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RESEARCH ARTICLE

IOT-BASED WASTE COLLECTION MANAGEMENT SYSTEM FOR CITIES: CASE STUDY OF PARAKOU CITY IN BENIN

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Abstract

Waste management is a critical issue for cities around the world, and Parakou City in Benin is no exception. In this article, we propose an innovative solution to address the challenges of waste collection and management in urban areas. Our approach utilizes the Internet of Things (IoT) technology to create an efficient Waste Collection Management System tailored specifically for Parakou. The core of our system lies in equipping waste bins with sensors capable of detecting their filling levels. These sensors continuously monitor the status of each bin, and when a bin reaches its capacity, the system triggers an alert. This real-time data collection ensures that waste collection resources are deployed only when needed, optimizing operational efficiency and reducing unnecessary costs. The case study conducted in Parakou City highlights the significance of our IoT-based approach. Parakou faces unique challenges in waste management due to its urban landscape and growing population. With limited resources, it becomes essential to maximize the efficiency of waste collection operations. By implementing our system in Parakou, we aim to demonstrate how technology can be harnessed to tackle these challenges effectively.

Introduction:-

The rapid urbanization of cities across the globe has brought with it a pressing concern: the efficient management of waste. Nowhere is this challenge more apparent than in Parakou City, a vibrant and populous commune located in central Benin. Parakou, a town within the Borgou department, has undergone substantial demographic growth in recent years, making it a focal point for urban development and environmental sustainability. As the population of Parakou continues to surge, the municipality faces an increasingly complex problem: how to effectively handle the mounting household waste generated by its residents. This dilemma is compounded by the fact that Parakou serves as a crucial storage site for garbage from surrounding communities, especially during the rainy seasons when waste disposal becomes even more challenging. The management of household waste in Parakou has been a persistent headache for the municipal authorities. In light of this, the municipality has embarked on a mission to revitalize the waste management sector. Significant reforms have been introduced, aimed at not only addressing the immediate issues but also laying the foundation for a more sustainable and efficient waste management system.

Situated between 9°18'15" and 9°24'35"N latitude and 2°34' and 2°40' longitude, the city of Parakou stands as the largest urban hub in northern Benin. Serving as the capital of the Borgou/Alibori departments, Parakou holds a pivotal role as a significant administrative, financial, industrial, and educational center in the northern region of

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Benin. It is located at an average altitude of 350 m [1]. It covers an area of 441 km2. It claims the third spot in the hierarchy of major cities in Benin, trailing only behind Cotonou and Porto-Novo. With an estimated population of 229,051 inhabitants as of 2015 (data sourced from the General Population and Housing Census (RGPH3) of 2002 [2], extrapolated at an annual growth rate of 4.81%), the city grapples with a substantial waste disposal challenge that local authorities struggle to address. The figure 1 represents the Geogrphical location and administrative subdivisions of the municipality of Parakou.

