Smart Solutions for Smart Cities: Using Wireless Sensor Network for Smart Dumpster Management

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***Abstract*—Wireless sensor networks are being deployed in civil, military, environmental and health applications due to their versatility, low cost and rapid communication capabilities. Smart cities would be able to manage their services with the help of information and communication technologies relying to a great extent on wireless sensor networks. In this paper, we propose the use of wireless networking technologies to optimize the solid waste management through the use of smart dumpsters equipped with waste level sensors. These sensors can read the level of waste as being low, medium or high. The HC-SR04 ultrasonic sensors, selected for this study, yield the level sense results that can be used at the municipal authority server to deploy just the sufficient number of trucks and staff for waste collection. In addition, path planning and routing can be done to minimize the time and fuel needed. We have developed a simulation model and performed simulation for optimization of fuel and time.**

Keywords- wireless sensor network; automation; optimized routing; smart city; agent based modeling

I. Introduction

Wireless sensors are devices based on MEMS (Micro Electrical Mechanical Systems) with integrated sensing, digitizing, processing and communication capabilities. A set of wireless sensors can be configured as a WSN (Wireless Sensor Network) that can be deployed in numerous applications in healthcare, environment, defense and disaster management. Sensors have specific requirements to minimize the communication overhead and reduce the power consumption. The WSN runs its own routing and power conserving protocols and it can be configured in various topologies.

Smart cities are envisaged to harness the ICT (Information and Communication Technologies) to optimize the use of their assets including the traffic lights, roads, water supply and sewage system and solid waste collection and disposal system. The versatility of wireless sensors and their diverse usage makes them an integral part of the city's smart infrastructure. Traffic sensors can be used in aiding decisions to open and close lanes to ease congestion. Audio sensors can help narrow down the area of active shooting in order to encircle the culprits. Location aware sensors can communicate the exact location of disasters and accidents to nearest hospitals. In a similar way, dumpsters equipped with level sensors can provide valuable information for path planning, routing and enumerating the number of trucks and staff needed for waste collection and disposal.

In this paper, we present our approach to finding optimized path and resources for solid waste collection in a smart city environment. We have worked to apply an agent based modeling approach to solve the problem of resource optimization for solid waste collection. Each smart dumpster (with a HC-SR04 sensor) is modeled as an agent. Its behavior (low, high states) is modeled using a state machine. The HC-SR04 ultrasonic sensor uses sonar to determine distance to an object. It offers excellent non-contact range detection with high accuracy and stable readings in an easy-to-use package from 2cm to 400 cm. The sensor can detect several waste levels as experimentally verified in this study however we have considered only low and high levels. The change of states is simulated using random number generator. These FSMs (Finite State Machines) communicate with a control station (agent) through events (message passing). The control station communicates with trucks (agents) that react to the events and optimize their paths on the fly.

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The rest of the paper is divided into four sections. In section II, we discuss the concept of smart city and the state of the art from literature. In section III, the options and selected approach of our work is discussed. In section IV, simulation results are presented and future work is identified in the conclusion section.

II. Previous Work Review For Smart City Services

The authors in [1] discuss the importance of improving the MSW (Municipal Solid Waste) by adapting the RFID (radio frequency identification) to the trash bins. This results in enhancing the growth of PAYT (Pay as You Throw) use-based billing for waste management service and encouraging the recycling program. They highlighted the impact of RFID in waste handling. Reference [2] developed and implemented an automated system of garbage collection. Their system was provided by the City-Parish and Allied Waste Services. They distributed a 96-gallon wheeled cart used as garbage can to the residents. It is the responsibility of the residents to place it in the correct position for pickup. The pickup process has been implemented by using a special collection vehicle that has a robotic arm to empty the contents and to return the cart back to its original position. These vehicles operate at a lower RPM with noiseless collection by professional drivers.

The authors in [3] proposed an IoT-based smart garbage system (SGS) to decrease the amount of food waste. Their system includes router, server and set of a battery-based smart garbage bins (SGBs). The set of battery-based smart garbage bins (SGBs) exchange information via a wireless mesh networks while the server and the router are responsible for collecting and analyzing the information of the service provisioning. They developed a web based service to achieve efficiency in the disposal and the collection.

The authors in [4, 5] discussed the analytic framework, research questions, policy context and technical and market analysis of RFID and its role in waste management. The study examined the RFID tags from two perspectives: i) objects in waste streams; and ii) efficiency and effectiveness of recycling at various stages in the lifecycles of a wide range of products ranging from simple to complex objects containing a variety of materials. Reference [6] contains an extensive survey of the types and applications of WSN (Wireless Sensor Networks) including environmental, health, commercial and military applications.

