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IOT-BASED MUNICIPAL SOLID WASTE COLLECTION MODEL

The increase of waste generation has been counted as a significant challenge to big cities worldwide and represents a critical issue for countries with high urbanization rate. The effective use of Internet of Things (IoT) and cloud computing is the way to change existing MSW management by developing an efficient, cos-effective, and environmentally friendly solution for MSW collection and transportation system. In this paper an IoT-based reference model is described, and a comparison analysis of the available solutions is presented, with the goal to highlight the most relevant approaches.

Key words: *municipal solid waste, IoT, smart city, smart waste bin, sensor.*

Introduction. Municipal solid waste (MSW) management is a global environmental concern, especially in developing countries [1]. MSW management includes all activities of collection, transportation, processing, and disposal of waste [2]. In developing countries, most of municipal budget is spent for transportation cost, and the fixed and operational costs of used disposal facilities, and moreover, they are the most expensive elements of MSW management, while the frequency and efficiency are still very low [3].

In a regular scenario, the municipal administration provides the waste collection vehicles (WCV) on basis of predefined schedule. However, this traditional way of waste collection is not considering the filling level of dumpsters or bins, which may vary from emptying to overflowing and high fuel consumption. In other words, collecting partially filled or almost empty bins increases decreases collection efficiency and collection cost [4].

Another facing challenge in MSW management is waste transportation vehicle movement routing. The constant change of travel time and duration of vehicle for a stated area makes it difficult to track and monitor the overall process [1]. Moreover, with the rise of environmental pollution problems, there is more attention is paid for production of carbon emission. The WCV produce emissions while driving and loading/unloading waste due to necessity to keep engines running and producing constant exhaust emissions [4].

This inaccurate waste collection and transportation processes do not provide optimized path to collect maximum garbage in minimum time span with less resource consumption. Thus, the purpose of this paper is to probe the literature on existing WCVRO techniques that involve solid waste bin monitoring system. The study gives a general view of existing solutions in different countries.

Literature Review. Over the past several years, considerable studies have addressed the problem of growing solid waste and its collection by applying different intelligent techniques. The most articles published in Web of Science database, related to this problem,

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proposes WCVRO methods which considers to improve along with cost efficiency, the environmental, technological and social aspects [2].

The literature review introduces a noticeable solution which is monitoring of the status of waste bins using advances of Internet of Things technologies. One of the researches introduces "Smart Clean City" system - solution to optimize waste management process. By receiving level data of bins via cellular communication, server application generates optimal route for each WCV considering the road traffic data. The implementation of described system in Region of Saratov (Russia) helped to achieve effective results in the travel time of vehicle and fuel cost saving [1].

Also, following a cost-effective and energy-efficient goals, Kristano et al. recommend dynamic routing using a smart trash bin. However, despite of advances in routing optimization, the power consumption issues appear due to constant volume measurement and which negatively affect to battery life [9]. In order, to improve the work of cleaning operators to manage hygiene issues in real time and to increase their productivity, the research work in [10] proposes a Smartbin system that identifies the fullness of litter bins. The proposed system collects data and transmits it through a wireless mesh network. Intelligent waste management model for the improvement of waste collection is presented in [11]. In some countries, for instance Australia, municipalities charge fees for waste produced in the city by counting the weight of garbage for each neighborhood or street and then rate the average of each user per household. This collection model is not the most accurate, and as the cost of waste disposal increases every year, waste producers requires an efficient solution that reduces the cost and changes the form of charging, applied through a fixed rate. Intelligent waste management can solve this issue by ensuring that the user is taxed only based on the waste that they produce.

After achieving progress in collecting and storing data of level of bins on the cloud, researchers feel necessity for applying machine learning algorithms to avoid occurrence of overflow and predict waste generation, i.e. by analyzing behavior of people using Geographical Information System (GIS) technology. Aemu et al. in their work analyzed the impact of optimal bins location using GIS approaches and proposed that it has a direct impact on the overall cost, residents' convenience and satisfaction, efficient collection for waste carrier vehicles, to name a few [9]. A younger study has been conducted by Imran et al. [10] for Jeju Island. In this study, quantum GIS is used to investigate the behavior of people towards waste disposal and the prediction of waste for a certain residential area using predictive analytics.

