UAV 2D Path Planning Considering Ground Suitability for Flying Safety in Digital Twin

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Abstract

The utilization of various UAVs such as facility inspection and delivery is increasing. Ensuring safety in carrying out various UAV missions is an important issue related to human and property damage. Safe operation of UAVs flying autonomously along pre-located routes requires safe route planning to prevent collisions between aircraft in consideration of ground and air obstacles. Pass flight is also essential to minimize damage in the event of a crash. This paper deals with the optimal UAV 2D routing plan considering ground compatibility for flight safety. High ground compatibility here means that the damage caused by the crash is less than when it is not. In this paper, we first defined dynamic and static obstacles. Next, we derived ground compatibility considering dynamic and static obstacles. We used estimation algorithms and land use data to calculate ground compatibility values for flight safety, and through experiments, we calculated an optimal 2DUAV route plan for flight safety.

1. Introduction

With the recent rapid development of drone technology, the world is actively investing in the drone industry competitively. Services using drones are mentioned in various fields such as environmental monitoring, transportation and logistics delivery, facility inspection and on-site monitoring, quarantine, and safety services. Securing safety in drone flight is an important issue related to human/material damage. For the safe flight of drones flying autonomously along the pre-promised route, it is necessary to design and construct a virtual airway that can consider obstacles between the ground and the air and prevent collisions between aircraft. In particular, since enormous damage on the ground (life/vehicle/building, etc.) is expected in the event of a drone crash, it is appropriate for the drone's virtual airway to be designed in an area that minimizes the damage on the ground in the event of a crash.

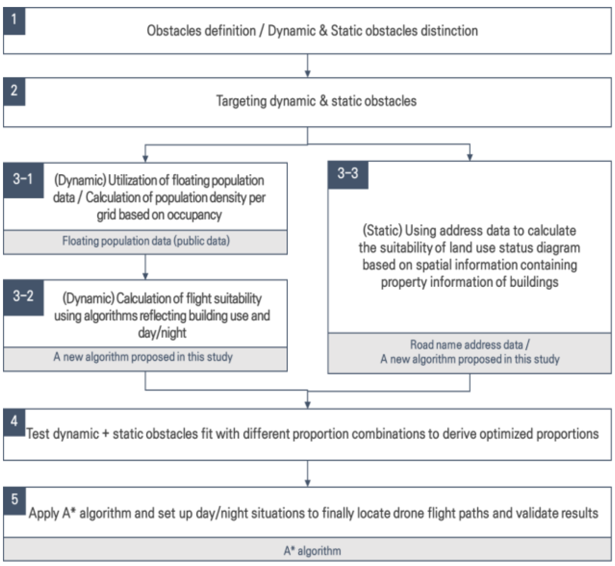

Figure 1. Process of this research

This study aims to derive a suitable route for the installation of public roads, including dynamic obstacles (ground floating population, etc.) that are expected to cause major damage in case of a crash. To this end, it is reviewed previous studies related to drone safety flight, and based on this, the ground fitness for flight safety is derived through the analysis of dynamic/static obstacles on the ground in Chapters 2 and 3. In Chapter 4, the optimal flight path calculation and verification are performed based on the derived fitness, and the conclusion is finished with implications. Figure 1 is the process of this study.

As drone technology is applied to various fields and its utility is gradually proven, research cases on the efficient flight path and flight safety of drones are increasing significantly. Previous studies on drone optimal path exploration can be largely distinguished from those that study optimal paths considering obstacles and transit or destination points, and those that study optimal paths to prevent damage in the event of a crash or collision between planes.

Optimal route studies considering obstacles and transit/destination include route search techniques to visit destinations while considering intermediate transit points for monitoring or avoiding 3D or 2D obstacles, and collision prevention route search studies between drones. (Woo et al., 2020, Phung and Ha, 2021, Kim et al., 2021, Yoo et al., 2021)

Research on the optimal route considering the damage in the event of collision or crash between flying objects was mainly conducted by considering the risk of accidents based on land coverage, route exploration to prevent collisions between drones, or route exploration using transportation card tag information. (Hong et al.,2021, Yoo et al.,2021, Lee et al.,2019, Park et al.,2019)

This paper focuses on presenting a way to explore the optimal path that distinguishes outdoor and indoor population concentration using free public data.

2. Definition of Dynamic obstacle/Static obstacle

In this study, the hazards present on the ground within the flight area are referred to as obstacles, and are classified into moving dynamic obstacles and static obstacles that are fixed in consideration of ground suitability. In general, drone obstacles mean objects that can collide in flight.

