Geomatics Methods and Soft Computing Techniques for the Management of Public Transport and Distribution of Medical Goods

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Abstract: - Initially used exclusively for military scopes, RPAS (Remotely Piloted Aircraft Systems) have become increasingly common and versatile thanks to continuous technological innovations and today they find applications in many other fields. Two of the most interesting applications of drones concern the transport of goods and the monitoring/control of crowding in public transport for the management of the LPT (Local Public Transport). In the first case, drones can be used to deliver goods in different areas with the advantage of saving costs and delivery times; in the second case, drones can be used to monitor and control the flow of people inside public transport, to detect any situations of overcrowding and take prompt action to ensure the safety and comfort of passengers. This research aims to propose an innovative automatic management system for a group of RPAS used for the transport of essential medicines and for monitoring the crowding of people in relation to the use of Local Public Transport. This was possible through the creation of an experimental system for recharging drone batteries and above all the implementation of different soft computing algorithms and tools such as YOLO (You Look Only Once), SORT, and MAC address. All the information obtained in real-time and continuously updated, are transmitted to an Open GIS studied and programmed by us.

Key-words: - GIS, Machine Learning, Genetic algorithm, IFTTT, YOLO, SORT

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1 Introduction

Drones have become an increasingly used tool in different fields due to their ability to fly and collect aerial data quickly and efficiently. Nowadays, research is progressively directed towards the automated flight of routes, to make the use of drones more efficient and safer. In addition, the research is focusing on the extent of the flight duration and the use of different sensors, so that the full potential of drones can be exploited. In the context of delivery and crowd monitoring, in the literature, many applications can be found, [1], [2], such as in the case of emergencies, [3], [4], [5], [6], in searching for survivors in catastrophic and natural events, [7], [8], and to monitor crowds, [9], [10]. The use of drones in this field mainly concerns the ability to carry out only flight operations without, however, fully integrating into wider-ranging projects that use other dedicated methodologies and technologies. To overcome these limitations, our research was focusing on the use of GIS (Geographic Information System) and different soft computing algorithms to give an important contribution beyond the actual studies present in the literature both in relation to the delivery of medical goods and the management of Local Public Transport (LPT). Thanks to these technologies, we can collect and analyze a vast amount of geospatial data, which can be used to plan and optimize drone routes, monitor crowds, and prevent potential security risks. Our research which has already been partially tested during the pandemic period, [11], is, therefore, part of a very precise framework: the management of a group of drones in an automated way with a system that combines many Machine Learning algorithms, geomatics methods and soft computing techniques such as IFTTT (If This Then That), YOLO (You Look Only Once), SORT and MAC addresses. The tested methodology allows us to deliver goods and monitor crowds with the images acquired by drones and from cameras of public transportation (simulated by us experimentally, with smartphones on poles) and installed in bus stops (also installed experimentally). Once acquired and downloaded, they have been transmitted to an Open GIS multi-platform, editable and searchable, [12], programmed in Python. Some well-known scientific research in the sector highlights the role of aerial photogrammetry using drones in the evaluation of road traffic flow and presents drone-based traffic monitoring systems that use artificial vision techniques to identify vehicles, pedestrians, and obstacles on the road, [13], [14]. In this context, we presented a system that allows, at the same time, delivery of necessary goods, in this case, first aid medicines, and monitoring of public transport, to help in its management and its possible improvement. Given that our system for monitoring and transporting materials via RPAS is fully automated and that the current regulations in the study area only permit VLOS (Visual Line of Sight) operations, our fleet of drones is fitted with safety parachutes that are triggered by an accelerometer. This parachute is compatible with drones that have sensors capable of detecting flight interruptions. The sensor sends a command to an actuator that deploys the parachute, which is protected from the propellers to prevent damage.

2 Materials and Methods

The main purpose of this work is twofold: the delivery of necessities by a scheduled flight of drones and the simultaneous monitoring of crowds of people at bus stops and on buses. For the research in question, therefore, we have used: a group of drones, a self-implemented GIS, and a series of different soft computing algorithms and tools. Among all the drones available, we have chosen the DJI Matrice 100 (Fig. 1) due to its technical characteristics, which were useful for the study we conducted. This type of drone is furnished with omnidirectional vision sensors, an obstacle detection system, intelligent features such as Point of Interest, allowing the drone to keep easily the point centered in the camera creating complex shoots, and are equipped with a fully stabilized three-axis gimbal camera, with a 1/2-inch CMOS sensor to record 4K videos and take 20-M Pixel photos. The main feature to take into consideration when choosing the drone, in addition to the camera specifications for image resolution, is the type of battery and its autonomy. DJI Matrice 100 has a 4500 mAh TB47D 6S battery with an autonomy of some minutes that we have managed to extend with a wireless charging system described below.

