# A Model of UAV-Based Waste Monitoring System for Urban Areas

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**Abstract** This paper presents an approach in using unmanned aerial vehicles (UAVs) with remote imaging for urban waste monitoring. The system is designed to monitor green areas, public trash cans, and unregulated landfills and to detect possible violations of garbage disposal rules. Public green urban areas, such as parks, green surfaces, sport terrains, and bathing areas, are gathering places for people and therefore prone to unregulated waste disposal. The proposed solution describes the real-time monitoring of the area using drones and the detection of irregularities in a garbage disposal. The cameras mounted on drones are used to take images of public targeted areas at pre-mapped points. Visual data collected by supervisor drones are used for further processing and notification of authorized personnel and institutions.

**Keywords** Internet of Things (IoT) · Urban waste monitoring · UAVs · Supervisor drones · Docking station

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## 1 Introduction

The utilization of new technologies such as the Internet of Things (IoT), UAVs, robotics, and artificial intelligence can play an important role in the efforts to make cities greener, safer, and more efficient. Improving safety and quality of life can be achieved by connecting devices, vehicles, and infrastructure across the city. According to research conducted by the United Nations, the population in cities by 2050 should grow up to about 66% of the total population [1]. On the other hand, the development of modern information and communication technologies provides huge opportunities for the implementation of artificial neural networks and modern communication technologies such as Narrowband Internet of Things (NB-IoT). NB-IoT is a low power wide area network (LPWAN) radio technology standard developed by 3GPP to enable a wide range of cellular services. NB-IoT focuses on outdoor and indoor coverage, low cost, long battery life, and high connection density. For these reasons, this technology is very suitable for implementation in the system of control and management of waste in urban areas. Building such solutions on open standards-based communication platforms that can be used continuously is a serious challenge. The usage of other LPWAN technologies, such as LoRa and LoRaWAN, in combination with UAVs for smart city environments, is considered in [2].

One of the problems of big cities is the problem of waste management and waste collection. It is important to note that currently almost all applications that use the "Internet of Things" for smart waste management focus on commercial waste and municipal, public waste containers, rather than household waste. Efficient waste collection is a necessary service and the application of smart cities. The use of emerging technologies, such as UAVs, can lead to significant improvements in the waste management process. The best technological solutions can be achieved in smart cities by creating different stakeholders to work together. Integration of institutions, utilities, and service companies from different areas is necessary to create the solutions that provide a new quality of life in urban and rural areas.

The traditional way of managing waste collection from waste containers has been to schedule and send large trucks around the city at regular intervals. When a truck arrives at the location of the container, it would be emptied regardless of whether the container was full or half empty. Some of the containers may be empty for a longer period while, depending on the structure and behavior of the citizens, some containers can be filled faster than usual, leading to excessive waste and garbage-related health hazards. The additional problem can be caused by uncontrolled garbage disposal in green areas such as parks, sports grounds, and picnic places. Therefore, these places should be monitored together with the public waste containers. Another big problem is the illegal disposal of waste in places that are not planned for that purpose, resulting in unregulated landfills. Therefore, there is a need for constant monitoring of certain critical points to obtain timely information, providing vital data for further activities. To address all enlisted problems, this paper is presented the solution for the system based on UAVs for monitoring, surveillance, and collection of data from the critical areas.

This paper proposes a UAV-based IoT system that solves the problem of observing and monitoring predefined drone trajectories in urban environments where there are static and dynamic obstacles. The system includes the model with the proposed algorithm of random UAV path planning. The algorithm is based on traveling salesman problem (TSP). We proceed as follows. Section 2 provides an overview of related works. The proposed model of the system for monitoring and identifying garbage in public areas is present in Sect. 3. Section 4 presents the random path planning algorithm of the proposed model in a specified environment. Finally, we present our conclusions and a reference to future research in Sect. 5.

## 2 Related Work

There is a lot of related research works dealing with the topic of monitoring and controlling urban waste using AI and emerging technologies, as well as dealing with the implementation of UAVs in smart cities applications. In Ref. [3], the authors follow a case study for a city in the Republic of Iran and use an artificial neural network to predict the generated waste weekly. The authors trained the proposed neural network model using data collected in the period from 2004 to 2007. As a result, it was found that a neural network with 16 neurons in three hidden layers gives the best prediction results.

