An IoT-Based Culvert Monitoring System for Urban Flood Prevention

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Abstract

Urban floods cause several damage to both the cities and the citizens. The rain water triggers the floods, which is aggravated by the impermeable soil, which forces the water to be released mainly by the drainage system. However, the solid residues on the streets are dragged into the culverts, obstructing it. As a result, the culvert becomes breeding site for mosquitoes. The cleaning of the drainage system is expensive and time consuming. In order to mitigate this problem, we propose a system for monitoring culvert obstruction, which is divided into three subsystems: The basket collector, the gateway for data flow control and analysis, and the web server. The developed system uses solar power for energetic autonomy, and sensor accuracy on the culvert environment presented good reliability during tests. The IoT approach for the system's design favors the scalability for a more precise analysis on the real world.

Keywords: IoT, Monitoring System, Embedded, Urban Floods, Solar Energy, Smart Cities.

1 Introduction

Urban floods are one of the major issues on the big metropolis in Brazil and have been an increasing topic over the last 10 years. It happens mainly due to the impermeable soil, which forces the rainwater to be released only through the drainage system[1]. Trash and other residues on the streets are dragged by the water into the culverts, the entrance of the drainage system. When the trash accumulates inside the culvert, it may clog the pipes and hold the water, becoming a breeding site for mosquito. The urban floods cause several problems to the city's infrastructure, workforce and citizen's health.

Maintenance for the drainage system can be very expensive and time-consuming, reaching R$70 million/month in São Paulo[2]. The high cost of culvert cleaning is due to the laborious work of removing the residues from the pipes. Redesigning a city and its vital systems is not a feasible task, but we may use microelectronics for optimizing and making our cities smarter. There are some projects being developed for improving culvert management and cleaning[3][4], but we identified a gap on the solutions, about the targeting of both operational issues regarding the cleaning and the technological efficiency.

Analyzing the problem, we developed a system to monitor residues level and manage the cleaning of culverts throughout a city. The system, named EccoBin, is divided into three modules, designed for maximizing the scalability, sustainability, and efficiency. The first module is responsible for collecting data, acting, and retaining residues on the culvert. The second module is able to manage the data flow from many culverts, analyzing the data and monitoring the rain. And the third module is responsible for storage, display, control, and intelligence concerning the data collected by the system.

This paper presents the design and development of an Internet of the Things system, from the embedded components to the application on the web. The architecture of the system, technologies, and main decisions are presented on the following section.

2 The EccoBin System

2.1 System Architecture

The system was divided into three subsystems: the basket collector, the gateway for analysis and control and the web server, as shown in figure 1. These three modules communicate with each other through wireless technology, following a protocol designed to avoid data loss and deadlocks.

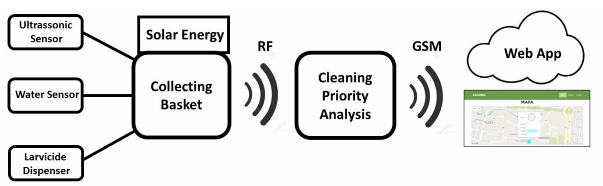

Figure 1: System Architecture

2.2 Description of the modules

2.2.1 Basket Collector

The Basket Collector is composed by a perforated basket located next to the culvert's opening. It is responsible for collecting the garbage dragged into the place, in order to ease cleaning and allow the water drainage. The basket measures the volume occupied by the retained residues, and verifies if there is water in the culvert.

The collector basket communicates with the gateway using an transmitter which sends the requested information. If there is clogged water, it will be treated for avoiding mosquitoes. In order to save power, after sending the data, the module enters a standby mode, lasting for the set period. The module design is shown in figure 2.

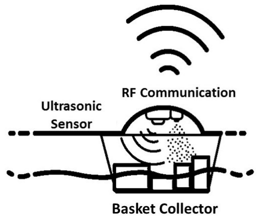

Figure 2: Basket Collector Design

2.2.2 Gateway

The gateway is able to communicate with the Basket Collector module, following a communication protocol designed specifically for this situation. The module requests and receives data from then, checks the communication and sensors, and measures the rain amount in the neighborhood. With these data, the module performs an analysis and defines the culvert cleaning priority, taking into account the garbage volume in the culvert and the information about rain on the neighborhood.

The gateway module sends the verification and analysis results to the web server, and receives back the time interval that the basket collector module should be in the energy economy mode. This information is then forwarded to the Basket Collector.