III. Our Approach for Optimizing the Smart City Solid Waste Collection

Typical assets of municipal authorities include schools, libraries, fire stations, hospitals, municipal offices, solid waste transport trucks, landfills, water hydrants and traffic control mechanisms. Smart cities, as per standard definition, use ICT to improve the performance of their assets and bring interactivity to their services [7]. Their services take advantage of the ICT infrastructure in order to make the smart decisions to save cost and reduce the time needed for specific services. Solid waste collection and disposal is one of the services provided in the cities around the world.

In this paper, we propose deployment of smart dumpsters to optimize the route, fuel consumption and work hours for municipal staff tasked to collect and transport the solid waste in the city. Each dumpster is installed with one HC-SR04 ranging module. This sensor can accurately measure the fill-level of the dumpster from 2cm to 400cm with a measuring angle of 15 degrees. These modules include ultrasonic transmitters, receivers and control circuits [7]. We conduct a study to measure performance enhancements in solid waste collection after deploying the wireless sensor network consisting of smart dumpsters. In this study, we model the trucks, dumpsters and locations of dumpsters in order to optimize the use of resources in waste collection.

The design and implementation of our agent based model of smart dumpsters is presented next. In this model, we use an overlay of an arbitrary area of Islamabad city located in Pakistan for running the case study. Three types of entities are defined as agents: (a) Dumpster (b) Control Station and (c) Truck. We briefly discuss these as follows:

A. *Dumpsters*

A set of 20 dumpsters are placed in the selected area at random locations. Each dumpster is assumed to have two states: (i) Empty and (ii) Full. Fig. 1 shows a state chart that represents these states.

Initially a dumpster is in the EMPTY state. For our study, we used uniform probability distribution with Min = 8 hours and Max = 24 hours to represent the behavior of the usage of dumpster in a residential area. After a random time period uniformly distributed between 8 – 24 hours, the dumpster will transit to FULL state. It can only return back to EMPTY state when a truck unloads the dumpster. This is simulated by sending a message: “Emptied” to the Dumpster agent. It is equivalent to the municipal staff resetting the dumpster’s state when the dumpster is emptied.

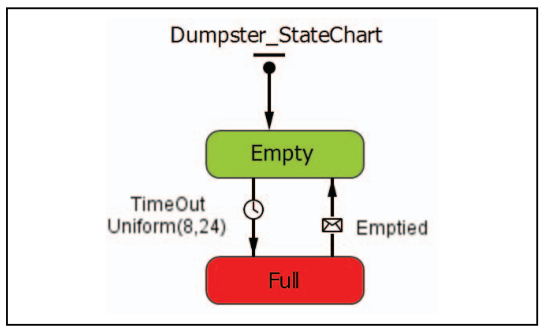

Fig. 1: Dumpster State Chart

B. *Control Station*

We assume that the control station is located in a facility where a fleet of trucks are parked. Whenever a dumpster is FULL, it will send a “Request” to the control station in the form of a message. The request will contain the dumpster’s ID, GIS co-ordinates and the timestamp when the request is generated. The control station will queue these requests in the order of occurrence on the route. In this way only those dumpsters will be added in the task list which are full.

C. *Trucks*

Each day the trucks are assigned a list of tasks by the control station to empty the dumpsters on their daily route. In this case study we assume to have only 1 truck for the sake of simplicity. However the agent based model is designed to support a whole fleet of trucks and can instantiate an agent population of N-trucks, where each truck can proceed to a different route and is assigned a list of tasks corresponding to its particular route. This applies when the model is scaled up to a larger area for detailed experiments. The behavior of each truck is modeled using the following state chart as shown in Fig. 2.