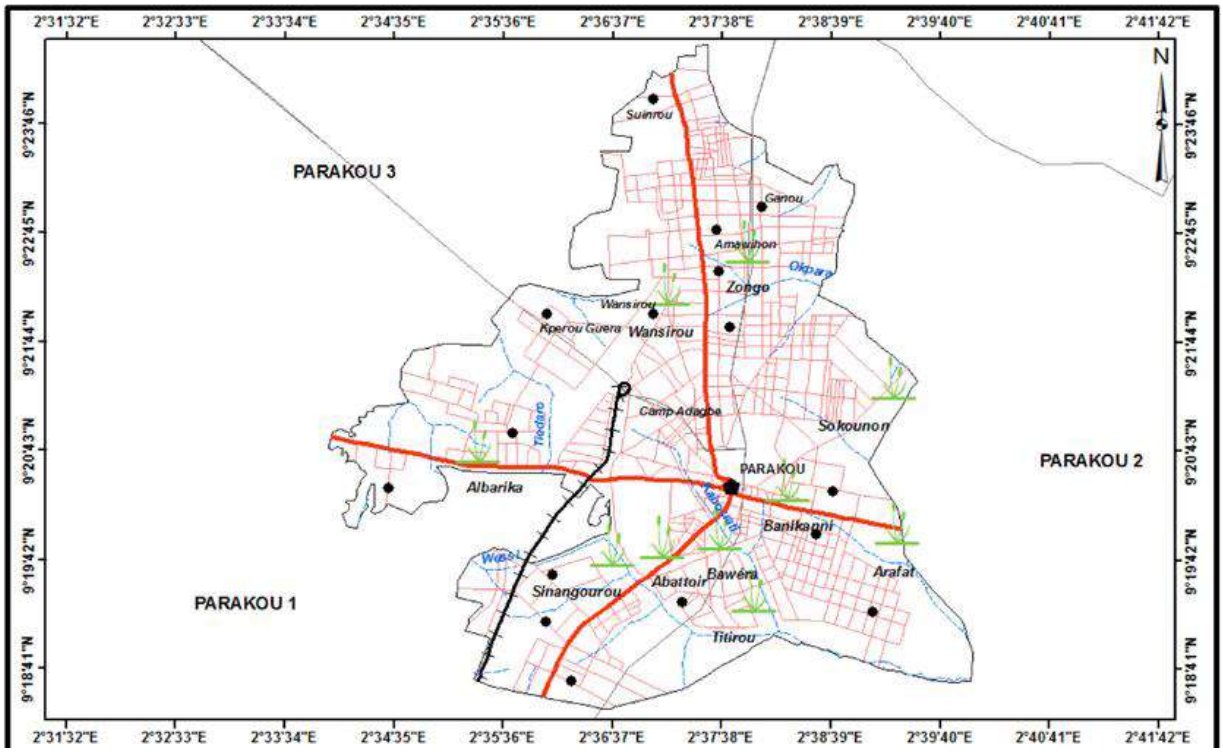

Fig. 1:- Geographical location and administrative subdivisions of the municipality of Parakou [3].

The use of information and communication technologies for the design of waste management systems has already been proposed by certain works [4-7]. One of the most significant advancements in this regard is the proposed IoT-based Waste Collection Management System. This innovative approach leverages cutting-edge sensor technology to monitor the filling levels of waste bins strategically placed throughout the city. These sensors provide real-time data, enabling waste collection resources to be deployed precisely when needed, thereby optimizing operational efficiency and reducing unnecessary costs. In this paper, we will delve into the details of this groundbreaking system and explore how it can revolutionize waste management in Parakou City. Our case study focuses on the unique challenges faced by this dynamic urban center and how the IoT-based approach can provide tangible solutions. We will examine the practical implementation of this system, the benefits it offers, and its potential to transform waste collection not only in Parakou but also in other cities grappling with similar issues. Through this article, we aim to shed light on the critical importance of innovative waste management solutions in burgeoning urban areas. Parakou's story serves as an inspiring example of a community dedicated to overcoming waste management challenges, and the IoT-based system proposed here holds the promise of turning this challenge into an opportunity for a cleaner, more sustainable future.

The rest of the paper is organized as follow. The next section presents the technical aspects of the solution. The third section of this paper presents results and discussion. Finally, we end this article with a conclusion.

Proposed system

Managing household waste concerns everyone. It is essential to put in place an effective solid and household waste management system to achieve sustainable development objectives, hence the proposal for a monitoring system which consists of optimizing a connected trash bin management system. The system uses ultrasonic sensors to measure the empty space in the bins, analyzing and visualizing the data through geolocation technology via an

application in order to provide information such as: the filling rate of the bins, the distribution by sector of operators, the routes and timetables to follow. The strategy used for interconnecting the bins will be based on technology taking into account the Internet of Things (IoT) coupled with an algorithm for searching the shortest path in a graph system. Our algorithm takes as input a directed graph weighted by positive reals (the different roads of the city of Parakou to access the trash cans) and a source vertex (connected trash can of the city of Parakou located at a crossroads) which using ultrasonic sensors connected to a trash can will provide real-time information on its filling. Then its filling information will be sent via wifi modules from the bins to the back end of the application located at the municipality. The connected trash is essentially made up of four (04) blocks: the power supply block, the application block, the processing unit and the sensor block.

1. The power supply unit: this is the unit which provides power to the system via a solar panel.
2. The sensor block: has an Ultrasonic sensor which records the distance between the top and the bottom of the bin in order to give a signal if this distance is zero or not (the bin is filled when this distance is zero) and another ultrasonic sensor for detecting an object at 15cm at the entrance
3. The processing unit: the analysis of information from the sensor block and the control of the other blocks will be done by the microcontroller.
4. The application block: recovers data from memory cards in order to send them to the cloud located at the municipality.

Remote processing of the data thus collected by the information system will make it possible to optimize collection rounds and flows. Once the information about the saturation of the trash can is detected on the municipality's application, it is transmitted via the intranet network to the team designated for garbage collection. Thanks to the application, this team will use the shortest path search algorithm to quickly access the filled trash can. The shortest path algorithm progressively constructs a subgraph in which the different connected bins are classified in increasing order of their minimum distance from the starting vertex constituted by the agents' vehicle (vehicle carrying a GPS to ensure engagement and activation).