Fig. 1: UAV used for road inspection

It is impossible with the sole autonomy of the drone battery to reach some destinations. For this reason, for our research, we have implemented a system with which the drone can recharge the battery in an automated way (Fig. 2). Drones recharge their battery along the path thanks to recharging bases, located in predetermined points, [15]. These bases allow not only recharging but also the transmission of data. If a drone in flight senses that its battery is running low, it searches for the closest charging station. After receiving clearance to land, the drone utilizes its knowledge of the station's GPS coordinates, [16], [17], to touch down. Once it has landed, a subsystem either recharges or replaces the battery, [18]. During this process, a special connector is used to power the drone to prevent communication loss.

Fig. 2: Wireless charging base

The entire proposed method is governed by a DTGIS (Data Transfer GIS) that consists of a computer system used for the management and transfer of geospatial data. This system makes it possible to integrate various sources of geographical data and use them interactively and collaboratively. The system already tested by the authors in other applications, [11], consists of a system of 4 software: a Plug-in module, a Kernel Module, an NNS (Neural Network System), and a GIS I/O module. The scheme that highlights its operation is shown in Fig. 3.

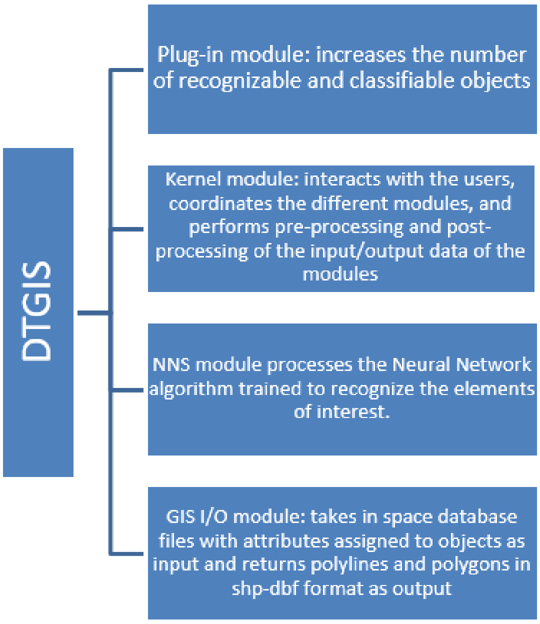

Fig. 3: Structure of DTGIS.

For the drones' flight plans for goods' delivery, we have used a Genetic Algorithm: Bubble Sort Genetic Algorithm. The multi-objective genetic algorithm is used to solve multi-objective optimization problems, [19]. The goal of the algorithm is to find a solution that satisfies more than one, often conflicting, goal at the same time. This algorithm, according to the criterion of the dominance of the Pareto front, allows the creation of new solutions starting from initial parameters by recombining them with elements of disorder. These new solutions are evaluated by choosing the best to converge toward optimal solutions. This function was used for determining the flight plan choices of drones.

In this application, the flight plan was established through four fundamental parameters that are the results of the multi-objective analysis by considering different input parameters (expressed with ID from aeronautics as highlighted in Table 1), depending on the characteristics of the study area and the destinations of the requested medical goods. The optimal route, in fact, needs to account for different features, and for this reason, we have defined a cost function (Fig. 4) starting from the parameters shown in Table 1.

Table 1. Input parameters for flight plan.

INPUT PARAMETERS	ID
Maximum flight time	Tmax (min)
Maximum mission time	MTmax (days)
Radius from area centre	R (m)
Speed	S (km/h)
Intersections of air routes	IAR (variable point coordinates
Drone position	PSN (variable point coordinates)
Time until intersection of air routes	TIAR (if no, ok; else change speed)
Track	TR
Destination coordinates	DEST
Wind Speed	WSPD
Wind direction	WDI
Flight altitude	A
No Fly Zone	NFZ (area coordinates)

$$F_{cost} = C_{Tmax} + C_{MTmax} + C_R + C_S + C_{IAR} + C_{PSN} +$$

$$+ C_{TIAR} + C_{TR} + C_{DEST} + C_{WSPD} + C_{WDI} + C_A + C_{NFZ}$$

Fig. 4: Cost Function.

