Toros University FEASS Journal of Social Sciences
Special Issue on 2nd International Symposium of Sustainable Logistics "Circular Economy"
Toros Üniversitesi İİSBF Sosyal Bilimler Dergisi 2. Uluslararası Sürdürülebilir Lojistik "Dögüsel Ekonomi" Sempozyumu Özel Sayı

ARAŞTIRMA MAKALESİ/ **RESEARCH ARTICLE**

ISSN: 2147-8414

Three-Dimensional Path Planning of UAVs in Complex Urban Terrains: A Case Study of Emergency Medicine Delivery in Shanghai (China)

Karmaşık Kentsel Arazilerde İHA'ların Üç Boyutlu Yol Planlaması: Şanghay'da (Çin) Acil Tıp Teslimatına İlişkin Bir Vaka Çalışması

Yutaka WATANABE[1] **Shan XU[2]**

ABSTRACT

Unmanned aerial vehicles (UAVs), widely known as drones, are used in various domains for tasks including geological prospecting, e-commerce business, and emergencies. Because of the necessity for fast and efficient delivery for emergency medicine distribution, drones can play crucially important roles by their ability to pass through complex urban environments. Drones might therefore aid people living under strict lockdown conditions during surges cases of COVID-19 or other communicable diseases. Nevertheless, distribution routes are usually planned in two-dimensional space. Moreover, restricted areas in urban aerial domains might be overlooked because of complex environmental considerations. To boost the feasibility of drone use, three-dimensional (3D) path routing can be applied when planning aerial distribution routes for drones, such as those used for delivering emergency medicines. This study specifically examines a more reliable method of using heuristic algorithms and software ArcGIS. After collecting location data of chronic patients in lockdown areas from the Shanghai official information system database, 3D visualization of the terrain and complex airspace was done using ArcGIS. Secondly, UAV routing constraints are summarized according to current laws and regulations for UAV operation at low altitudes. Furthermore, feasible solutions are incorporated into this model. Finally, after improved ant colony optimization (ACO) application to 3D route planning problems, programming was done using MATLAB (ver. 2017b). Assuming guaranteed safety and compliance with regulations, the solutions demonstrate the algorithmic efficiency and provide a satisfactory route plan for emergency medicine delivery that might guide emergency delivery system routing design in similarly complex urban environments.

Keywords: 3D route planning; emergency; geographic information system; heuristic algorithm; medical emergency; unmanned aerial vehicle.

ÖZ

Yaygın olarak insansız hava araçları olarak bilinen insansız hava araçları (İHA'lar), jeolojik arama, e-ticaret işi ve acil durumlar dahil olmak üzere çeşitli alanlarda kullanılmaktadır. Acil ilaç dağıtımı için hızlı ve verimli teslimat gerekliliği nedeniyle, dronlar karmaşık kentsel ortamlardan geçme yetenekleriyle çok önemli roller oynayabilir. Bu nedenle drone'lar, COVID-19 veya diğer bulaşıcı hastalıkların dalgalanma vakaları sırasında katı karantina koşulları altında yaşayan insanlara yardımcı olabilir. Bununla birlikte, dağıtım yolları genellikle iki boyutlu uzayda planlanır. Ayrıca, kentsel hava alanlarındaki kısıtlı alanlar, karmaşık çevresel hususlar nedeniyle gözden kaçabilir. Drone kullanımının fizibilitesini artırmak için, acil durum ilaçlarının teslimi için kullanılanlar gibi dronlar için hava dağıtım rotaları planlanırken üç boyutlu (3D) yol yönlendirme uygulanabilir. Bu çalışma özellikle sezgisel algoritmaları ve ArcGIS yazılımını kullanmanın daha güvenilir bir yöntemini incelemektedir. Şanghay resmi bilgi sistemi veri tabanından karantina bölgelerindeki kronik hastaların konum verileri toplandıktan sonra, ArcGIS kullanılarak arazinin ve karmaşık hava sahasının 3 boyutlu görselleştirilmesi yapıldı. İkinci olarak, İHA'nın düşük irtifalarda çalışması için mevcut yasa ve yönetmeliklere göre İHA yönlendirme kısıtlamaları özetlenmiştir. Ayrıca, uygulanabilir çözümler bu modele dahil edilmiştir. Son olarak, 3B rota planlama problemlerine geliştirilmiş karınca kolonisi optimizasyonu (ACO) uygulamasından sonra MATLAB (ver. 2017b) kullanılarak programlama yapılmıştır. Güvenlik ve düzenlemelere uygunluğu garanti eden çözümler, algoritmik verimliliği gösterir ve benzer şekilde karmaşık kentsel ortamlarda acil durum dağıtım sistemi yönlendirme tasarımına rehberlik edebilecek acil ilaç dağıtımı için tatmin edici bir rota planı sağlar.

Anahtar Kelimeler: 3D rota planlaması; acil Durum; coğrafi Bilgi Sistemi; sezgisel algoritma; tıbbi acil durum; insansız hava aracı.