The distance corresponds to the sum of the weights of the arcs taken by the vehicle. Initially, it is considered that the distances from each trash can to the vehicles are infinite, except for the team vehicle whose distance is zero. The subgraph of the starting set is the empty set since the updates for filling the trash cans must be progressive and dependent on household activities. During each iteration, a vertex of minimum distance is chosen outside the subgraph and added to the subgraph. It is therefore updated the distances of the bins neighboring the one added. The update is carried out as follows: the new distance from a neighboring bin is the minimum between the existing distance and that obtained by adding the distance to travel between the neighboring bin and the added bin to the distance of the added bin. We continue like this until the filled bins run out. As the problem of finding the shortest path is well known and several solution approaches exist, it is applied using classical programming the Dijkstra algorithm. This type of algorithm is one of the algorithms used to solve this type of problems, some examples can be found in Koc et al. [8].

API Municipality:
It is an application that helps recognize filled trash cans, directly integrate the algorithm where the routes to be covered in the city of Parakou are predefined, choose the optimal traffic and send collection notifications to the teams responsible for collecting waste.

Database:
In the database, we record the GPS position (longitude, latitude and altitude) of each bin, the distance between two bins and the mobile coordinates of the vehicles. These are its geographic coordinates that are provided as input parameters to the algorithm to specify the target to reach.

Target specification:
It is taken from the database where the departure is known and then the geographic coordinates are provided to update the new coordinates in relation to the mobility of the vehicle in order to reach a target.

Finding the shortest path:
The core of the architecture is based on the Dijkstra algorithm. After specifying the target, we proceed to search for the shortest path to reach the identified target in order to save time in obtaining the optimal path.

Garbage collection:
As the collection team is proud of the proposed route of the application, the Dijkstra algorithm will facilitate the journey to carry out the garbage collection without taking other routes not included in the defined system.

Checking the filling rate:
Checking the garbage filling rate which is 85%, we retain two conditions:
1. If yes, the filling rate is reached, we search for the nearest landfill
2. If not, do not trigger anything automatically and resume the cycle.

Figure 2:- Shows an overall view of the solution.