The paper [4] discusses monitoring the garbage capacity with mobile phones to prevent the overflow of the garbage from the container. The system consists of three garbage robots, namely (G-Bot 1, G-Bot 2, and G-Bot 3). Each of these robots sends the data to the mobile phones, and the collected data can be checked with mobile phones using Blynk application. The goal of the research presented in [5] is to evaluate the effectiveness of UAVs in monitoring landfill settlement in a real post-closure scenario, by comparing two models obtained through the acquisition of UAV imagery from two separate flights, repeated after about 6 months.

The authors of [6] attempt to show how collaborative drones and IoT improve the smartness of smart cities based on data collection, privacy and security, public safety, energy consumption, and quality of life in smart cities. Article [7], presents a real-time and power-efficient air quality monitoring system based on aerial and ground sensing. The architecture of this system consists of the sensing layer to collect data, the transmission layer to enable bidirectional communications, the processing layer to analyze and process the data, and the presentation layer to provide a graphic interface for users. For data processing, spatial fitting and short-term prediction are performed to eliminate the influences of incomplete measurement and the latency of data uploading. This implementation has been deployed in Peking University and Xidian University since February 2018 and has collected almost 100,000 effective values so far.

IoT and UAV technology cooperation play a vital role in green IoT by transmitting collected data to achieve a sustainable, reliable, and eco-friendly Industry 4.0. The survey presented in [8] gives an overview of the techniques and strategies proposed to achieve green IoT using UAVs infrastructure for a reliable and sustainable smart world. In [9], the authors investigate the possibility of using drones to monitor garbage disposal at unauthorized locations. The proposed system uses machine learning and artificial intelligence techniques to detect illicit waste in images collected by drones. The authors suggest the further research be based on developing an automated robotic system to handle the detected waste. Paper [10] shows the smart system for the detection of garbage with image processing and the usage of a drone to capture images of locations with garbage. The authors use drones, with an Arduino microcontroller device, a deep neural network, the Python programming language, and Google's cloud platform.

Youme et al. [11] presented an automatic solution for the detection of clandestine waste dumps using unmanned aerial vehicle (UAV) images in the Saint Louis area of Senegal, West Africa. This task has a very high spatial resolution of UAV images (on the order of a few centimeters) and an extremely high level of detail, which require suitable automatic analysis methods. The proposed method begins with segmenting the image into four regions, then reducing the size of input images into $300 \times 300 \times 3$ for the CNN entries, and labeling images by determining the region of interest. The results show that the model recognizes targeted areas well but has difficulties with some areas lacking clear ground truths.

The paper [12] discusses the applications of UAVs in smart cities, their opportunities, and their challenges. Considering that UAVs have a wide range of applications in many fields like environmental hazards monitoring, traffic management, and pollution monitoring, all of which contribute greatly to the development of any smart city, authors discussed the challenges and issues such as safety, privacy, and ethical uses of UAVs.

An additional role model for the system proposed in this paper and its further development can be taken from the experience in building automated video surveillance (AVS) systems that are designed to automatically monitor objects in real time. One of these works presents the experience in building the distributed video surveillance system based on a client–server architecture as it is presented in [13]. The proposed system is accessible from portable devices such as tablets and smartphones. Similarly, the paper [14] targets the demand for a realistic wireless AVS system simulation framework that models and simulates most of the details in a typical wireless AVS framework. The proposed simulation framework is built over the well-known NS-3 network simulator.

## 3 The Model of the System

The model of UAVs-based urban waste monitoring system is presented in this section. The model is designed to monitor green urban areas, using the unmanned aerial vehicle (UAV). The role of UAV is to monitor the city region to prevent illegal waste dumps and containers overloads in public areas. Also, the goal of the model is to create a balanced low-cost and effective solution that will reduce the cost of the deployment and maintenance, without reducing the efficiency of monitoring. The idea is to use a single or minimized number of UAVs to cover all specified locations. The model is built on the algorithm for UAV path planning based on the traveling salesman problem (TSP) and genetic algorithm (GA). The model assumes the usage of the centralized system. Data processing is placed in the control center, but it is out of the focus of this model. The model is based on the usage of available and commercially popular drones. Furthermore, the equipment of commercial drones plays a significant role in shaping their price. The system has centralized data processing and drone management. The system architecture is based on [14] and consists of preferably one, but possibly more drones (depending on the size of the area to cover), and the control center to detect and identify improperly disposed waste. The system is automated and operates with the help of a drone called the supervisor. The drone supervisor enables the detection of illegal garbage and unregulated garbage dumps on green urban areas. The image processing component is deployed in the control center, but it is not considered in this proposed model.