The Bubble Sort Genetic Algorithm has minimized this cost function and returned four fundamental output parameters: TR (Track), S (Speed), RA (Requested Altitude), and FR (Battery Consumption). By setting the flight plan, the number of shots to take during the path and the height above the ground were also established, to calculate the optimal GSD.

For tracing the path of people to monitor overcrowding, we have used the following algorithms/methodologies:

- *IFTTT (If This Then That)*. IFTTT is a software code (Fig. 5) that enables the creation of real-time condition chains, known as applets, and allows the creation of connections between them simply and intuitively, even without programming knowledge. These applets are triggered by various services such as Twitter, Facebook, and Instagram, and can send a message or initiate an action in response. IFTTT can also automate processes related to home automation or web applications, such as receiving personalized weather forecasts or alerts in case of events. In this study, we have utilized this service to send alerts for requesting medical materials and to automate the flight of drones when the alert is received. The programming logic of applets is based on the following structure: if a specific event occurs (trigger), then execute a specific action.

```
[ ] var currentHour = Meta.currentUserTime.hour()
    if (currentHour >= 8 || currentHour < 16 ) { }
    else {
    Fly.FlyFleet.skip
```

Fig. 5: Part of code IFTTT code

- *YOLO (You Look Only Once).* The YOLO algorithm (Fig. 6) is a popular object detection algorithm that is widely used in computer vision applications. It is a convolutional neural network, [20], that can detect human figures by dividing the image into regions. In the context of the bus or stop cameras, the YOLO algorithm is used to identify and classify objects present in the images captured by the cameras, [21]. The YOLO algorithm works by dividing the image into a grid of cells and then predicting the object classes and bounding boxes for each cell. The convolutional neural network (CNN) is trained to identify and classify objects within each cell, and the algorithm uses a "convolutional sliding window" approach to process each cell individually. The resulting output is a vector of the form [pc bx by bw bh c1 c2 c3], where:

- Probability of object presence (pc): This is the probability that an object is present in the given cell of the image. If this probability is high, it indicates that there is a high likelihood that an object is present in that cell.

- X-coordinate of the center of the object (bx): This value represents the horizontal position of the center of the bounding box containing the recognized object.

- Y-coordinate of the center of the object (by): This value represents the vertical position of the center of the bounding box containing the recognized object.

- Width of the bounding box containing the recognized object (bw): This value represents the width of the bounding box containing the recognized object.

- Height of the bounding box containing the recognized object (bh): This value represents the height of the bounding box containing the recognized object.
  Once this vector is returned, the visual interface would be able to draw a box containing the object (bounding box).

```
import numpy as np
import time
import cv2
from darkflow.net.build import TFNet
import matplotlib.pyplot as plt
```

Fig. 6: Part of YOLO code

- *SORT algorithm*. SORT is a sorting algorithm (Fig. 7), which can be used to sort a list of objects based on a certain property. This algorithm can be used to sort objects based on their spatial location, such as the x and y coordinates of an object in an image, [22]. SORT works as follows: First, object detection systems (such as YOLO) identify people in a frame. Next, the sorting algorithm (sort) sorts the objects according to their spatial position. Finally, an association algorithm is applied to assign a unique ID to each person being tracked. The sort algorithm plays an important role in the people tracking process because it helps ensure that people being tracked are correctly associated with their unique IDs, even when people overlap or move quickly.

```
from sort import *
#create instance of SORT
mot_tracker = Sort()
#get detections
...
# update SORT
track_bbs_ids = mot_tracker.update(detections)
#track_bbs_ids is a np array where each row contains
a valide bounding box and track_id (last column)
...
```

Fig. 7: Part of the code of the SORT algorithm

- *MAC address.* The MAC address is not an algorithm but a unique identifier for a device (Fig. 8). When a mobile device has Wi-Fi enabled, it leaves a trace of its MAC address in the log of any nearby Wi-Fi router. This trace can be used to track the device's path. This tracking is necessary for users of the LPT (Local Public Transport), who may be waiting at a bus stop and could potentially take any bus to reach their destination.

```
function showPosition(position) {
    var latlon = position.coords.latitude + "," + position.coords.longitude;
    var img_url = "http://maps.googleapis.com/maps/api/staticmap?center="
    +latlon+"&zoom=14&size=400x300&sensor=false";
    document.getElementById("mapholder").innerHTML = "<img src='"+img_url+"'>";
```

Fig. 8: Part of the code for the single MAC address.