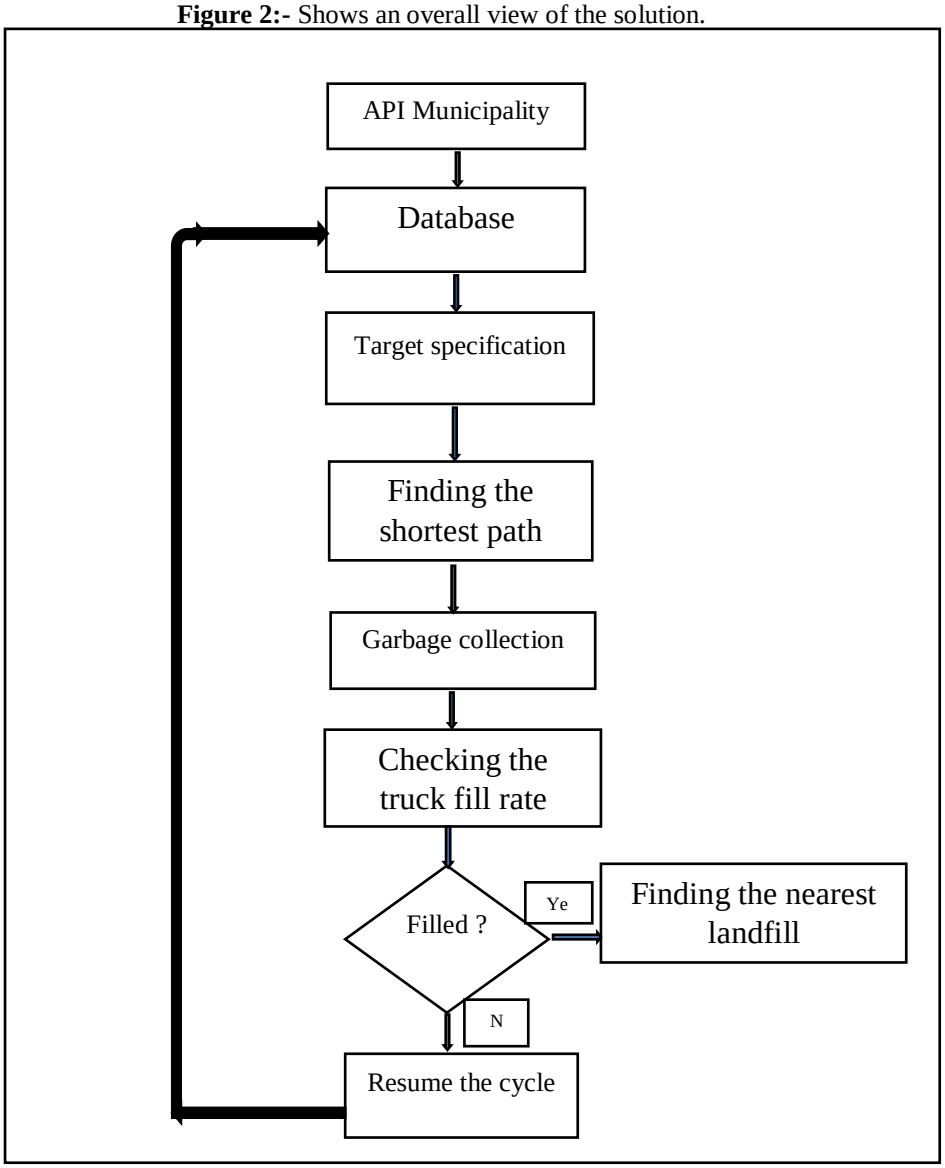

Fig. 2:- Overall view of the solution.

Analysis of results and discussion
The current waste collection system in the city of Parakou is simply based on the experience of truck drivers, leading to high operational costs, repeated visits to some bins while others are ignored. The result of this work will have positive impacts on the administration of the municipality of Parakou, the inhabitants of the city as well as on civil society as well as the environmental reality of the city, more precisely, the impact on the administration of the municipality appears in the form of a reduction in collection time and operational cost (fuel, energy consumption, maintenance of trucks and labor). The impact on the city's inhabitants will also be manifested by the improvement of

the service and the overall reduction in fuel consumption and therefore gas emissions, coupled with rapid and punctual waste collection, which is beneficial for the environmental reality of the city and the quality of life of its inhabitants. In fact, the smart trash can send an automatic alert to the cleaning service once it is full. Thanks to this automated system, we have easy access to information on waste thrown in the trash. Therefore, the quantity of waste produced per district as well as the filling speed will be known. All data will be available in real time, via an application. Traditional municipal solutions involve wasting time in collecting garbage (some bins are not often filled when trucks pass by). This is considered unoptimized, and by far an approach to waste collection, which simply depends on the judgment of truck drivers in choosing routes. For the implementation of the solution, a field survey (qualitative study) was carried out in order to assess the impact of the solution on the organizational system and on garbage collection.

An interpretation of extracts from survey data shows that: the population opts for a change in the garbage collection process. In this context, the proposal which will help in the organization of the system would be acceptable to its stakeholders. In the current system, according to the remarks that there is no fixed schedule per truck, delays can be experienced due to traffic jams, a phase shift between the garbage collection schedule and the saturation of the trash cans in neighborhoods, households and the filling of trash cans is random; This shows the failure of the population to collect garbage. Intuitively, the higher the filling rate, the more trucks must go to the landfill for waste disposal. It should be noted that each truck makes two trips. Variability in distance can be justified by the fact that the truck route is not fixed, that certain places (bins) are not visited the following day (sometimes by mistake) and that, consequently, some bins are too filled. The fact that some bins are overfilled creates an environmental problem represented by the bad smell of household waste, some waste is left behind the bin, attracting animals and insects. Since the landfill is located outside of residential areas, frequent trips to the landfill increase collection time and costs, not to mention the possible overfilling of some trash cans. Taking into account its analyses, the proposed solution for optimizing the data collection system would contribute to improving sustainable management.

Conclusion:-

Waste management constitutes an environmental, public health and waste of resources issue. This is a major challenge for both developed and low-income countries. Collection can be improved, but considerations are still more focused on sorting and recycling waste, while for low-income countries, their concern lies in collection. The latter wish to draw inspiration from the example of waste management in northern countries by technically modernizing the management of their waste. However, this strategy creates strong inequalities in cities in terms of quality of service, since they do not have the means to implement it throughout the territory. The installation of smart trash cans is expected to improve the efficiency of waste collection, transportation and recycling. Additionally, sensor-equipped trash cans can reduce the number of trips garbage truck drivers have to make, thereby reducing expenses and greenhouse gas emissions.

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