## *3.1 Supervisor Drone*

The goal of surveillance drones is to observe public areas. The takeoff of the supervisor drones is performed according to a predetermined schedule. Drone monitors locations along defined paths, at an altitude of 30–70 m above the ground. Depending on the size of the terrain and the needs of the system, several surveillance drones can be deployed. Higher flight altitude (e.g., 70 m) is required to reduce the number of static obstacles in process of designing the drone trajectories. Furthermore, the higher altitudes of the drone can make drones hardly visible to the persons who are violating the regulations and can avoid disturbance to the citizens. Drone captures the current state of the monitored area at defined locations. The defined locations will be discussed later (Sect. 4), together with the algorithm used for drone path planning. After capturing images, the drone returns to the control center to upload images for further processing. The monitoring drones should have the following configuration: GPS module, optional sensors to avoid obstacles, Wi-Fi, LTE (4G), or both communication modules (depending on the network infrastructure and communication requirements), and a camera for capturing images. In addition, drones should have support for route tracking. Using the location definition and path to location data, the drone goes to one or more inspection sites, where it captures images and optionally a video. The drone arrives at the position by a dynamically defined path formed in the control center. When the supervisor drone reaches the position, it descends to a height of 3–5 m above the ground to perform a more detailed survey of the location. Captured location images are stored on SD card. After completing the capturing at all defined locations, it returns to the drone docking station, where it loads the data, reloads the logs, and charges the batteries. Data collected with supervisor drone are used to initiate further actions. In addition to GPS, communication modules, and sensors, this type of drone should have support for route programming, a high-resolution camera for capturing images and videos, and larger SD storage for captured images.

### *3.2 Control Center and the Communication System*

The control server receives data from the drone, stores the data in a database, performs analyses, and performs further processing. It should have high data processing capabilities for image processing and processing algorithms for defining drone routes. If the processing module detects an irregular situation, it proceeds with the actions in alarming the authorized personnel. The image processing module and the further actions are not considered in this paper and the presented model. The communication infrastructure of the model is not also considered in more detail. It should provide the connectivity of the PC (Docking Station) with the drone. This connectivity is important for two major tasks. One task is uploading the calculated path to the drone from the PC. The second task is downloading captured images to the control center. A drone Docking Station is a fully automated system that serves drones. A Docking Station is a specific place for the safe vertical takeoff and landing of drones. In addition to this function, it should enable fast charging of drone batteries, establish communication between the control center and the drone, and maintain their airworthiness. It would be desirable for the proposed system to use static stations with a wired connection to the control center and the power supply infrastructure [14]. The important component of the presented model is the module for route calculation located in control center. The process is shown in Fig. 1.

Figure 1 describes the process of route planning and UAV operations. This procedure is designed to enable the use of one or a minimal number of drones for covering the specified areas, thus reducing the UAV fleet costs and maintenance. First, the traveling salesman algorithm (TSP) with genetic algorithm (GA) is used to calculate the path for the UAV route. The calculated route is randomly formed from the set of nodes of interest. The definition of the set of nodes of interest is described in the following section. After the route calculation, the system checks if the route is longer than deployed UAV capability. If the route is longer, it is calculated again. If the route is within the UAV operational range, it is uploaded to the UAV. After uploading the route, the UAV moves according to the schedule, following the uploaded path. UAV takes images at defined locations, and after the ending of the tour, it returns to the control center. The images are uploaded to the system, and the recharge of the batteries is initiated. The presented set of actions is repeated at the defined period.

## 4 The Path Definition

This section describes the process of path calculation and the node set definition. The first step of the process is node set definition, and it is performed once at the start of system operation, after some upgrade of the system, or change of the waste management policy. The node set depends on the targeted items of the system. The system presented in this paper is designed to monitor the unregulated waste disposal at the places of interest by taking photos at the given locations. The collected photos