The most often encountered algorithms in addressing the WCVRO problem are integer programming, decision-making methods, heuristic and metaheuristic algorithms, Petri Net simulation, fuzzy goal programming, or empirical studies. Moreover, the recent publications include upgraded versions of these algorithms, for instance, Shaoqing et al. developed a hybrid metaheuristic algorithm based on simulated annealing algorithm (SAA) and a heuristic algorithm to solve the capacitated arc routing problem [12]. Italo Ruan et al. proposed a mathematical model for the best location of waste electrical and electronic equipment (WEEE) bins, where used a heuristic and metaheuristic algorithms, such as greedy randomized adaptive search procedure (GRASP) and genetic algorithm (GA) respectively [13]. Reference [14] used three heuristics (GA, simulated annealing, and relocation search) to solve a location-allocation problem on a continuous space. Researchers described and compared constructive algorithms, like local search algorithms and tabu search algorithms with arc-exchange-based and node-exchange-based neighborhoods, while employing different and interacting tabu lists to solve the vehicle routing problem with integrated goods distributions and the waste collection supply chain [15]. In the case of stochastic parameters and uncertain environment, fuzzy logic-based methods, like the interval fuzzy possibility model, fuzzy goal programming, or fuzzy colored Petri net simulation can be used [16].

The result of Banyai's study shows the scientific potential of the design of MSW management system. Specifically, the design of waste collection systems still needs more research and study. The key point of the study is to determine mathematical model and algorithm to design and control the waste collection and transportation processes

Solid Waste Collection System.

A. Available IoT Architecture Reference Models for WCVRO problem

According to reviewed papers, many authors present a solution for WCVRO problem through intelligent monitoring which allows planning of waste collection. Figure 1 illustrates the basic five layered architecture that authors used.

• Perception Layer. The IoT architecture perception layer is like the physical layer, which responsible for collecting physical information, processing them, and transferring them to the higher layers through secure channels. It applies technologies for the detection of parameters through specific sensors, such as weight, level, temperature, humidity, etc., also, it includes object identification data, such as 2D barcode and RFID, camera, GPS terminals etc.

• Network Layer**.** It carries and transmits the information collected from the physical objects through sensors. It also takes the responsibility for connecting the smart things, network devices and networks to each other.

• Middleware layer has some critical functionalities, such as aggregating and filtering the received data from the hardware devices, performing information discovery, and providing access control to the devices for applications. It employs many technologies such as databases, cloud computing, and big data processing modules.

• Application Layer. This layer is responsible for delivering various application services. These services are provided through the middleware layer to different applications and users in IoT-based systems.

• Business layer. This layer is responsible for managing the entire IoT System, including service-related applications such as providing high-level analysis report of the underlying layers, as well as addressing user privacy [17].

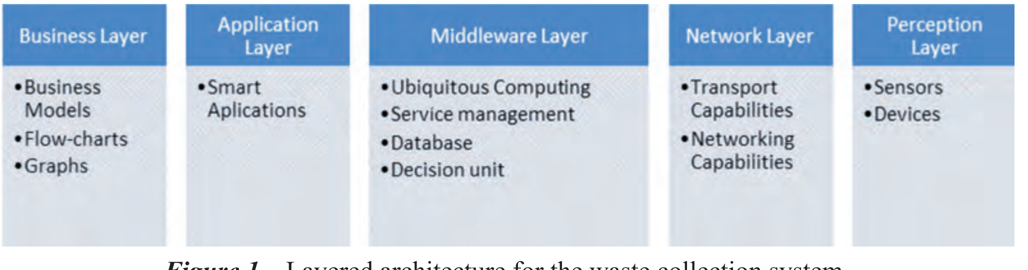

Figure 1 **–** Layered architecture for the waste collection system

Since IoT connects everything to exchange information among themselves, the traffic and the stores within network tend to increase exponentially. Thus, IoT application development depends on technology progress and design following a reference model of an IoT architecture.

A. Sensor node

Due to the harsh nature of waste management, trucks and bins face harsh environmental conditions, such as temperature, moisture, dirt, rain, and so on. Therefore, the system components of truck and bin monitoring system must meet these challenges to monitor the waste collection efficiently. This section describes the hardware components used in the waste collection system.

Aiming to determine the fullfillness of the waste bins different type of sensors used in proposed waste collection systems. For instance, Martijn in his study [18] used a motion sensor to count the number of lid openings of containers. Such monitoring of filling process gives several advantages, like no contact with citizens on the scheduling of emptying's time and deep insights into the speed of container fillings. However, during the analysis, the author meets with several error and inconsistencies in proposed system. The registration system provides only the information on lid opening, but the volume of waste collected is still unclear.

In this section, the main sensor types applied in smart waste systems are described and compared. These transducers may be ultrasonic, infrared, Time of Flight (ToF), or Light Detection and Ranging (LiDAR). Each one of these transducers has different features that must be considered, such as range, measuring accuracy and amplitude of the working angle etc.