Atıf (to cite): Watanabe, Y. & Xu, S. (2022). Three-Dimensional Path Planning of UAVs in Complex Urban Terrains: A Case Study of Emergency Medicine Delivery in Shanghai (China). Toros University FEASS Journal of Social Sciences, 9(Special Issue),65-78. doi: 10.54709/iisbf.1168831

Makale Geliş Tarihi (Received Date): 01.09.2022 Makale Kabul Tarihi (Accepted Date): 31.10.2022

[1] Prof. Dr. Tokyo University of Marine Science and Technology, Tokyo, Japan. ywatana@kaiyodai.ac.jp ORCID: 0000-0002-1308-9855
[2] Tokyo University of Marine Science and Technology, Tokyo, Japan. jyosan0309@126.com ORCID: 0000-0001-9205-031X

1. INTRODUCTION

With advancements in unmanned aerial vehicles (UAVs) intended for use in various domains, they are applicable in times of emergency. For emergency medicine delivery, drones can play a crucially important role by passing through complex urban environments because of the urgent necessities of fast and efficient delivery. Particularly in traffic-restricted areas, drones can be substituted easily for traditional transportation in lockdown areas. On March 29, 2022 ,with the advent of the Omicron pandemic and the surge in the confirmed cases, the local government of Shanghai, China chose to prevent all human travel and commuting in the city. Subsequently, 25 million people in Shanghai lived under strict lockdown for two months. In the lockdown area, roads were closed by fencing, making it impossible to continue the use of traditional traffic methods. Patients were confined to their homes, where they waited for volunteers to deliver medicines on foot. Along with extension of the lockdown, delivery services become increasingly overwhelmed, leading to inability to deliver medications to patients as quickly as possible in emergency situations. In such cases, drones can be deployed to deliver emergency medicines. However, earlier studies of drone emergency medicine delivery presented several limitations in its application to real practice. Primarily, the complex urban terrain conditions and the high density of buildings increase the difficulty of transporting emergency medicines by drones. Secondly, the flight path nodes of drones fluctuate severely, increasing power consumption and instability during transport. Therefore, carrying out a new safe and efficient method for drones is important to overcome those obstacles and serving patients who urgently need medication during a lockdown period. Otherwise, there might be no way for medicines to be delivered to patients in an emergency.

This study uses heuristic algorithms and ArcGIS software for specific examination of a more reliable distribution method. First, location data of patients in lockdown areas are collected from the Shanghai official information system database. Then three-dimensional visualization of the terrain and the complex airspace was done using ArcGIS. Secondly, a complex urban flight environment within a blocked area is modelled and simulated for actual terrain ground conditions. Flight constraints on UAV performance are summarized. Integrated cost functions are established. Threat areas are added. Optimal paths are calculated. The drone path planning environment is assessed, including representation.s of paths and search spaces, threat space models involved in the path planning, and the main constraint models for track planning. Drone routing constraints are summarized according to the current laws and regulations for drone operation at low altitudes. Finally, heuristic features of the ant colony algorithm are analyzed. After the algorithm parameter factors are improved to address shortcomings in the algorithm, a mathematical model of the problem and a flow chart of the algorithm are presented to model the drone's three-dimensional path planning problem. The improved ant colony optimization (ACO) was applied to three-dimensional path planning problems, with programming done using MATLAB (ver.2017b). Assuming guaranteed safety and compliance with regulations, the solutions demonstrate algorithmic efficiency and provide a satisfactory route plan for emergency medicine delivery that might be useful to guide emergency delivery system routing design, which can be resolved similarly to complex urban terrain problems.

The conceptual framework of this study is shown as Figure 1:

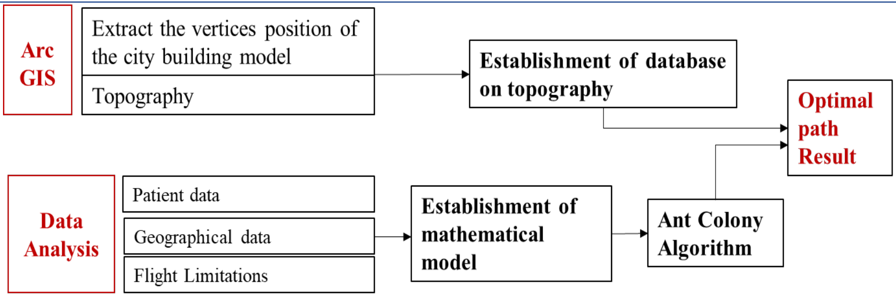


Figure 1. *The conceptual framework*

2. LITERATURE REVIEW

2.1. Drone path planning

In the mid-twentieth century, several economically developed countries began researching drone path planning technology. By the 1970s, a series of basic theories on flight had been constructed in this research area. Along with the widespread application and rapid development of computer technology, it was applied to remote control and remote sensing in the middle and late 1980s, leading to a qualitative change in operational planning systems. The United States, as a global military technology powerhouse, has continued to increase its investment in intelligent path planning and other aspects of research, taking the Predator as an example and establishing a ground control station system for drones. The newest model, the Air guard, can generate new paths in real-time based on navigation systems. Its drones can already fly independently around the world, across regions such as the Pacific and Atlantic Oceans, applying and performing various functions such as target surveillance and image processing. Rosner et al. (2018) designed a sensor that judges electromagnetic fields during UAV flight and which reduces the destructive power of magnetic fields during disruptive flights. Hirsch et al. (2011) developed a method of geometric mathematics to resolve difficulties of constraining the radius of a turn and choosing a direction in the trajectory planning process. This method allows the shortest path to be planned quickly, but it does not add a threat factor. Moreover, it is unsuitable for practical applications. Voos et al. (2018) investigated the detection and recognition of obstacles in complex and changing environments, using rapid commands through the autonomous judgment of flight control systems for collision-free navigation. Lobo et al. (2018) developed three-dimensional models to estimate drone trajectories using predictive models, to simulate wind speeds, and to calculate the likelihood of flight direction, with adjustment of the flight attitude to reduce crash probability. The research directions related to drone path planning mainly follow real-time planning, multi-aircraft collaborative planning, and ground station software system planning. In response to the difficulties posed by slow speed and flawed accuracy in the calculation of route length in path planning, the following shortcomings are readily apparent: Control must be maintained in a complex environment with a certain degree of randomness, with little assumed stability, with cooperation among different drones, and with monitoring of the emergency environment, in addition to strong requirements for technical personnel operation skills. Secondly, in response to the frequency of multiple events, operators must carry out re-planning and manual adjustments to change the path offsets. In summary, research on drone path planning in terms of algorithm accuracy and simulation of the real environment must still be enhanced, technical development is still limited, and research on drone path planning technology is urgently necessary.

2.2. Applications of drones for medical needs

Literature related to drones in medicine and healthcare studies is increasing. The rapid development of drone technology has led to a revolution in the medical domain. Major drone applications include pre-hospital emergency care, pre-laboratory diagnostic testing, and first aid. Choi et al. (2021) developed a UAV-AED flight simulation using topographic information such as natural terrain and buildings in Seoul, South Korea. Saeed et al. (2021) developed an Android application for patients through which the patient can send a request to the control centre whenever the patient must test for COVID-19. Khan et al. (2021) studied effective path planning methods applied to provide medical first aid in real-time with efficacy. Ling et al. (2019) studied a NASA medical supply delivery test conducted at a medical clinic in rural Virginia for the first government-approved drone delivery in the United States. The role of healthcare is crucially important for humanity. Therefore, research in this field is extremely important because it can save many lives, especially during urban lockdowns under epidemics. Therefore, we also emphasize ideas of applying drones for emergency medicine delivery.

3. METHODOLOGY

3.1. Basic methodology for path planning

3.1.1. Data sources and analysis

(1) Geographical data

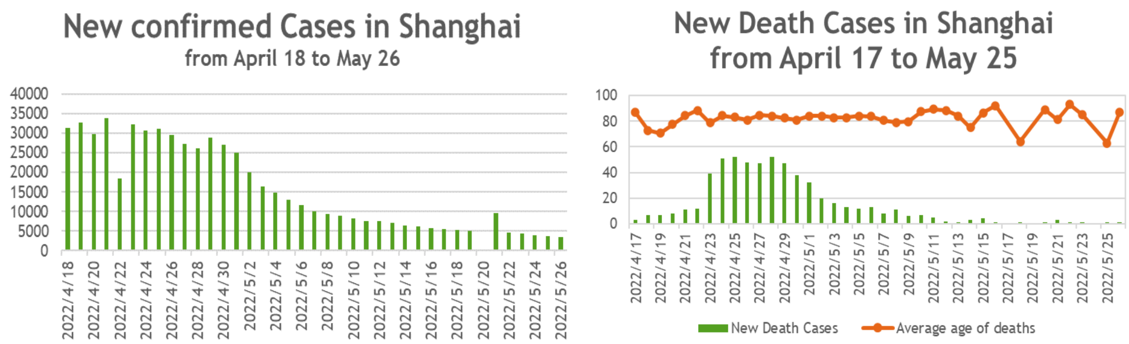
To develop drone flight path planning and simulation, we compiled a geographic information database that includes building height by combining data related to the altitudes of terrain features with the altitudes of all buildings in the lockdown area.

The geodatabase includes not only urban geospatial data (e.g., rivers, slopes) but also data from elevation models (e.g., buildings, roads) in the area. Geographic information can be collected in various ways: photogrammetry, field surveys, extraction of existing digital maps and extraction of existing Digital Elevation Model (DEM) databases. Because of the terrain complexity and the density of buildings in the lockdown area, photogrammetry and field surveys are difficult and time-consuming, although they might provide complete data. Therefore, we extracted data related to the topography and altitude of Shanghai city from Open Topography. The existing DEM database was chosen for this study. The data were then vectorized in ArcGIS: vertex positions of the building models in the city area were extracted. Data structures of two types are useful to represent urban geospatial data for experiments in ArcGIS, raster data structures and vector data structures. The chosen data structures differ among the types of data in the study area. The chosen data structure differs for each type of data in the study area. For this study, the raster data structure was chosen because of its ease of describing terrain undulations, the convenience of overlaying and combining spatial data, and the ease of performing spatial analyses of various types. The raster data structure is used to describe the topographical environment of the city. Because this study elucidates the route planning of drones in complex urban environments, accurate three-dimensional models of sensitive airspace and parametric modelling of feature data are required. Therefore, to describe the flight environment of drones in cities, it is necessary to use the vector data structure with its small data volume, easy processing of graphic data and attribute data, and high accuracy of geographic information data.