The use of these algorithms, therefore, does not raise problems concerning the privacy of public transport service users as the YOLO algorithm does not identify a specific person. Tracing, on the other hand, is possible thanks to the SORT algorithm and the MAC address which is immediately obfuscated through the application of a cryptographic function. An origin/destination matrix is thus constructed and updated on an hourly basis. The aim was to follow people along the path from the origin to destination using Machine Learning techniques and to do that we have correlated the images collected by drones to those downloaded from bus stops.

By combining the above algorithms, the Origin/Destination matrix was built with which we have obtained a statistical distribution of departure-arrival points to know the path of the LPT users. The flow present in each cell of the matrix was subdivided into the numbers of users using a certain line of the LPT, also using the MAC address. We have created, therefore, a system to obtain complete O/D matrices automatically in a GIS programmed in Python. The aim was to generate hourly forecasts of flow data and continuously monitor trends by comparing real-time data with historical data.

The methodology used for this system is composed of distinct phases (both of which use the GIS platform). The first phase consists of the setting of input parameters and the Genetic Algorithm resolution for the determination of the different and optimal flight plans, the positioning of the recharge bases, and the following image acquisition and medical goods' delivery. The second phase consists of the elaboration of the images acquired using ad hoc algorithms and integrating the results with other algorithms to define the origin-destination matrix and to identify the movements of people. In relation to the methodology used for the delivery of necessities and the monitoring of crowding of people, the flow chart in Fig. 9 shows the various stages of the process which involved the algorithms described above.

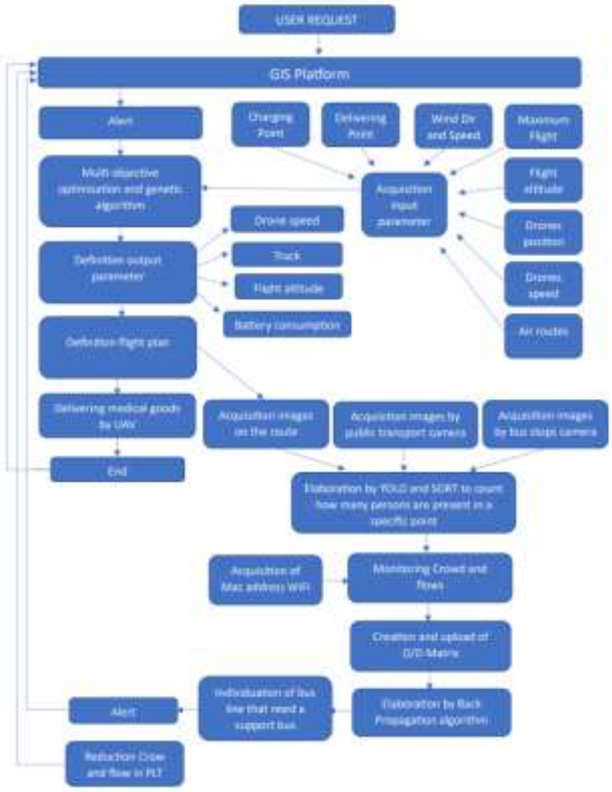

Fig. 9: Flow chart describing the proposed system.

The proposed system follows this process: through the open GIS platform, the user reports the medical supplies he needs, and an alert is generated and sent to the Operations Centre. With Genetic Algorithms, the multi-objective problem is solved, and the flight plan is automatic: the drone chooses the best alternative in terms of distance and input parameters given. Once the drone is equipped, it leaves capturing images along the way. If the destination is too far to reach for the autonomy of the drone's battery, it recharges or swaps the battery through the wireless recharging bases along the path. During this stop, it transmits data acquired. Once the drone delivers medical material, an alert is generated with the IFTTT algorithm. In the end, it returns to the original depot or goes to another depot.

During the flight for necessary goods delivery, drones acquire images thanks to their cameras and from cameras installed on buses and at bus stops with which we have identified areas of the route that require reinforcement buses to reduce crowding.

3 Case Study

The proposed system has been evaluated in an area near the Via Marina, in the city of Reggio Calabria (RC), Italy shown in Fig. 10. The study area was chosen with a scale such as to visualize a district of the city, therefore a sample area; in fact, the purpose is only to show the proposed research method, but it can also be implemented on wider areas of interest. We have analysed step by step the procedure for delivering goods and monitoring the crowd.

Fig. 10: Study area, a neighborhood of Reggio Calabria (RC), Italy.