2.2.3 Web Server

The web server receives, through the Internet, the measured data and the analysis result. It includes the information concerning the communication status and sensors checking. The server is responsible for storing, in a database, all the information related to each culvert, in addition to showing, in a map, each one's location and recent values. When a culvert receives a high cleaning priority or a malfunctioning is detected, the server sends an email alert to the responsible authorities.

The module also allows the residents to make a report of the flooded culverts and offers the possibility to change the data collecting periodicity through the web application. Lastly, the server also defines an optimized cleaning route from the database information.

2.3 Implementation

2.3.1 Basket Collector

The Basket Collector module, shown in figure 3, was implemented using an Arduino Uno, which is responsible for the module control. The Arduino is connected to two ultrasonic sensors, which measure the distance to the closest obstacle and, using the volume of the basket as a parameter, determine what is the percentage of the basket occupied by garbage.

A water sensor attached to the side of the basket that measures the level of retained water in the basket. Also connected to this module, an RF transceiver performs the communication task. The module is connected to a battery, a solar panel, and an energy management module, in order to be self-sustainable.A Real Time Clock allows the module to enter in the stand by module and to wake up from it. A servomotor connected to the module, when requested, pours larvicide powder in the Basket with the objective of avoiding mosquitoes' procreation.

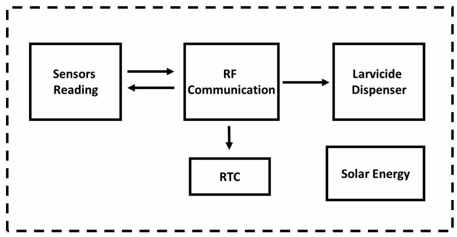

Figure 3: Basket Collector Module

2.3.2 Gateway

The gateway, responsible for the system analysis and control, was implemented using the Galileo Gen 2 and is shown in figure 4. It is connected to a pluviometric sensor, that measures the rainfall amount, and to an RF transceiver, that requests and receives information from the Basket Collector. The gateway is able to communicate with up to six Basket Collector modules.
The communication between the Basket Collector and the Gateway follows a protocol in order to avoid data loss and deadlocks. The protocol is based on the sent and received messages, so that while the module does not receives the message it is supposed to, it keeps asking for the message repetitively. If a timeout is reached and the expected message still hadn't arrived, the gateway will notify that there may be a communication problem in the next time it sends a message to the web server.

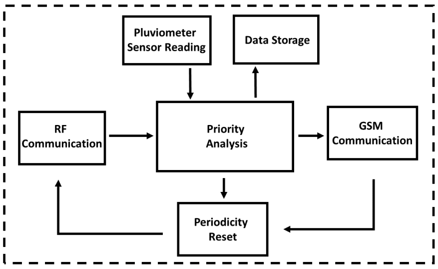

Figure 4: Gateway

The module has an message list that is transmitted to the Basket Collector module. The message that is being computed at the moment is initially decoded, as shown in table 1, and then sent through the RF transmitter.

Table 1: Messages Set

Code	Message
1	Data Request
2	Communication Checking
3	Larvicide Dispenser
4	Sensors Checking
5	Low Consumption Mode

The gateway follows a cyclic sequence of messages in order to communicate with the Basket Collector module. Initially, the gateway sends the message number "2" during a certain number of times to assure the verification of the communication module. After that, it sends message number "4" with the goal of verifying if the sensors in the Basket Collector module are working properly and sending reliable data. In sequence, message number "1" requests the data provided from the sensors.

The module analyzes the received data and, if necessary, message number "3" requests the Basket Collector to pour larvicide powder. Then, message number "5" sends the command for the Basket Collector to get in the energy economy mode, sending also the time interval that it should remain in this mode. When the analysis module receives the message saying that the collector basket left the stand by mode, the cycle restarts. As the gateway also knows the time that the Basket Collector was supposed to wake up, if this message is not received in the expected time, the gateway will send a message to the web server notifying about the situation.

The priority computation done in the module is based on the rainfall amount collected along with the garbage volume in the culvert. According to various tests performed and their results, the system is divided in 5 levels:

- Level 1: it is not raining and the garbage percentage was smaller than 20%.
- Level 2: it is not raining and the garbage percentage was greater than or equal to 20% and smaller than 50%.
- Level 3: it is not raining and the garbage percentage was greater than or equal to 50% and smaller than 80%.
- Level 4: it is not raining and the garbage percentage was greater than 80% or it is raining and the garbage percentage was smaller than 80%.
- Level 5: it is raining and the garbage percentage was greater than 80%.