(2) Patient data

The data of COVID-19 patients in lockdown areas were collected from the Shanghai Municipal Health Commission using programs in Python. The data include the locations of newly confirmed cases and reported death cases from April 17 through May 25, 2022.

Data for causes of death in lockdown areas were also collected. More than half of the deceased were chronic patients who required timely use of medicines daily, and who might even need emergency medicine in a case of sudden illness. As presented in Figure 2, the line in orange shows the average ages of newly reported deaths. Almost all new death cases in the Shanghai lockdown area were elderly people. Data related to newly reported deaths were analyzed. Results in Figure 3 were obtained, indicating that more than half were patients with chronic diseases (e.g., hypertension). Greater attention must be devoted to elderly people, and especially to older people with chronic illnesses.



(a) New confirmed cases *(b) New death cases*

Figure 2. *Cases in Shanghai Lockdown Area.*[*1]

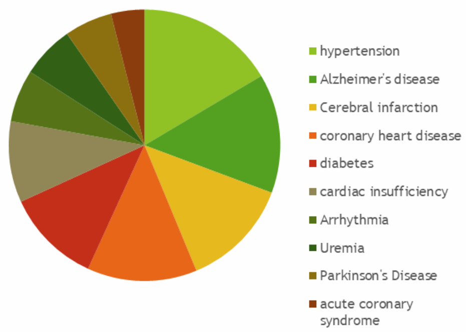


Figure 3. Top 10 Causes of death in Shanghai lockdown area.[*2]

[*1,2] *Data Source: Daily Reports from Shanghai Municipal Health Commission (up to 2022.5.26)*

3.1.2. ArcGIS Technology

With powerful data storage, spatial analysis and data visualization, ArcGIS is a highly scalable, comprehensive software platform that is able to describe complex urban geographic environments and to provide a good database. Therefore, this study uses ArcGIS for route planning. At the same time, the geographic information database used for this study is a data table form that can convert a large range of geographic information into an information model, and which can store and manage geographic information in a simple data table line book. Finally, the information model can be managed in a hierarchical manner according to the different needs of users, thereby ensuring the data effectiveness.

3.1.3. Modelling of complex urban terrain

Description of the complex urban environment for drones consists of two parts: creation of spatial terrain and representation of flight constraints. Digital elevation models of three types are in common use: the contour model, the irregular triangular network model, and the regular network model. The contour model is a map that represents the undulations and height conditions of the ground by joining adjacent points of the same elevation to form a collection of closed curves. The model shortcomings are that it does not represent all elevations, and that it is insufficiently three-dimensional. Calculating and representing some fine terrain features between two contour lines is difficult. An irregular triangulation model consists of a continuous triangular surface on which the surface shape and size depend on the sampling point location and density. Compared to regular grid cells, the map resources required for construction and processing are greater. For that reason, the costs of acquiring the original map data can be high. Also, the computational efficiency is low. The regular grid model is used widely for the creation of terrain environments because of its structural gridding characteristics. Actually, the model can be represented by a matrix that is easy to process by computer and which can better reflect the actual terrain topography.

As described herein, the regular grid model approach is used to achieve a spatial description of complex urban terrain. Furthermore, the relevant literature shows that the interpolation algorithm can restore the real terrain better. The initial map data are constructed using the original terrain map generated according to this method, as shown in Figure 4.

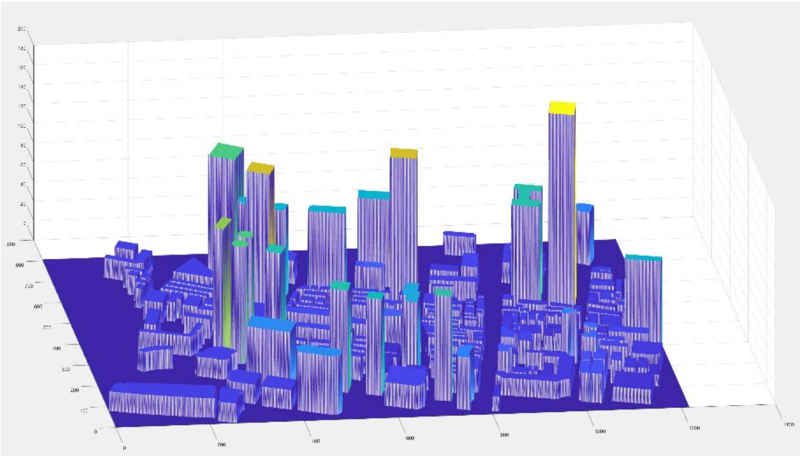


Figure 4. Three-dimensional mathematical model of complex urban terrain.

3.1.4. Ant colony algorithm

The ant colony algorithm (ACO) is an intelligent optimization algorithm that simulates an ant colony's foraging activities. Biologists have demonstrated that ants have no visual system and that they mutually communicate by releasing pheromones along the paths they travel. By sensing the presence and concentrations of pheromones during movement, ants can guide their movements, and those of ants following later, and ultimately find the best path to food. The ACO algorithm is based on the method used by real ants to find an optimal path. It is a simulation of evolutionary algorithms, which simulates ant behaviors in finding paths during their food searching.