In this area we have established:

three deposits of departure (with a green icon representing a drone)

five delivery points (with a yellow icon representing a package)

four recharge bases (with a red icon representing a drone with a flash)

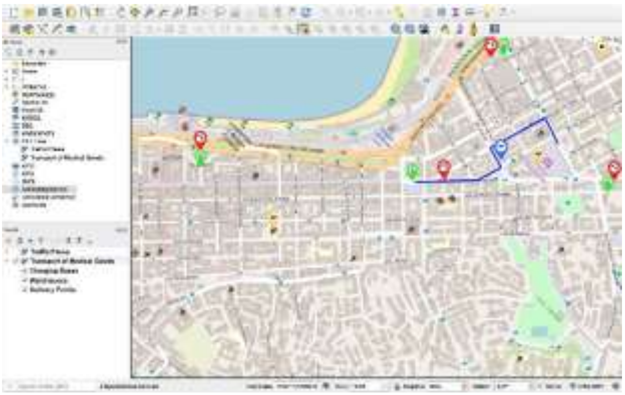

Fig. 11: GIS visualization of the medical goods' delivery.

Fig. 11 visualized, with a blue line and a blue icon representing a drone , the path taken by the drone once the genetic algorithm is solved. In this case, the drone takes off from one of the deposits of departure represented with the green icon (near the Lido station of the city of Reggio Calabria) with the medical goods and follows the path highlighted with the blue line along which there are the recharging stations represented with red icons.

In relation to the monitoring of the crowing of LPT users, using YOLO, SORT, and MAC Address, we could build the Origin/Destination Matrix and display the requested information on the GIS which is able to process the data on an hourly basis according to the bus line ID. Fig. 12 shows the Origin-Destination (O-D) Matrix. These are matrices that have several rows and columns equal to the number of zones, where the generic element supplies the number of movements originating from one point to arrive at another point in the reference period considered. In the image we have divided the study area into 5 zones: 1, 2, and 3 are internal zones, and 4 and 5 are external zones. Thanks to this matrix, it was possible to identify when the peak of people using public transport occurred in September, i.e., at 8.00 a.m. for the lines leading to the center.

O/D	1	2	3	4	5
1	452	47	43	134	474
2	93	406	57	321	86
3	12	18	136	197	97
4	31	108	265	379	30
5	185	402	100	144	24

Fig. 12: Origin-Destination Matrix.

In the table are shown:

- internal displacements with the orange
- exchange displacements with the green
- crossing displacements with the blue

By analysing the Origin-Destination matrix, it is possible to identify the areas with the highest displacement flows and highlight the routes (indicated with lines with different thickness and colours) that traverse those areas. Fig. 13 shows that the thicker lines correspond to bus routes with the highest levels of congestion based on the results of the Origin-Destination matrix within the relevant area.

Fig. 13: GIS showing the busiest LPT lines.

As can be seen from Fig. 14, the thickest lines are in Via Marina which connects the center to the outskirts of the city and where most of the public transport bus lines pass.

Moreover, DTGIS also allowed us to visualize (Fig. 13) the degree of crowding through circles that grows as the number of people waiting at the bus stop increases.

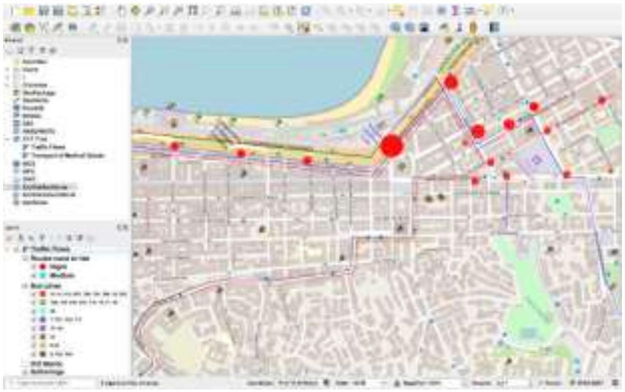

Fig. 14: GIS, bus stops most crowded.

The image shows that the busiest stop is the one adjacent to the Lido station, which connects the center to the other peripheral areas of the city. The stops located along the routes heading towards the city center tend to have the highest number of people waiting, as indicated by their thicker representation in Fig. 13 and larger circles in Fig. 14. To mitigate overcrowding, passengers may choose to select less congested stops or adjust their travel times on LPT (Local Public Transport) vehicles accordingly.

The experimented system allows, also using NNS (Neural Networks System), the analysis of historical data to identify trends in the use of LPT lines. Then an alert was sent to GIS that returned a signal in the platform (red triangle shown in Fig. 15) showing the need to integrate the line with another bus or to distribute the LPT users.

