but they are more precise and can remain on site for their entire operational life.

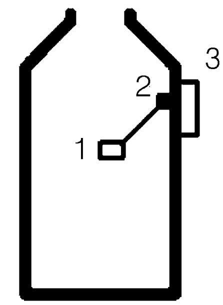

Figure 2. Recipients with switch based alert mechanist.

After field-testing the prototypes built, some problems were identified when using the switch-based system. Mainly, the malfunctions were caused by the mechanical stress they were subjected to through the industrial cleaning process. These results will be addressed more thoroughly in a following section.

Management module

The management system provides several functionalities that can be divided into the following five main modules: administration, alert, routing, synchronization and report modules.

This modular structure of tasks allows the reduction of dependencies within the system, enabling the main sys-

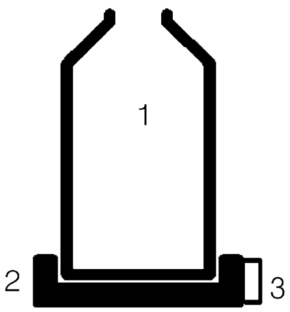

Figure 3. Recipient with load cell based alert mechanism.

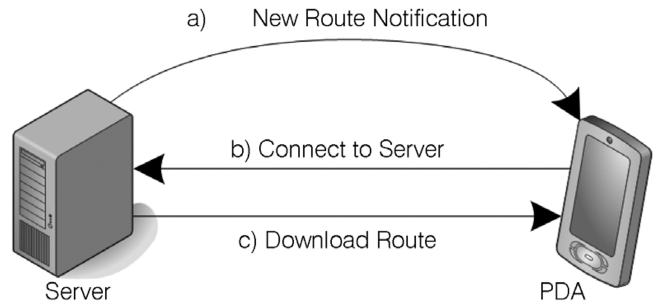

Figure 4. Synchronization process between server and PDA, with notification.

tem to assist the user in a specific task even when another module is currently unavailable.

A monitoring module was also created primarily to provide the system overview, considering all modules, from the alert module to the database connection. This module is intended to give information about the current status of all modules, alerting the user in case any of the modules are faulty or have even stopped working and need immediate repair.

The alert module is responsible for the alert reception and processing. It has been designed to run autonomously, without user interaction. To fulfill this purpose and from a development perspective, this module is a system service that starts automatically, continues running permanently, even if the other modules are not, and restarts automatically in case of failure, without user interaction. This module has two basic components, the reception and sending services (GSM modem).

The GMS modem is configured to send an alert to the central management framework, by SMS, each time it receives any input. If offline, the messages are stored and scheduled to be sent when GSM service is available.

The workflow steps are defined as follows: 1) modem initialization and configuration, 2) monitoring module is informed of successful startup, 3) GSM modem is requested to transmit any eventual message stored when offline and the alerts are processed and added to the database and deleted from the queue, and 4) service goes into standby, waiting for new inputs from the modem.

In the case of error in any of the steps, the user is notified by the monitoring module and may proceed with any adjustment, if necessary, as in the case of modem malfunction.

Synchronization module

The synchronization module is responsible for the communication between the main system and the mobile application. In contrast to the alert module, the synchronization module has an interface, providing information about the synchronization with the user. The module creates a communication channel using two different wireless interfaces (802.11g or Bluetooth). A USB connection can also be used.

This module has two main actors: the server, as the main system, and the client application on the mobile device. To save energy while synchronizing, the concept of push is used instead of pull. In simple terms, the client application starts synchronization, but only when the server sends notification of the existence of a new route, instead of periodically checking for updates. In practical terms SMS are intercepted by the client application. Whenever an SMS is received, containing a specific data format (A in Figure 4), the client application starts syncing through the interface also specified in the SMS (B, C in Figure 4). This module is also responsible for sending urgent notifications to the client application, using the described process. In this case, the company employee will use the client application to connect to the Internet and receive updated data about new container collection points.

Routing module

This module allows for route generation, route map visualization and route assignment to employees. The generated routes are optimized taking into account several variables, such as the maximum number of daily collection points, client availability, and need for collection. This last variable, the need for collection, is calculated every day based on the estimation of the day in which the container will be fully filled. This estimation is made considering the date of last UCO collection, the collection request and the need for collection of neighboring UCO collection points. Based on this estimation it is possible to generate highly optimized routes.

After generation the route is displayed overlaid on a map containing all collection points. This is done so that the user can check for any generation errors. After validation, the user is requested to assign the route to the collection team or employee and the route is synced with the client application by the synchronization module. Route reports are available at any time by checking the route history.

This module also allows for the inclusion of urgent collection points. In practical terms, if a sensor is broken and a filling alert has not been received, the collection point (e.g.: restaurant) requests urgent collection. From the previous route generation the system automatically checks the collection team or employee that passes by closest to the newly added collection point and sends and emergency alert to the respective client application, using push, as previously mentioned, and GPRS/3G. This functionality allows the system to continue working even in the case of route update and detour. GPS is also used to increase the location accuracy of the teams/employees.

Administration module

Finally, the administration module allows the user to administrate and manage the system. This module allows employee, vehicle and mobile device management for collection support. Each employee can be assigned with a specific route, vehicle and mobile device. The module provides an administration interface. From a company's point of view the modules allow system analysis and report generation, providing filtering by week, month, restaurant, employee and collection statistics. This module is intended to plan and control the collection system.