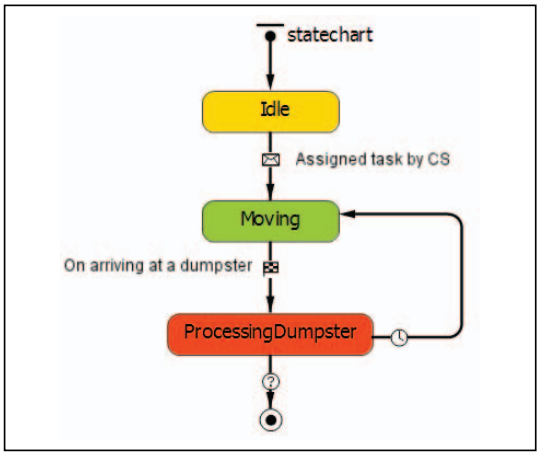

Fig. 2: Truck State Chart

Each truck is at IDLE state until it receives a message from the control station along with a list of tasks. Using the task list, the truck proceeds to the route. On arrival at each dumpster, the truck processes the dumpster if its state is FULL. We assume that it takes a constant 5 units of time to process a dumpster. When the dumpster is processed, the truck agent sends a message "emptied" to the dumpster agent and transits back to MOVING state and proceeds to the next dumpster in the list. Note that if a dumpster is not in the list the route will be updated to the nearest FULL dumpster. In this case study, we observe the behavior of 20 smart dumpsters. This initial model can be extended as more complex scenarios of smart dumpster behavior are simulated over a population where trucks are assigned to different routes. In our model, we use an extension of the classical Dijkstra's algorithm to find the shortest traveling path for the truck. It is given below in Table 1.

TABLE 1: TRUCK ROUTING AND LOADING ALGORITHM

Let the truck start from control station called: **initial node**. Let each dumpster be represented by a node with known distances from each other. Each node connects to a neighboring node with an edge carrying weight as **distance** in Km and the truck **capacity** is **c** dumpsters.

1. Set the initial node as **current**. Mark all other nodes as unvisited.
2. Create a set of all the unvisited nodes called the **unvisited set U**.
3. For each node in U
   a. consider an **unvisited neighbor n** in 'Full' state
   b. compare the distance of **n** from **current**
   c. mark the neighbor **n** with **minimum** distance as **current** and subtract 1 from **c**.
4. When we are done considering all of the neighbors of the **current** node, mark the **current** node as visited and remove it from the **unvisited set U**. A visited node will not be checked again
5. If the truck capacity **c** has reached zero or **U** has become empty, the algorithm has finished, otherwise go back to step 3

Fig. 3 shows the simulation scenario. Empty dumpsters are shown mostly on the left whereas full dumpsters are towards the right of the area in the diagram. The control station has dispatched a truck that is receiving the current state information from the dumpsters and finding the shortest route to fill itself quickly and completely.

IV. RESULTS AND DISCUSSION

In this section, we briefly discuss the results of the simulation run. It is observed that using the proposed technique of smart dumpster, the overall service time is reduced thus using the ICT to the advantage of the municipal authorities. Fig. 4 illustrates the comparison of distance traveled when using smart dumpsters and when using dumb dumpsters. The difference between the results is due to the fact that if the truck proactively knows about the state of the next nearby dumpster on its path, it skips it if the level recorded by the sensor shows it is not full. The truck determines the next dumpster to be visited by running the modified constrained routing algorithm as given in Table-1. This algorithm is based on the remaining capacity of the truck and the closest full dumpster. Thus the total traveled distance is reduced. Each dumpster is geographically plotted on the map using longitudes and latitudes. We stored all the dumpster locations in a database. It is a scalable approach for larger models i.e., up-to the level of a city.