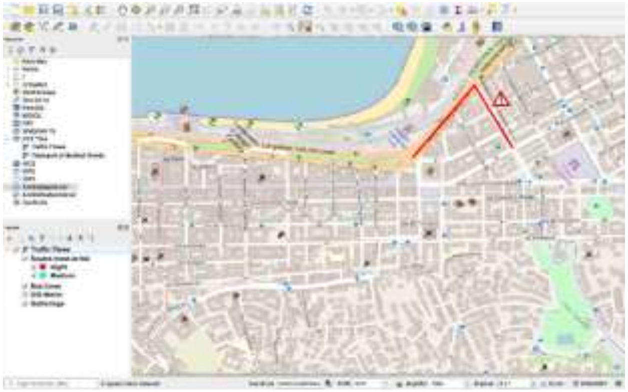

Fig. 15: GIS showing the line that will be most crowded.

4 Discussion

An innovative and automatic system of delivery and simultaneous monitoring of public transport traffic has been proposed in this research, thanks to which we are now able to visualize in the GIS platform many useful and completely anonymous information about the density, the exact arrival time, and the duration of people at the bus stops. Most importantly, we are now able to monitor people along their route on the bus, so from the boarding to the alighting at individual stops. In the GIS we visualize not only the traffic flow but also alerts in case of crowding levels that become critical and the delivery requests of various users. The integration of this system could provide important implications in our society, first allowing to facilitate all those people who need first aid items or who are unable to travel long distances and also, to view and possibly even manage the flow of people and vehicles within cities. In fact, people unable to leave their homes could benefit from this service quickly and safely. Delivery would also be possible in all those areas not yet properly connected to the city centre which would therefore require more time and costs in terms of fuel and personnel employed. The drone can reach any destination and allow continuous monitoring of the various areas of the city. A further advantage of the proposed system lies in the possibility of controlling the flow of people as the proposed system allows to visualize (thanks to the transmission of the data acquired with the proposed systems) of computerized GIS support in real-time, the level of crowding of people at stops and therefore the advantage that the traffic management system can have is evident, as the service can vary according to the data acquired.

The GIS provides a continuously updated framework that allows users and bodies that deal with the management of means of transport to view information on the crowding of people. All thanks also to the innovative recharging system that allows you to extend the autonomy of the drone without the need for personnel present on site. Users will thus be able to choose whether to take one line rather than another and the institutions will be able to make important decisions regarding the possibility of integrating other means. All within a constantly evolving historical and social context that is leading to the digitization of many of the services offered by provincial, regional, and national institutes.

5 Conclusions

RPAS are systems that represent fundamental tools in the field of research for many reasons which concern, to name a few, the monitoring of the conditions of the infrastructures, the delivery of necessities as well as the control of human activities. There are undoubted advantages in their use but there are still important limitations in relation to flying in crowded areas or respecting privacy while acquiring the images or videos captured by them. This study was carried out on a small sample area and aims to show the method for determining some relevant information, but it could lead to more comprehensive results if the method were implemented in a larger area or by using better-performing hardware and software. Through the proposed method, it was possible to deliver small goods and monitor the degree of crowding at bus stops, but there are several and many future developments of this technology that uses soft computing and machine learning techniques. Some of the possible future directions in this field include real-time data analysis that would enable the identification of patterns and trends in the data, as well as the prediction of future crowd movements; collaboration with public authorities such as police departments, emergency services, and local government agencies. This collaboration will be essential in developing effective crowd management strategies and ensuring public safety. For example, this method could provide information about people waiting at bus stops or available seats on transportation. Providing this information is important for public transportation for several reasons. They allow for improving passenger experience by reducing the stress and anxiety of waiting for passengers; increasing ridership because it can encourage more people to use public transportation; reducing traffic on the roads; optimizing service by helping public transportation companies to better plan bus routes.

The contribution of this research beyond alternative studies consists of the integration of different technologies. In fact, the study was based on the analysis of the multi-objective function for determining the optimal route of the drone, on the use of innovative recharging systems for extending the drone's autonomy, and on the integration of image data from the drone with soft computing and machine learning algorithms for estimating the crowding of people, displaying everything in a GIS environment.

Furthermore, the system could be equipped with the API or The Application Programming Interface which allows access to resources while maintaining security and control. This field is certainly in continuous evolution and there can be numerous applications as well as possible upgrades to be proposed. Future developments of monitoring the degree of crowding with drones, with soft computing and machine learning techniques.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

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Conflict of Interest

The authors have no conflict of interest to declare.