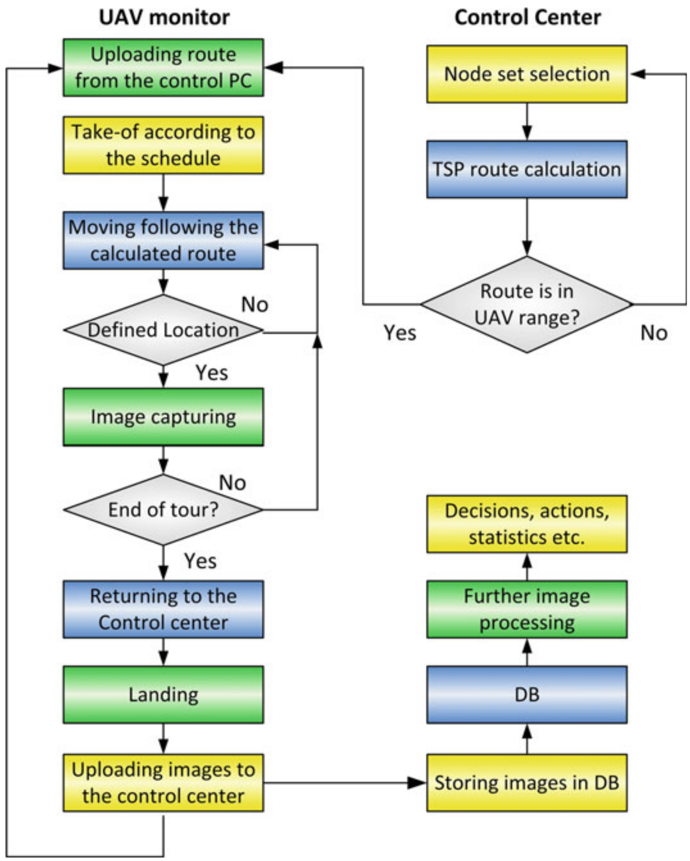


**Fig. 1** Route planning and UAV operations algorithm

are further processed in the search of pollution and unregulated waste detection. As places of interest, the gathering places of the people such as parks, green surfaces, sport terrains, and bathing areas are considered. The presented model of the system is designed to randomly select a smaller number of observing locations (10, 15, 20, or 30) to program the drone route each time before sending the drone to the mission. In this way, the locations will be supervised randomly in turns, providing the possibility to monitor a large area with one drone. This will significantly reduce the investment in the system and its maintenance costs.

The example node set is tailored by the city of Zrenjanin. Zrenjanin is a city in Serbia, located in the Central Banat region. Its geographical coordinates are 45° 230 N, 20° 2322 E, the urban area covers 193.03 km$^2$ (74.53 miles$^2$), and the population is 76,511 (2011 census). The observing locations (observing points) have the structure as follows: 29 parks, green surfaces, sport and bathing areas, 97 public garbage container locations, and one unregulated solid waste landfill, see Fig. 2. The

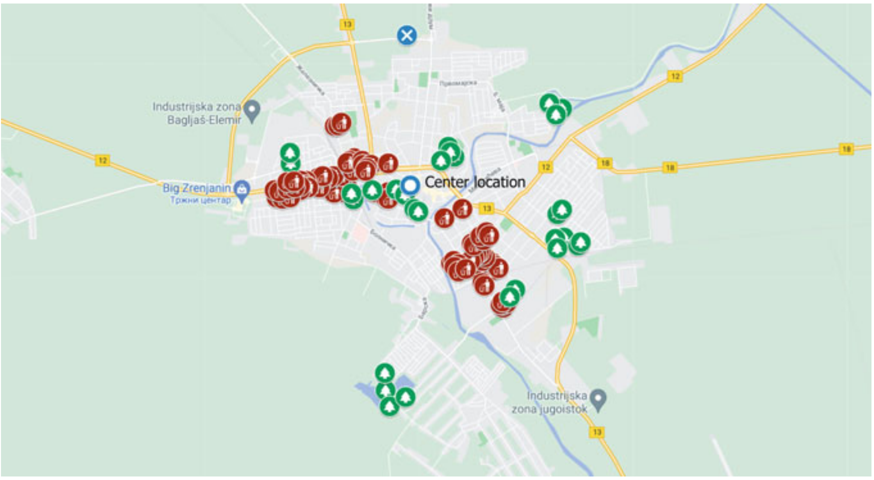


**Fig. 2** Observing point locations in the city of Zrenjanin

garbage container places are located near multi-story residential buildings where two or more containers are grouped. Because the citizens dispose of their garbage at these locations frequently, some containers can be over-filled, and the garbage in some cases might be scattered around the container. Only one unregulated solid waste landfill is covered with these locations because such places are located outside the city, and their inclusion in the system coverage area will significantly increase the range of UAV flight, which will require the deployment of UAVs with significantly better performance and thus higher costs.

The central location is used as a headquarters and a placement of control center. It is the starting and ending locations of each route. The number of observing locations is 127 with one central location giving a total of 128 locations. The traveling salesman algorithm (TSP) with genetic algorithm (GA) is used to calculate the path for 10, 15, 20, or 30 randomly selected observing locations [15]. Each calculated route starts at the central location and ends at the same point.