Russian researchers in [1] have developed "Smart Clean City" system. Within the system a special vandal-resistant device was developed as a sensor node. It includes infrared (IR) and ultrasonic sensors to detect fullness of containers. Data from the container transceiver unit is transmitted to the control room using a built-in GSM module. Aiming to save battery lifetime of node, the sensors work within the time controlled by microcontroller.

The same ultrasonic sensor used in implementation of smart trash bin [19]. It detects the distance to objects by emitting high-frequency ultrasonic waves. The advantages of this type of sensor are that it able to measure the distance of wider area compare to IR sensors, its operation is not affected by dust, dirt, or high-moisture environment, or sun lights, tend to consume lower current/power, and multiple interface options for pairing with a microcontrollers. The IR sensor offers a high resolution with quicker response time, compared with the ultrasonic sensors. LiDAR measures the range of targets through light waves from a laser instead of radio or sound waves. The advantage of this sensor are high measurement range and accuracy, and applicable for usage in day and night. ToF technology provides significant benefits over other distance sensing methods covered: wider range, faster readings, greater accuracy. The advantages and disadvantages of these sensors are listed in Table 1.

Table 1 – Comparison of sensors

Parameters	Ultrasonic	Infrared	LiDAR	Time-of-Flight
Range	10cm to 1.5m	0 to 20cm	Wide range	0 to 2.5 m
Suitability to use for complex objects	No	Yes	Yes	Yes
Sensitive to external conditions	No	Yes	No	No
Beam pattern	Conical	Narrow (line)	Narrow (line)	Narrow (line)
High reading frequency	No	No	Yes	Yes
Response Speed	Slow	Fast	Fast	Fast
Accuracy	8 mm	5 mm	0.5 to 10 mm	5 mm
Cost	Low	Low	High	Moderate

B. Networking Technologies

In order, to integrate different objects and provide specific services within and IoT environment, it is necessary to apply communication technologies with low power consumption:

- RFID, NFC, Bluetooth Low Energy (BLE);
- Wi-Fi, ZigBee, Z-wave;
- Cellular GSM/GPRS, Long Term Evolution (LTE), Licensed LPWAN (LTE M, NB-IoT), Unlicensed LPWAN (LoRa, Sigfox).

All listed communication technologies and their parameters are shown in Table 2.

Table 2 – Comparison of different communication technologies used in IoT.

Network	Connectivity	Data Rates	Pros	Cons	Popular use cases
1	2	3	4	5	6
RFID	Frequency wave Short-range (up to 2 m)	40 kbps	Data captur-ing with no duplication	Limited range	Healthcare, smart retail, logistics and asset tracking
NFC	Wireless Ultra-short range (up to 10 cm)	40 kbps	Reliability Low power consumption	Limited range Lack of avail-ability	Payment systems, smart home
Bluetooth LE	Wireless Short-range (up to 100 m)	1 Mbps	High Speed Low power consumption Low cost	Limited range Low band-width	Smart home devices, wearables, health-care, smart retail
Wi-Fi	Wireless Short-range (up to 50 m)	200 Mbps, max. 600 Mbps	High Speed Great compat-ibility	Limited range High power consumption	Smart home, devices that can be easily recharged

1	2	3	4	5	6
ZigBee	Wireless Short-range (10-100 m)	250 kbps	Low power consumption Scalability Low cost	Limited range Compliance issues	Home automation, healthcare, and industrial sites
Z-wave	Wireless Short-range (up to 30 m)	< 100 kbps	Reliability Low cost Low power consumption	Limited range	Home automation
LPWAN	Wireless, Long-range (2 to 5 km)	< 50 kbps	Long range Low power consumption	Low band-width High latency	Industrial IoT, Smart home, Smart city, Smart building, Smart agriculture (field monitoring)
Cellular networks	Wireless Long-range (up to 35 km)	< 170 kbps GPRS, 3-10 Mbps LTE	Nearly global coverage High speed Reliability	High cost High power consumption	Drones sending video and images

D. Application Layer Protocols

Once parts of the IoT solution are networked, they still need messaging protocols to share data across devices and with the cloud [20]. The most popular protocols used in the IoT ecosystems are:

- DDS (the Data Distribution Service) which directly connects IoT things to each other and to applications addressing the requirements of real-time systems;
- AMQP (the Advanced Message Queuing Protocol) aiming at peer-to-peer data exchange between servers;
- CoAP (the Constrained Application Protocol), a software protocol designed for constrained devices - end nodes limited in memory and power (for example, wireless sensors). It feels much like HTTP but uses fewer resources;
- MQTT (the Message Queue Telemetry Transport), a lightweight messaging protocol built on top of TCP/IP stack for centralized data collection from low-powered devices [5].