The ACO algorithm has been used widely for solving hard combinatorial optimization problems in several domains, such as the traveler problem, resource scheduling, and other problems. The ACO algorithm has excellent robustness, making it an effective method for solving drone path planning problems. In the drone path planning problem and the simulation algorithm, the ants represent the drones. Furthermore, the probabilities for choosing the next spatial coordinate location are related to the pheromone. Dorigo et al. (2005) established the transition probabilities, which are defined as presented below.

$$p_{ij}^{k}(t)\begin{cases}\frac{\tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)}{\sum_{s\in allowed_k}\tau_{is}^{\alpha}(t)\eta_{is}^{\beta}(t)}, j\in allowed_k \\ 0, \qquad otherwise\end{cases} \tag{1}$$

Therein, $p_{ij}^{k}(t)$ stands for the transfer probability of ant k from node i to node j at time t. The following variables are also used:$\tau_{ij}(t)$ denotes the amount of pheromone on path (i, j) at time t; $\eta_{ij}(t)$ expresses the heuristic function indicating the expected degree of transfer of ant k from node i to node j; $\tau_{is}(t)$ signifies the amount of pheromone from node i to destination s at time t; $\eta_{is}(t)$ denotes the expected degree of transfer of ant k from node i to node j; and node i to node j; α and β respectively represent the information-inspired and expectation-inspired factors. Also, $allowed_k$ denotes the set of transfer nodes allowed by ant k.

The ACO algorithm is influenced by the pheromone update model, which tends to cause the population to lose diversity and fall into a local optimum. To overcome that tendency, some research is conducted to propose a three-dimensional path planning method to improve the ant colony algorithm and to ascertain the guiding factors of ants and the nodes to be transferred. The new regeneration mechanism and pheromone diffusion mechanism are established. The feasibility and effectiveness of the proposed algorithm are verified through realistic examinations. The feasibility and validity of the proposed algorithm are verified through real-life tests.

3.2. Study setting

3.2.1. Problem description

First, data on the topography and altitude of Shanghai city are extracted from Google maps (Figure 5). Secondly, a 2 km × 2 km lockdown area in Shanghai is chosen. In this area, there are 1034 buildings, including one hospital (red building), two government offices (pink buildings), and three residential buildings (blue buildings) in which the patients reside. As shown in Figure 6, the drone takes off at the red point and ends at three blue points. The route involves traversing a complex of urban terrain while avoiding pink government buildings.

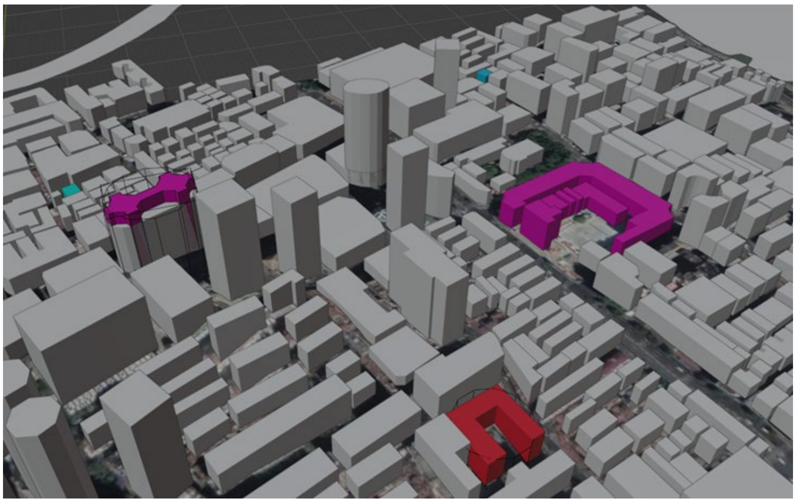


Figure 5. *Three-dimensional model of complex urban terrains in Shanghai lockdown area.*

Figure 6. *Locations of buildings in google maps.*

3.2.2. Problem description

The drone constraints are the performance indicators of the airframe itself. These indicators measure the maximum distance travelled, the maximum altitude flown, the maximum speed flown, etc. The indicators limit whether the drone can safely traverse the area, whether a possibility of flight failure exists, and whether the attitude and speed adjustments are restricted during flight. As described in this paper, the performance indicators above are regarded together. The constraints of the corresponding mathematical model are established.

(1) Minimum step length

The drone might shift its flight attitude during performance of its delivery. In the process of completing an attitude shift, it will perform a straight flight to a distance necessary for an actual safe flight. This distance is designated as the minimum step length. At the same time, the minimum stride length is also the minimum value of the stride length of the drone to maintain the inertial state in an unexpected situation, which, in general is the length of one second flown at the current speed conditions. The constraint of minimum stride length is determined mainly by the flexibility of the drone itself and the compactness of the airframe, but is also related to the navigation performance of the vehicle. If the attitude is not adjusted correctly or if it is adjusted too slowly, then the remote control and guidance functions will fail during subsequent flights. The aircraft might crash in treacherous terrain.