The MATLAB/Octave code is used for the simulation. The code is built upon the [15] and modified according to the presented model. The results of the simulation are presented in Table 1. The simulation uses algorithm with the changeable number of randomly selected nodes, number of iterations (required with the MATLAB/Octave code), and number of tests as well.

The distance for the calculated path for each set of randomly selected nodes is calculated and recorded for the analyses. As one can see from Table 1, the average distances for 10 nodes are 10 km, for 15 and 20 nodes 15–17 km, and for 30 nodes are around 26 km. The results also show that 1000 iterations give accurate results.

In Fig. 3, the two route graphs for 10 and 15 randomly selected nodes are given. The first route is for the following locations: Center-L0011-L0108-L0139-L0135-L0015-L0004-L0185-L0182-L0162-L0106-Center. The second route is as follows: Center-

**Table 1** Summary of simulation results

| No. | Nodes | Iterations | Tests | Avg. (km) | Min (km) | Max (km) | St. dev. (km) |
|---|---|---|---|---|---|---|---|
| 1 | 10 | 1000 | 100 | 13.18 | 12.93 | 16.08 | 0.57 |
| 2 | 10 | 1000 | 500 | 13.26 | 13.14 | 15.12 | 0.19 |
| 3 | 15 | 1000 | 100 | 17.27 | 15.21 | 22.81 | 1.84 |
| 4 | 15 | 1000 | 500 | 15.75 | 14.25 | 21.72 | 1.22 |
| 5 | 20 | 1000 | 100 | 16.02 | 13.83 | 21.37 | 1.55 |
| 6 | 20 | 5000 | 100 | 16.38 | 14.94 | 21.52 | 1.38 |
| 7 | 30 | 1000 | 100 | 26.21 | 19.05 | 35.10 | 3.04 |
| 8 | 30 | 5000 | 100 | 26.83 | 22.42 | 35.96 | 2.56 |

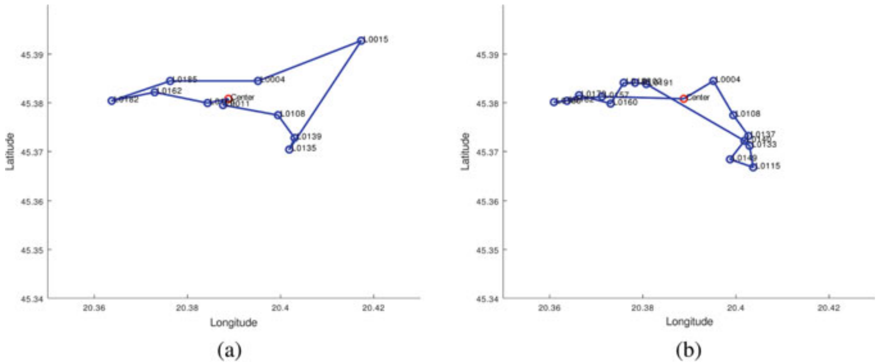


**Fig. 3** Calculated routes with **a** 10 nodes and **b** 15 randomly picked nodes

L0004-L0108-L0137-L0149-L0115-L0133-L0140-L0191-L0102-L0188-L0160-L0170-L0182-L0180-L0157-Center. The results show that considering the average route length (up to 15 km) the 10 or 15 locations can be easily monitored with one low-cost UAV.

## 5 Conclusion

This paper has presented an approach to using UAVs for remote imaging for urban waste monitoring. The presented model of the system is designed to monitor green areas, public trash cans, and unregulated landfills and to detect possible violations of garbage disposal rules. Public green urban areas, such as parks, green surfaces, sport terrains, and bathing areas, are gathering places for people and therefore prone to unregulated waste disposal. Other places of interest for monitoring are locations of public garbage containers located near multi-story residential buildings and possible locations of unregulated waste disposal.

The proposed model includes a method for random path selection allowing utilizing a minimal number of UAVs, as low as only one, for covering the specified area. The idea is to select the random locations for monitoring, thus giving the optimal ratio of drone utilization, areal coverage, and monitoring efficiency. The low number of drones affects the lower system purchase and maintenance costs. The paper has presented a model of system deployment with a general description and a detailed description of the method for path selection and drone operations. The path selection model is based on the traveling salesman problem (TSP) and genetic algorithm (GA).

Further work will include further development of the model. The priority of the model development will be the addition of statistics of locations monitoring frequency, the addition of priorities for certain locations, and modification of the path selection algorithm. The path selection algorithm will be required in cases when drones cannot use direct paths between certain nodes and are forced by the regulation and other factors to follow streets and other restrained paths.

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