Edge AI based Waste Management System for Smart City

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Abstract

With the upcoming Internet of Things (IoT) and AI technologies, the development of an edge AI based waste management system is proposed in this paper. The proposed system is an innovative system which helps to improve the efficiency of waste management, and reduces the involvement of manual labor in the process. This system involves two main subsystems: i) a waste monitoring and garbage trucks allocation system and ii) an automated bin exchanging system. The waste monitoring process is performed at edge-based computing stations which also autonomously control the truck assignment and bin exchanging. These stations will be distributed over urban areas, monitoring waste levels of trash bins in their respective areas by using sensors. They are responsible for deciding which bin needs to be exchanged and which truck in that area is to perform the exchanging process. In the bin exchanging process, an automated truck navigates to the location of the full trash bin and exchanges that bin with an empty one it carries. By applying this proposed edge AI based waste management system in the real world, it can be expected to reduce manual labor, time and cost with a regular and automated waste management process, thus resulting in a healthier and cleaner environment.

1. Introduction

With the development of information and communications technology, cities are being transformed into smart cities providing services for smart living, smart education, smart environment and so on. Despite the countless benefits of smart city innovations, it still needs to focus on many challenges as rapid urbanization creates demand for smart cities solutions [1]. Among them, the rapidly growing modern society is generating an increasing amount of waste and thus, waste management has become one of the primary problems nowadays [2]. The traditional method of manually monitoring and collecting the waste from the bins is a complex process and it utilizes more human effort, time and cost that is incompatible with present-day technologies.

With the advancement of Internet of Things (IoT) and Cloud technologies, the world today has created and is currently using smarter ways of waste management system. However, as most of the existing waste management systems approach to centralized cloud computing paradigm, it may encounter high service delay and high bandwidth cost. Transforming centralized cloud computing systems into distributed edge computing systems can bring the server closer to the data sources, resulting in several benefits such as low latency response, efficient use of network bandwidth, ability to perform time-critical operations, etc. In order to overcome the problems faced by centralized cloud computing paradigm, this paper proposes an edge AI based waste management system for smart city.

The proposed system is a combination of two main subsystems: i) a waste monitoring and garbage trucks allocation system which is carried out in distributed edge computing environment and ii) an automated bin exchanging system. It effectively helps resulting in a healthy and clean environment without any human intervention. Our contributions are summarized as follows:

- We design the system architecture of an edge-based waste management system to jointly work with AI technology.
- We design a heuristic algorithm to choose the most suitable truck to perform bin exchanging process.
- We utilize a Dijkstra's algorithm to find the shortest path among possible paths for a bin exchanging truck to navigate the full bin.
- We analyze the performance of the proposed system by using python-based simulator.

2. System Model and Problem Formulation

The proposed system architecture consists of a set of trash bins $B = \{b_1, b_2, b_3, \dots, b_N\}$, a set of bin exchanging trucks $C = \{c_1, c_2, c_3, \dots, c_N\}$ and an edge-based control station. Each trash bin is responsible for monitoring and uploading the level of waste in it to the control station. Each bin exchanging truck is responsible for exchanging waste full bins with the empty ones. The edge-based control station is responsible for making decisions of which bin needs to be exchanged according to the level of waste uploaded by each bin, which truck should be assigned to navigate that full bin and perform bin exchanging process in a short time duration by considering the best route through which it can get faster to the location of the full bin. Figure.1 shows the system model of the proposed waste management scheme performing in the designated sample of an urban area. It is assumed that the trash bins, each comprising a microprocessor and sensors, are placed at each defined area (i.e., (x_{b1}, y_{b1}) for b_1, (x_{b2}, y_{b2}) for b_2, ⋯, (x_{bN}, y_{bN}) for b_N) sensing and uploading the percentage of waste in it to the respective control station. The server at the control station records the real time values uploaded by the bins with a graph by setting 80% as a threshold. All the bin exchanging trucks are at the control station and each is equipped with five empty trash bins. By the time the collected waste percentage reaches the threshold, the control station considers that bin to be full and decides to exchange it with an empty bin. Then, it assigns one of the bin exchanging trucks to navigate that full bin and perform bin exchanging process. After the bin exchanging process, the truck comes back to the control station to put the full bin under the process of cleaning and sanitizing.

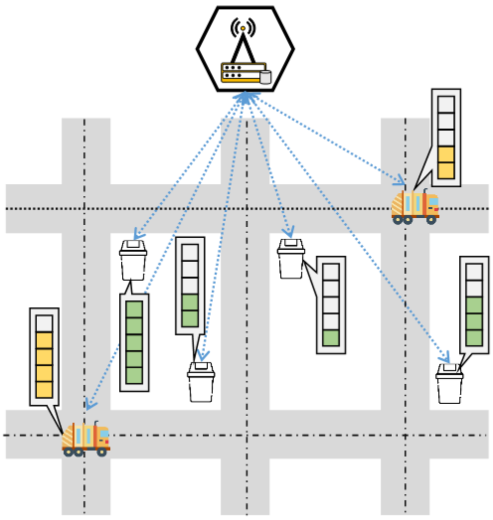

Figure 1. System Model

In the case of truck assignment for bin exchanging process, the control station calculates the distances between the full bin and all the bin exchanging trucks under its control.