Letting L_i represent the total route length in segment i and letting L_{min} denote the minimum total route length, then the minimum step lengths can be defined as shown below.

$$L_i \geq L_{min} (i = 1,2,\ldots,n) \tag{2}$$

(2) Maximum voyage

The drone range is the main indicator of the maximum flyable distance of a drone during flight. The maximum range is the maximum distance a drone can fly with a full charge, assuming the maximum range as L_{max}. The total route length of the drone must meet the following conditions.

$$\sum_{i=1}^{m-1} L_i \leq L_{max} \tag{3}$$

(3) Minimum height from the ground
When carrying out distribution tasks, drones should be operated at as low a height as possible to prevent effects their operations, but too low a height from the ground can easily pose a threat to people on the ground. Therefore, a minimum height from the ground should be set in conjunction with relevant legislation. Letting $[x_i, y_i, h(x_i, y_i)]$ be the elevation coordinates of the route point, and letting $Z(x_i, y_i)$ be the elevation of the geographical model point corresponding vertically to the route point, and letting h_{min} and h_{max} respectively denote the minimum and maximum flight altitudes, then the constraint can be expressed as shown below.

$$h(x_i, y_i) - Z(x_i, y_i) \geq h_{min}, \quad h(x_i, y_i) \leq h_{max} \qquad (4)$$

(4) Total route length
The maximum power storage and power consumption determine the maximum distance that the drone can fly. From a flight safety perspective, the total range of the drone must be as short as possible. Letting d_{max} be the maximum route length, then the total route length constraint is the following.

$$\sum_{i=1}^{n} L_i \leq d_{max} \qquad (5)$$

3.2.3. Implementation process of the improved algorithm

The specific implementation steps of the improved ant colony algorithm are presented as shown below.
Step 1: First initialize the parameters. Empty the forbidden table. Then set the number of iterations; place the ant in the initial node.
Step 2: Place the ants at an initial node in the neighborhood space and start iterating.
Step 3: Increase the number of ants.
Step 4: Calculate the probability of state transfer from node i to node j based on the transfer probability formula. Then move the ant from node i to node j. Add the coordinates of node j to the taboo table of k ants.
Step 5: Return to step 3. If $k <$ m , then perform step 6 if this condition does not hold.
Step 6: If the ant traverses all nodes, then find the paths of all ants. Follow the update node pheromone method to find the number of pheromone increases. Then update the pheromones on all paths for updating and empty the taboo table of all ants.
Step 7: Determine whether it falls into a local optimum. If so, then dynamically adjust the volatility factor according to the distribution.
Step 8: If the maximum number of iterations is reached, then the search ends. Compare the resulting paths after each search and output the shortest path. If this condition does not hold, then go back to step 2 and search again.

3.2.4. Improvement Strategies

After a certain number of iterations of the ant colony algorithm, the search for the optimal solution is fundamentally the same. A stagnation phenomenon occurs. This phenomenon can reflect an excessive pursuit of optimal solutions, resulting in overly rapid convergence and a gradual decrease of the solution space. Reasons for this phenomenon are explained hereinafter: the algorithm lacks blind search capability at the beginning of the iteration; moreover, the direction of travel cannot be determined, therefore increasing the search time. The pheromone size determines the choice of subsequent ants. With an extreme increase in pheromone concentration, the algorithm falls into a local optimum. The pheromone concentration is constantly volatile along the paths along which the ants pass. The volatility per unit of time affects the guidance function of subsequent ants. The basic idea of the improved ant colony algorithm is to adjust the pheromones during the search process dynamically, and thereby to influence the decisions of the ants which follow later.

As shown in Figure 7, no better result was obtained using the traditional ant colony algorithm. Most ants showed a local optimum solution on the route of operation and a large jump when traversing the buildings. Such simulation results are not conducive to a smooth drone ride. The Unimproved ant colony algorithm cannot be used directly for drone path planning problems.

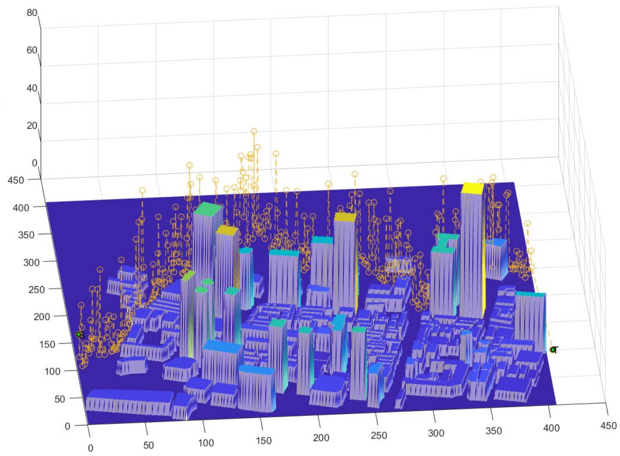


Figure 7. *Path results obtained using the unimproved algorithm.*

As described herein, the following improvements have been undertaken to address the shortcomings of the ant colony algorithm described above. Our calculated path makes the drone to deftly avoid obstacles when it encounters buildings along the way, as shown in Figure 8. A target node bootstrap factor was added to the state transfer probabilities of the algorithm. First, a target node bootstrap factor was added. It reduces the blind search of ants at the early stage of the algorithm, determines the main direction of feasible solutions, makes the ant colony move in that direction, determines the feasible solution range as soon as possible, reduces the iteration time of the algorithm and improves the convergence speed of the algorithm. Second, the pheromone on the path is updated reasonably dynamically. As the number of iterations of the algorithm increases, the paths of the respective iterations of the ants are sorted according to their length. The results are fed back to the ant colony for learning, thereby reducing the pheromones of the inferior ants and increasing that of the superior ants. The ranking is then weighted according to the degree of contribution, therefore expanding the path space available to the ant and increasing the diversity of solutions.