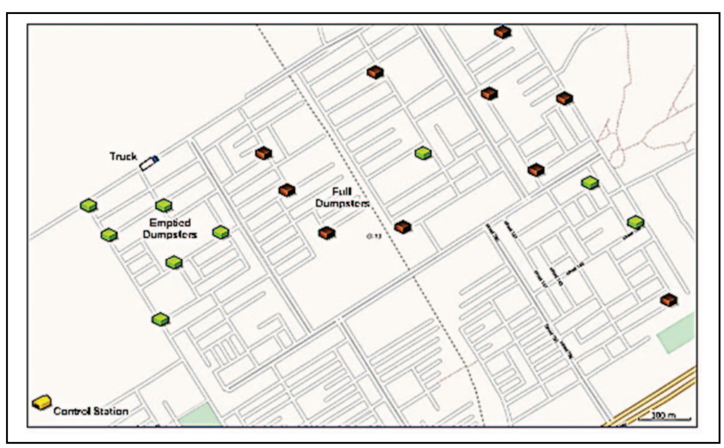

Fig. 3: Simulated Setup of Control Station, Trucks and Dumpsters

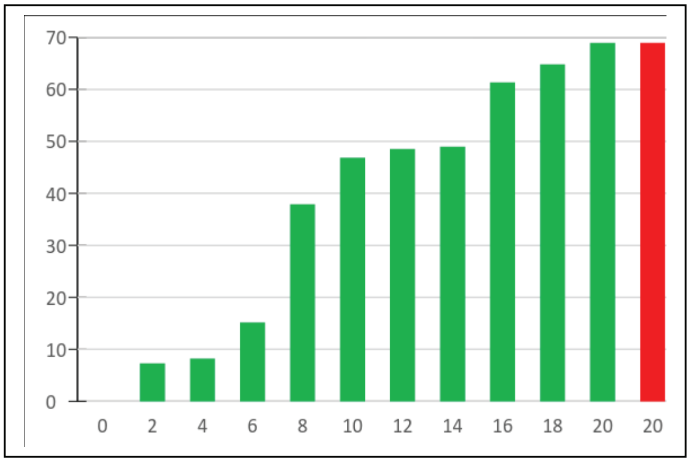

Fig. 4: Comparison of distance traveled with smart and dumb dumpsters

From a current point in space, in order to move to next dumpster, the truck automatically locates the nearest dumpster (agent) whose state = = FULL by following the constrained routing as per Table 1. For the dumb dumpster, the state check is ignored and the truck just moves on to the nearest neighbor. The chart represents total distance traveled by the truck for servicing N dumpsters where the number of dumpsters serviced is on horizontal scale and the distance covered is on vertical scale. The first ten bars represents data of the smart dumpsters where the dumpsters communicate with the truck prior to its arrival. If the dumpster state is full it will be included in the route and it will be serviced else it will be ignored. In our experiments we have randomly selected different numbers of dumpsters and observed the change in the total traveled distance ranging from 0 KM – 69 KM. The last bar shows the dumb-dumpster experiment in which all the 20 dumpsters are visited and serviced therefore the total travel distance is highest i.e., 69 KM, as seen in Fig. 4.

Considering the worst case scenario, it is observed that when the number of full dumpsters is 2, the truck would travel about 8 km in case of smart dumpsters and it would travel a distance of 69 km in case of dumb dumpsters. Thus, in the worst case, the distance traveled would be 88% less in the smart infrastructure. Even if the middle value of 10 full dumpsters is taken into consideration, the distance traveled would be 48 km instead of 69 km. It is a reduction of 30% over the case of dumb dumpsters. The distance traveled is directly proportional to the fuel consumed and the total service time. It is obvious that the smart infrastructure would result in substantial savings for the municipal authority.

V. Conclusion and Future Work

In this paper, we have presented our approach to optimize the resources of smart city and reduce expenses on the solid waste collection operation. We have proposed an agent based approach in which the dumpsters communicate with the municipal authority server and the trucks through a wireless sensor network to inform the truck about the level of waste accumulated prior to start of the collection trip. This information is obtained through HC-SR04 ultrasonic sensors that are installed in the dumpsters scattered around the city. Initial experiments with HC-SR04 sensors have yielded good results where the sensor is able to measure the level of waste at three different levels and the results are communicated back to the computer. The information about the level to which the dumpsters are full can be used to plan the route of the truck optimally and it can result in substantial savings. Results of simulating a set of dumpsters served by a single truck show that the total length of the trip can be reduced substantially if the fill level is known in advance. We plan to expand the model and implement additional constraints and dimensions. The multi-dimensional model would be most suitable for extending the study to some really large metropolitan areas.

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References

[1] D. Wyld, "Taking Out The Trash (and the Recyclables): RFID and The Handling Of Municipal Solid Waste," International Journal Of Software Engineering & Applications (IJSEA), vol. 1, no. 1, 2010

[2] Parish of City, "City of Baton Rouge; Parish of East Baton Rouge," [Online]. Available: http://www.brgov.com/. [Accessed 17 2 2016]

[3] I. Hong, S. Park, B. Lee and D. Jeong, "IoT-Based Smart Garbage System for Efficient Food Waste Management 2014.," The Scientific World Journal, Hindawi Publishing Corporation, 2014

[4] V. Steltenkamp, H. R. Schindler, N. Schmalbein and J. Cave, "SMART TRASH: Study on RFID tags and the recycling industry," RAND Corporation, Santa Monica, CA, 2012.

[5] I. Nielsen, M. Lim and P. Nielsen, "Optimizing supply chain waste management through the use of RFID technology", IEEE International Conference on RFID-Technology and Applications (RFID-TA) June 2010

[6] I. Akyildiz, E. Cayirci, W. Su and Y. Sankarasubramaniam, ""Wireless Sensor Networks: A Survey", 2(2002), pp 393-422," Elseveir Journal of Computer Network, no. 2, pp. 393-422, 2002

[7] Wikipedia, "Smart City," [Online]. Available: https://en.wikipedia.org/wiki/Smart_city.

[8] Micropik, "Ultrasonic Ranging Module HC-SR04," [Online]. Available: http://www.micropik.com/PDF/HCSR04.pdf. [Accessed 17 2 2016]

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