$$d(b,c) = \sqrt{(x_b - x_c)^2 + (y_b - y_c)^2}$$

Notation	Description
$C = \{c_1, c_2, \ldots, c_N\}$	Set of bin exchanging trucks
$l_b = (x_b, y_b)$	Location of full trash bin
$l_c = (x_c, y_c)$	Location of bin exchanging truck
$d_n(b,c)$	Distance between full bin and n^{th} truck
v	Vertex between full bin and assigned bin exchanging truck
u	Neighbor vertex of v

Table 1. Parameters used in this paper

By using heuristic algorithm as shown in Algorithm 1, the control station compares the calculated distances and ranks the trucks from the nearest to the farthest distance from the full bin. Then, it checks whether the nearest truck has an empty bin to perform bin exchanging. If the nearest truck is already full with waste full bins, the control station will choose the second nearest truck. In this way, the most suitable truck is assigned to perform bin exchanging according to the ranking of the trucks. After that, the control station finds the shortest path for the assigned truck to navigate the full bin by using Dijkstra's shortest path algorithm [3] as shown in Algorithm 2. The system flow diagram of the assigned bin exchanging truck is shown in Figure.2.

Algorithm 1: Garbage trucks assignment process for bin exchanging

Input: C, (x_b, y_b), (x_c, y_c), $d_n(b,c)$
Output: C
for $n = 1 \rightarrow N$ do
  $d_n(b,c) = \sqrt{(x_{bn} - x_{cn})^2 + (y_{bn} - y_{cn})^2}$
  set $D(b,c) = \{d_1(b,c), d_2(b,c), \ldots, d_N(b,c)\}$
  if $d_n(b,c) \leq d_{n-1}(b,c)$
    exchange the rank
  else
    do not exchange the rank
end for
rearrange C
set $n = 1$
while true
  if n^{th} truck has an empty bin
    assign bin exchanging process
  else
    $n = n + 1$
end while

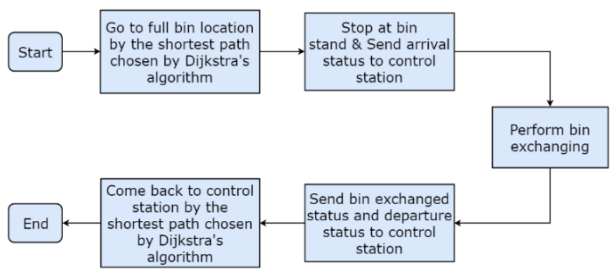

Figure 2. System Flow Diagram for Bin Exchanging Truck

In the process of automatic bin exchanging, as the truck arrival status is fetched from the control station, the stand with a full bin on it, is lifted up by the force of the DC motor attached to it until the contact sensor at the top of the stand is detected. Then, the servo motor attached to the bin stand pushes the full bin onto the truck. As the bin push status is fetched from the control station, three servo motors on the truck perform step by step to take the full bin onto the truck. After taking the full bin, the truck moves forward a little and puts the empty bin, it carries, onto the bin stand again by the performance of three servo motors on it. After the bin exchanging process, the truck comes back to the control station to put the full bin under the process of cleaning and sanitizing.

Algorithm 2: Shortest path finding process for garbage trucks

```
Input: Graph, l_b
Output: dist
dist[l_b] := 0
for each v in Graph:
    if v ≠ l_b
        dist[v] := infinity
    add v to Q
end for
while Q is not empty:
    v := vertex in Q with min dist[v]
    remove v from Q
    for each neighbor u of v:
        alt := dist[v] + length(v, u)
        if alt < dist[u]:
            dist[u] := alt
    end for
end while
```

3. Performance Evaluations

The performance of the proposed waste monitoring and garbage trucks allocation system was analyzed by using python-based simulator. As the simulation was carried out perfectly for several times, the accuracy for this subsystem is assumed as 100%.

The proposed automated bin exchanging system was carried out in three experiments to check the reliability of the system. Each experiment was performed for four conditions to check whether the system works properly or not. To perform the experiments, a prototype of bin exchanging truck and two prototypes of trash bins were equipped with all the required components. For a proper system, the values uploaded to the control station server by the truck must be the same with the fetched values of the bin stand and vice-versa. The recorded data for the first experiment is shown in Table 2.

No.	Value	Truck Arrival Status	Bin Push Status	Bin Exchanging Process
1	Uploaded	0	0	Skipped
	Fetched	0	0	
2	Uploaded	0	1	Mistakenly Performed
	Fetched	1	1	
3	Uploaded	1	0	Skipped
	Fetched	1	0	
4	Uploaded	1	1	Performed
	Fetched	1	1	

Table 2. Recorded values of bin exchanging process

The same experiment was performed for two more times to check the reliability of the system. According to Table 2, when the process was performed for the second condition, the bin exchanging process is mistakenly performed due to the incorrectly fetched truck arrival status value by the bin stand. Only one experiment table is shown in this paper as the rest two experiments were all carried out successfully. This subsystem is 91.67% satisfactory for automatic bin exchanging without human intervention. Thus, as a combination of two subsystems, the overall accuracy of this proposed edge AI based waste management system for smart city is 95.84%.

4. Conclusion

Using automated systems can obtain better efficiency than using ordinary systems, since these systems can operate 24 hours per day. Smart waste management system will also have reduced operation costs compared to traditional waste management systems since manual labor requirement is lower. Distributing edge-based control stations to operation areas can result in low latency response between the data source, the station, and bin exchanging trucks with efficient use of network bandwidth compared to using a single centralized control station.

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