E. Applied algorithms in state of art

In the last few decades, several studies have been conducted, in order, to solve routing problems. The provided solutions are aimed to compute the shortest route (time, distance, cost) of vehicle. In this works presented the most efficient algorithms which provide accurate results. These are algorithm that solves an integer linear programming (ILP) or mixed-integer linear programming (MILP) problem. Some works are based on nearest neighborhood search, ant colony optimization, genetic algorithms, particle swarm optimization or tabu search [2, 15, 19].

Table 3 – Comparison of the main features of algorithms.

Algorithm	Goal	Smart bins	GIS
Local search method	Min. distance	+	+
MILP	Min. distance	-	-
Nearest Neighborhood	Min. distance	+	+
Ant Colony Optimization	Min. distance	+	+
Genetic algorithm	Min. distance	+	+
PSO	Max. total waste collected	-	+
Tabu search	Min. transport cost, Max. service quality	-	-
ILP	Min. distance, Min. cost	+	+

Table 3 summarizes the features for the set of algorithms reviewed in this section. The comparison shows that most of the algorithms are based on heuristic or metaheuristic models to minimize the length of the routes. Except for the PSO algorithm which focused on maximization of the total waste collected. Tabu search algorithm aimed to minimize transport cost which depends on used vehicle and length of route. Also, it maximizes service quality by measuring the amount of waste that left on the street. It is noticeable that most algorithms solve the waste collection problem by minimizing the distance. With regards to initial nodes of the system, both smart bins and GIS technologies were used in the calculations.

Lessons Learned. Among all the papers analyzed, many authors propose a waste management model through IoT with waste collection focus and offering different scheduling models with dynamic routing for higher effectiveness of waste collection and using low fuel consumption. Considering aspects of IoT technology, the most used ultrasonic sensor is beneficial for waste collection optimization system in terms of low cost, quick installation, generally can be attached to any type of waste container in any type of climate conditions. The networking technology employed is also an aspect to be considered in terms of range, bandwidth, security, whenever possible, to use low power technologies, such as LPWAN, BLE.

The challenge of solid waste collection systems has been an opportunity for study and proposing different algorithms which capable of dealing with this issue. An additional study required to choose the right algorithm for solving these routing problems.

Conclusion. To achieve the transformation from traditional ways to the concept of smart cities, waste collection process becomes a critical element in achieving sustainability, efficiency in public spending, improving urban mobility, and preserving natural resources. The recent literature has been revised to investigate characteristics and aspects of intelligent waste management systems using the Internet of Things. Through a detailed literature review, solutions to identified problems were described, considering data detection, transmission, analysis, and processing of collected data, and obtaining the result for an efficient handling solution for solid waste.

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ЗАТТАР ИНТЕРНЕТІ НЕГІЗІНДЕ ҚАТТЫ ТҰРМЫСТЫҚ ҚАЛДЫҚТАРДЫ ЖИНАУ МОДЕЛІ

Қалдықтардың пайда болуының артуы бүкіл әлемдегі ірі қалалар үшін маңызды мәселе болып саналады және урбанизацияның жоғары қарқыны бар елдер үшін маңызды проблема болып табылады. Интернет заттарын (IoT) және бұлтты есептеулерді тиімді пайдалану - қатты тұрмыстық қалдықтарды жинау және тасымалдау жүйесі үшін тиімді, үнемді және экологиялық таза шешім жасау арқылы қолданыстағы қатты тұрмыстық қалдықтарды басқаруды өзгерту әдісі. Бұл жұмыс IoT-қа негізделген анықтамалық модельді сипаттайды және ең маңызды тәсілдерді бөліп көрсету үшін қол жетімді шешімдердің салыстырмалы талдауын ұсынады.

Түйін сөздер: *қатты тұрмыстық қалдықтар, IoT, ақылды қала, ақылды қоқыс жәшігі, сенсор.*

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МОДЕЛЬ СБОРА ТВЕРДЫХ БЫТОВЫХ ОТХОДОВ НА ОСНОВЕ ИНТЕРНЕТА ВЕЩЕЙ

Увеличение образования отходов считается серьезной проблемой для крупных городов во всем мире и представляет собой критическую проблему для стран с высокими темпами урбанизации. Эффективное использование Интернета вещей (IoT) и облачных вычислений – это способ изменить существующее управление ТБО путем разработки эффективного, экономичного и экологически чистого решения для системы сбора и транспортировки ТБО. В данной работе описана эталонная модель, основанная на IoT, и представлен сравнительный анализ доступных решений с целью выделения наиболее релевантных подходов.

Ключевые слова: *твердые бытовые отходы, IoT, умный город, умный мусорный бак, датчик.*