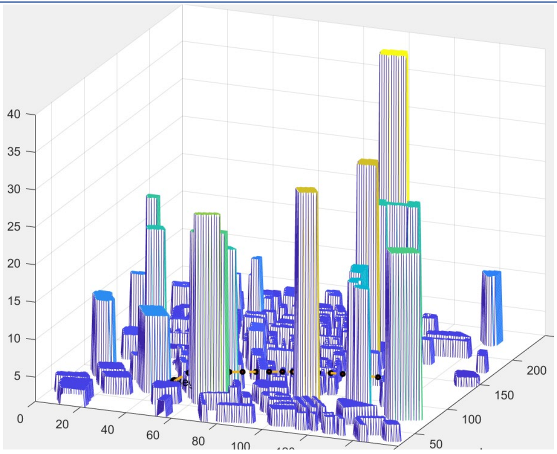


Figure 8. Path results obtained using the ımproved algorithm.

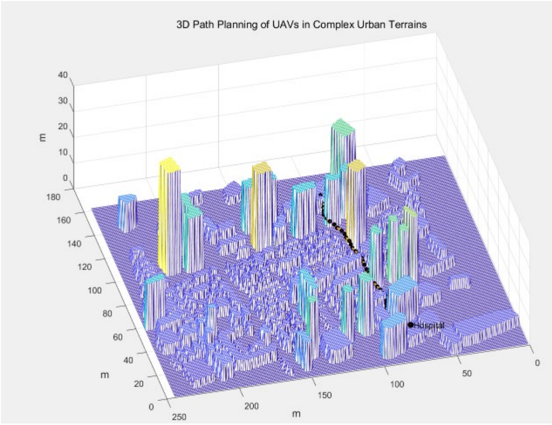
3.3. Simulation and analysis of results

To validate the simulation of emergency medicine delivery using quadcopter drones, several tests were conducted in the software. The Shanghai Renji Hospital was chosen as the test site, mainly because it is the only highest-level hospital in the lockdown area which had no shortage of medicines. In addition, three randomly selected emergency medicine demand nodes with different positions and different directions were chosen from within the lockdown area. In addition, two government buildings must be avoided. Detailed information of the building model is presented in Table 1.

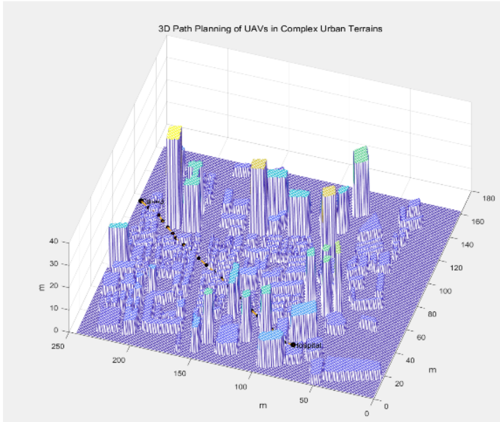
Table 1. *Building model ınformation*

No.	Address	Coordinate points of the model
Case 1	No. 556 Changping Road Jiangning Road Street	135.96.2
Case 2	Lane 420, Changhua Road, Jiangning Road Street	120.240.3
Case 3	No. 145, Shandong Middle Road	120.50.5
Hospital	Lane 99, Yongxing Road Baoshan Road Street	20.75.5
Government 1	No. 31 Shanxi Road	37.63.5
Government 2	No. 215 Jiangxi Middle Road	35.95.5

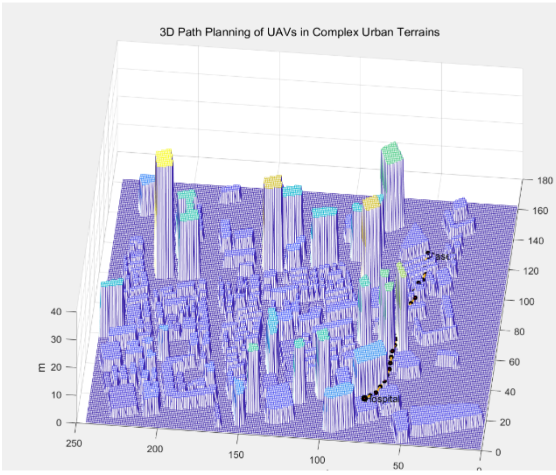
The paths for cases 1–3 can be derived using the algorithm. As shown in Figure 9, the improved ACO algorithm's route paths have better smoothness than the paths planned using the traditional ACO algorithm, as well as avoiding obstructions of buildings in complex urban terrains.