Dynamic obstacles are obstacles moving from the ground and are defined as outdoor floating populations that can be directly damaged by crashed drones. The basic data used local government data of "Seoul Living Population Data by Administrative Dong" and "Administrative Dong Boundary

Data" with four attribute information including the Administrative Dong code. Static obstacles are calculated based on building information. Space information and attribute information of each building are used by utilizing "road name address data" provided by the Ministry of Land, Infrastructure and Transport. Attribute information consists of a total of 30 pieces, including information on buildings and addresses, and the area of the building is not included, so it was calculated directly using spatial information.

DD/MM/YY	Time zone classification code	Gender classification code	Age classification code	Administrative Dong Code
20240402	0	F	age_70	11290660
20240402	0	F	age_70	11650550
20240402	0	M	age_20	11650610
20240402	0	M	age_20	11680640
20240402	1	-	_	11680590
20240402	1	-	_	11680610
20240402	1	-	_	11710620
20240402	1	-	_	11740650
20240402	1	F	age_10	11200535
20240402	1	F	age_10	11470570
20240402	1	F	age_30	11200650
20240402	1	F	age_30	11320514
20240402	1	F	age_30	11710690
20240402	1	F	age_35	11140540
20240402	1	F	age_35	11170570
20240402	1	F	age_45	11545610
20240402	1	F	age_45	11680720
20240402	4	M	age_15	11560690
20240402	4	M	age_15	11620725
20240402	4	M	age_20	11140665
20240402	4	M	age_20	11350619

Figure 2. Sample of living population data of Seoul

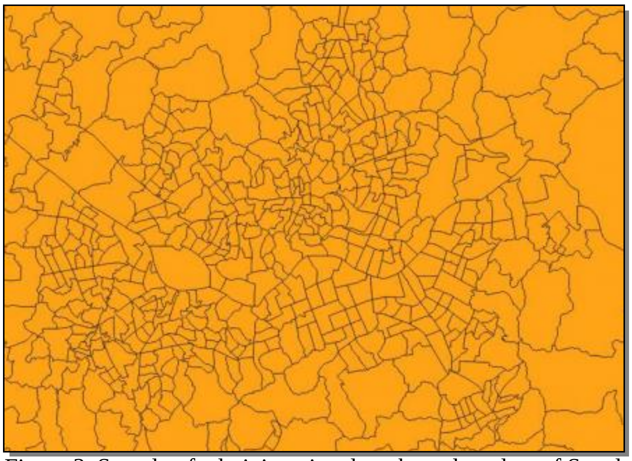

Figure 3. Sample of administrative dong boundary data of Seoul

3. Calculation of ground suitability for flight safety

The ground suitability for flight due to dynamic obstacles was calculated using a formula, considering the density of the outdoor floating population as an obstacle under the assumption that a UAV falls/collides in a place with a large outdoor population. The living population data of Seoul by used in the study is provided by the local government of Seoul as follow Figure 2. (KT Bigdata platform, 2024) And the population of the area by time zone is expressed in grid units, and the number of people in a certain base station is counted without distinction between indoor and outdoor. (Kim and Youn, 2022)

3.1 Estimation of ground suitability based on dynamic obstacles

In this paper, we propose a method for calculating the outdoor population by calculating the ratio of outdoor area as one unit grid, assuming that the living population is evenly distributed in the unit grid. This reduces the grid area and uses population distribution data by time zone, enabling more accurate population density calculation in the future. Since additional indoor population data must be collected to determine detailed residents of the building, the indoor population was assumed to be the average distribution of the total area of the building by calculating the simple occupancy density using public data.

Since buildings have different capacity for low and high-rise accommodation, floor area was simply considered by multiplying the number of building floors by building area. In addition, the density of the floating population was calculated according to the purpose of the building and the time zone because the availability of the pavilion varies depending on the purpose of the building.

If the living population is L, the grid area is A, the building area is B, and the number of building floors is N, the overall volume of the building is calculated as N x B. P_{oEB} (The outdoor population density with evacuated building) assumes that all populations are outdoors, and the number of populations per unit area is calculated by dividing the number of people in the grid by the grid area excluding the building area. P_{oOB} (The outdoor population density with evacuated building) assumes that the population is distributed in outdoor and indoor buildings, and the outdoor floating population density is determined by dividing the number of people in the grid by the area of the grid excluding the building volume. The following formula is about it.

$$P_{oEB} = \frac{C}{(A-B)} \tag{1}$$

$$P_{oOB} = \frac{L}{(A-B)+(B\times N)} \tag{2}$$

Based on the building applications defined by the Building Act, it was reconstructed into seven applications, such as Table00. After that, the pattern of outdoor floating population was analysed according to the application, and density was defined by dividing it into day time and night time.