Collection Module Application

As stated above, this module was primarily created to aid in the management of the collection routes and the synchronization of the data collected during the collection procedure. The data gathered during the collection procedure, such as the amount of waste collected in a specific location at a given time, is very important to the system because it can be used to improve the whole process. Usually this would be a manual, boring and slow process, which made it a perfect candidate for automation.

The mobile application was created to deliver the route with the locations to collect defined by the route creator to the collecting employee. It also automatically updates the management system with the data collected throughout the process. The mobile application consists of three modules: route, identification and synchronization modules.

The route module is responsible for presenting the optimized route to the user. When the route is downloaded from the management system, it shows the locations to collect on a map, along with relevant information about each specific location, such as possible difficulties in parking the vehicle. This module also interacts with a turn-by-turn navigation application, allowing the user to easily work in previously unfamiliar areas.

The identification module was created because the electronic components were embedded in the container and there was a need to identify every container. This enabled the system to track every container along with its status (full, empty or in storage). Identification was enabled by two methods, an RFID tag and a barcode. Both the tags and the barcodes are cheap, and this makes it possible to use an RFID-enabled PDA to quickly and accurately read the serial number or a cheaper, everyday PDA that only requires a camera to capture an image of the barcode. Reading the barcodes with this method is slower, less accurate and can lead to problems because the barcode is easily deformed or soiled in an industrial environment.

When the chosen measuring method is the instrumented base with the load cell this identification process is unnecessary because the base doesn't get moved during the process of recipient replacement. The base serial number is sent to the management system along with the threshold reached notification.

The synchronization module is a very important component in the optimization process. This module is responsible for downloading new routes from the route manager and starting the collection process. When all the points are collected and the mobile device is back in the company premises, this module saves time by uploading the data gathered during the process, data which otherwise would have to be entered manually by the user.

This module also supports 'emergency collection points'. If a new container sends a full notification near an employee in the field and his vehicle is not scheduled to be full with the current route, the management system uploads the new point and the user is notified.

Discussion of Tests

The prototype described above allowed to test the system in the laboratory and the results obtained revealed its commercial viability. In response, we established partnerships with commercial enterprises that evaluated the system in order to confirm its viability. An agreement was later established with a business partner, FiltaPorto, for testing the system in a real collection of UCO.

This partnership provides access to real world collection. We identified a limited number of restaurants in which to install the system in order to identify problems with our concept. In the first tests containers with a switch-based alert system were only used, which initially functioned well, but then began to stop working or send false positives. After some analysis of the process following the collection it was observed that the cleaning process, as the containers have to be cleaned for further use, was quite aggressive. Due to the nature of oil residue, the industrial cleaning process has to be done using industrial chemicals (detergents) and water at high pressure and temperature. This process proved to be too violent for the containers and especially for the sensor mechanism, which in some cases resulted in detriment and in others even physical damage of the parts.

In response to this problem, it became necessary to change the switch detection concept, which forced us to use another approach, that of mass-based detection. This concept solves the main problems, as the base never leaves its location, so it doesn't go through the industrial cleaning process. This also brings other advantages: since there is no need to put anything inside the containers, they can be produced at a lower cost and in case of damage, the losses are small.

Another design problem identified was related to the identification of the container. The original design used a barcode, and due to the harsh environment in which the containers are stored in restaurants, often under the sink or in the backyards, the tag was damaged over time. Not only that, but the cleaning process also damaged them, which forced us to replace them again. Due to this, and the identification process being difficult to use, it was hard to get a clear shot of the barcode, which almost never worked in the tests, so it was decided to use something more reliable. And with the need to change the alert-level concept, we decided to use RFID technology in the identification process, and in our tests this technology worked every time and in the most varied of circumstances. The new concept of detection also makes the requirement of identifying each container obsolete, so the identification came to be done at the client level since the base never leaves the restaurant. The unique ID is also being used to track repairs or to manage stocks within the system.

After solving these problems, a new round of tests was initiated, this time longer than in the first phase, in order to assess the algorithms for optimizing route creation. Thus far no flaws have been detected any and we are now acquiring data in order to check if it is possible to enhance the route optimization algorithm.

Conclusion

The prototype built for the test fulfilled its initial purpose, which was to test the viability of this concept in real word scenarios, and now the main research goal is to reduce the cost per unit. After finishing a stable low cost version we expect to start a city-wide test and progressively implement the proposed framework with all our partners' collection clients, in order to apply its full potential.

As a future development, our focus is on cost reduction, since we had to change sensors when the old ones proved to be ineffective, raising the final production costs higher than expected. Another focus of the research is the method of communication. As the use of SMS over GSM can become expensive, other forms of medium/long distance communication are being analyzed, as well the use of the mesh networks concept. In order to continue reducing production costs, and also continue improving the framework with new types of sensors, new levels of integration within the companies' existing systems and test new hypotheses, it was decided to continue testing for a longer period.

During the planning and first design phase, we built this concept in order to create an adaptable system that not only works with other types of residues with minimal adjustment, but can also work simultaneously with different types.

This framework, applied to the first prototype, has proven to be an appropriate solution, both in a controlled environment and real world scenarios. Therefore, we will continue research on this project in order to make this concept a fully marketable product and to place it on the market.

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