(a) Path for case 1



(b) Path for case 2



(c) Path for case 3

Figure 9. *Rendering for cases 1–3 using the ımproved algorithm.*

4. FINDINGS AND DISCUSSION

The advent of drones has led to huge technological advances in the 21st century. They offer numerous benefits for almost every area of life. These drones can also play a role in saving time and valuable lives by delivering emergency medication during the widespread pandemic of COVID-19. A similar study was conducted by the authors with the aim of safely and efficiently delivering medicines by drone to patients who are compelled to stay at home. In addition to simulate a realistic drug delivery scenario, we conducted a study to analyze data related to newly reported cases of infection and newly reported deaths in Shanghai during the outbreak. The study showed that elderly people with underlying medical conditions needed more help and attention during the epidemic. We developed a method for hospitals and medicine delivery volunteers to derive efficient and safe routes for drone delivery when patients need emergency medication, even in complex urban terrain. Based on the problem of three-dimensional path planning for drones in complex urban terrain environments, this paper first proposes a method for transforming GIS data models into mathematical models that extract urban geography and terrain conditions into polyhedra, making the simulation environment more closely resemble the real complex urban environment. Secondly, an improved ant colony algorithm is proposed to solve the three-dimensional path planning problem of drones. Characteristics of the traditional ant colony algorithm were analyzed. To improve the algorithm in terms of the search direction and the optimization heuristic function, the algorithm was improved based on the traditional ant colony algorithm to keep the algorithm from falling into a local optimum solution. The simulation experiment results confirm that the improved algorithm provides marked improvement in both optimal calculation results. The experimentally obtained data of route planning for the same task start point (hospital) and delivery target points (patients) indicate that the flight route of the improved ant colony algorithm is more stable. Moreover, it can obtain a better solution than the traditional ant colony algorithm under the same conditions.

5. CONCLUSION

The results obtained using Google Maps and algorithms for path planning are shown in Figure 10 and Table 2. However, it is readily apparent that a difference exists in cumulative times of walking and drone travel. The distance of the algorithm is shorter than that presented by Google Maps. When a patient needs medication, drones can get to a destination faster than a volunteer can reach it by walking. The advanced ACO solves the drone path planning problem effectively in complex urban terrains. As a future work, we are going to improve the stability and safety of drone in bad weather by combined with three-dimensional center of gravity. Also, we will improve the accuracy of the algorithm by comparing multiple heuristics algorithms.

Table 2. *Comparison between two methods of medicine delivery*

Case No.	Start coordinate points (hospital) of the model	Destination coordinates points of the model destination position	Distance of drone path (m)	Cost time of drone path (min)	Distance of Google map by walk (m)	Cost time of Google map by walk (min)
1	20.75.5	135.96.2	566.76	1.7	953.72	19.07
2	20.75.5	120.240.3	984.53	2.95	1893.78	37.88
3	20.75.5	120.50.5	454.68	1.36	923.62	18.47

Figure 10. *Emergency medicine delivery paths in a lockdown area*

REFERENCES

Choi D S, Hong K J, Shin S D et al. (2021) Effect of topography and weather on delivery of automatic electrical defibrillator by drone for out-of-hospital cardiac arrest. Scientific Reports, 11(1): 1-8.

Dorigo M, & Blum C. (2005) Ant colony optimization theory: A survey. Theoretical Computer Science, 344(2-3): 243-278.

Hirsch M J, Ortiz-Pena H, & Sudit M. (2011) Decentralized cooperative urban tracking of multiple ground targets by a team of autonomous UAVs. 14th International Conference on Information Fusion. IEEE, 1-7.

Khan S I, Qadir Z, Munawar H S et al. (2021) UAVs path planning architecture for effective medical emergency response in future networks. Physical Communication, 47: 101337.

Ling, G., & Draghic, N. (2019). Aerial drones for blood delivery. Transfusion, 59(S2), 1608-1611.

Marques, M. M., Gatta, M., Barreto, M., Lobo, V., Matos, A., Ferreira, B., ... & Marques, F. (2018, May). Assessment of a Shallow Water Area in the Tagus Estuary Using Unmanned Underwater Vehicle (or AUVs), Vector-Sensors, Unmanned Surface Vehicles, and Hexacopters – REX'17. In 2018 OCEANS-MTS/IEEE Kobe Techno-Oceans (OTO) IEEE. (pp. 1-5).

Rosner, D., Trifu, C., Tranca, C., Vasilescu, I., & Stancu, F. (2018, September). Magnetic field sensor for UAV power line acquisition and tracking. In 2018 17th RoEduNet Conference: Networking in Education and Research (RoEduNet). IEEE, 1-5.

Saeed F, Mehmood A, Majeed M F et al. (2021) Smart delivery and retrieval of swab collection kit for COVID-19 test using autonomous Unmanned Aerial Vehicles. Physical Communication, 48: 101373.

Shanghai Municipal Health Commission. Daily Reports .https://wsjkw.sh.gov.cn/yqtb/index.html.

Wang M, Voos H, & Su D. (2018) Robust online obstacle detection and tracking for collision-free navigation of multirotor uavs in complex environments. 2018 15th International Conference on Control, Automation, Robotics and Vision (ICARCV). IEEE, 1228-1234.