When the level is defined, the module stores and transmits it, through the GSM module, to the web server. Through the same module, the analysis module receives from the web server the information concerning the way the periodicity will be defined. In the case it is defined as automatic, the analysis module itself defines it, from the collected information. Otherwise, the periodicity manually defined in the web application is received through the GSM module.

2.3.3 Web Server

The central server module is implemented as a web application, that receives information from the system through the Internet from the GSM module connected to the Gateway. The received data is stored in a database, and the most recent entry for each culvert will be on display in a map, in order to improve the user interface. On the trace route section, the fastest route for cleaning the culverts in need is calculated according to the selected priority and then displayed. Using the Google Maps API, it is possible to easily map, display, and calculate the fastest route from point A to point B, passing through all the culverts marked. The periodicity in which the system retrieves new data can be reconfigured on the website, by the system manager.

The system shall alert by email the responsible for the maintenance in case it receives an entry of high priority (levels 4 and 5), communication error or sensor malfunction, informing the culvert's id, address and possible causes. The local community can also help in the data collection, reporting the status of a culvert with a picture, a short form and the address of the culvert. This data is going to be on display for the system manager.

3 Results

We developed a prototype for the system with the specified characteristics, to test on a real sized prototype culvert. On the event of not being able to test on a real street culvert, we tried to simulate the environment on its real conditions.

The battery took 40 minutes for the total charge on a sunny day, and about 30% more, or about 52 minutes on a cloudy day or under a tree's shadow, while the system was working. The battery kept the system working properly for 10 hours after the solar panel stopped producing electricity, simulating a night environment, while the basket was on sleep mode for 30 minutes before measuring new data. The developed system got to have a 91% uptime, using solar power for energetic autonomy, or about 22h a day, using the lithium battery. The system response time, from reading the sensors to passing through all stages, verifications and getting on display on the web server, is less than 1 minute.

The gateway was able to control the data flow of the system, managing more than one basket collector and analyze the data flow, and monitor the rain sensor in parallel.

We tested the basket collector with both trash and water, on different levels, and it was able to correctly measure the level of both solid residues and liquid in the culvert. We tested the communication range between the collector basket and the gateway, and the maximum range was about 150 meters on the open. This range may be shorter if there are obstacles between the modules, other than the wood culvert cover.

The cost for implementing the Basket Collector was about U$32. For the gateway, the implementation cost was about U$128. The basket collector module was implemented on 350 lines of code. The Gateway was implemented in 960 lines of code. Figure 5 shows the prototype of the Culvert and the Web Server.

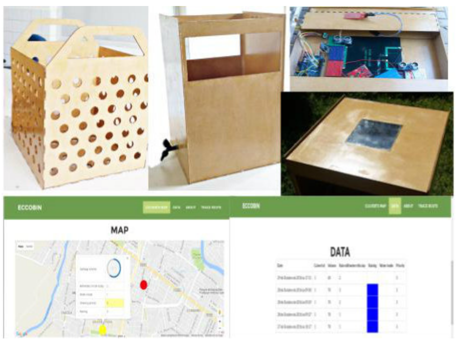

Figure 5: Evaluation Prototype: (from top left to bottom down) the perforated basket, the culvert, the culvert cover(up and down), the mapping interface on the website, and the display data.

In comparison to the current options to mitigate the urban floods problem, the proposed system brings the following advantages:

- Energy Efficiency: The solar panel and the battery attached to the Basket Collector make this module self-sustainable, assuring that it will have enough power to work, despite the environment.
- Intelligent data collecting periodicity: The systems allows the user to choose if the periodicity for data collecting will be defined by itself or by the gateway, according to the measurements and analysis results.
- Low response time and real-time information update: Due to the code simplicity and optimizations, the system shows a low response time. When it is not in the standby mode, the Basket Collector performs all the measurements and immediately sends the data to the gateway. This, in turn, is measuring the rain amount constantly, which assures the real-time data.

4 Conclusion

In this paper, we presented the architecture and implementation of an Internet of the Things system for monitoring the drainage system. The EccoBin is currently composed by a sketchy prototype, but an integrated circuit is in the horizon, if there is demand. For a final product, the Galileo in the gateway can be replaced by a cheaper board.

In order to lower the costs of the system, a wider range wireless module for the communication among the basket collector and the gateway is necessary. So fewer gateways would be needed.The GSM module can also be replaced by a less expensive alternative solution.

The proposed system architecture was designed to assure scalability, reliability and robustness for enduring the environment conditions. It was created a monitoring system to manage the maintenance of culverts and to decrease expenses with human resources. For future research, data provided by this system in a real environment can lead to flood prediction and prevention.

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