No	Use	Day Time (09~18)	Night (18~+09)
1	Residential	P_{oEB}	P_{oOB}
2	Commercial+Accomodation	P_{oEB}	P_{oOB}
3	Commercial(Only)	P_{oOB}	P_{oEB}
4	Industrial	P_{oOB}	P_{oEB}
5	Cultural/Education/Social	P_{oOB}	P_{oEB}
6	Large Hospital	P_{oOB}	P_{oOB}
7	Complex Apartment	P_{oOB}	P_{oOB}

Table 1. Density of floating population by time according to building applications

No	Use	Type	Code
1	Single-family House	Residential	01001
2	Multi-family House	Residential	01002
3	Apartment	Residential	02001
4	Community Facilities	Commercial(Only)	02004
5	Welfare Facilities	Commercial(Only)	02006
7	Dormitory	Residential	02007

Table 2. A part of road name address data

Based on the building law, the use of buildings was reorganized into seven, and the density was defined day/night by analyzing the outdoor floating population pattern according to the use as shown in Table 1. Table 2 is part of a table that maps the building usage code of the road name address to the building infrastructure usage system.
The purpose of the suitability to be obtained here is to minimize the safety and risk of the ground during drone flight, so the floating population reflected this and applied the maximum value for day time/night time. In addition, the suitability reflected in the final drone path calculation was weighted from 0 to 10 considering the density distribution of the floating population as follow Table 3.

No	Density of Floating population	Total	Degree of Suitability
1	0.248 ~	100.0%	0
2	~ 0.248	95.0%	1
3	~ 0.138	90.1%	2
4	~ 0.087	80.2%	3
5	~ 0.067	70.4%	4
6	~ 0.051	59.7%	5
7	~ 0.043	50.3%	6
8	~ 0.034	40.3%	7
9	~ 0.026	29.7%	8
10	~ 0.020	19.9%	9
11	0 ~ 0.013	12.4%	10

Table 3. A part of Road name address data

3.2 Estimation of ground suitability based on static obstacles

In this study, the suitability by land use status was converted to a percentile value in order to derive flight suitability by static obstacles. Therefore, the value obtained by adding the population density defined in Table 3 is given as the degree of conformity of the grid. We coded this, calculated the percentile, and defined it as Table 4.

Lv1	Lv2	Lv3	Code	Suitability	%
Forest	Meadow	Natural meadow	2110	3.81	70
		Artificial meadow	2120	3.81	70
	Woodland	Coniferous forest	2210	4.02	76
		Broad-leaved forest	2220	4.02	76
	Other	Golf course	2310	2.9	48
City & Dwelling	Residential and Commercial area	General residential area	3110	2.22	31
		High-rise residential area	3120	2.22	31
	Transportation facility	Road	3210	3.12	53
		Railways and surrounding area	3220	3.12	53
	Industrial area	Industrial facility	3310	2.77	44
		Other	3320	2.77	44
	Public facility	Power generation facility	3410	2.77	44
		Processing plant	3420	2.77	44
Water Sys.	Marsh	Mud flat	4110	3.85	71
		Salt field	4120	3.85	71
	River	River	4210	4.4	85
	Swamp and lake	Dam	4320	4.4	85

Table 3. A part of Road name address data

4. Optimal path planning

To test the above, this research selected a test area in Seoul and tried to present an optimal route plan for it in Figure 4. Test area is divided as grid, and the mid points of each grid are 8-connected with lines. Each line has weight value which is ground suitability for flying calculated in previous chapter. After selecting the starting point and destination point, optimal path is calculated by using A* algorithm.

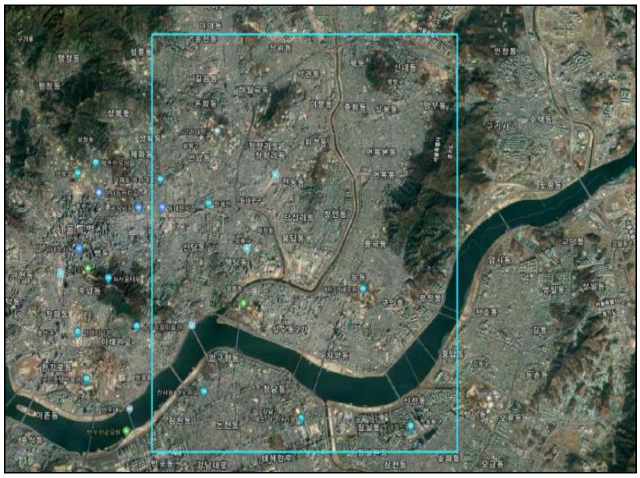

Figure 4. Test area in Seoul

A static obstacle fit map of the area to be tested is partitioned by a grid of 200 m x 200 m sizes. If there are various land use status themes in one grid, a representative value of the grid fit by the static obstacle is selected in proportion to the area, and the representative value of the grid by the dynamic obstacle is used above.
A center point of each grid is node and is connected in eight directions to constitute a link. An attribute value of each link gives a representative value of suitability by a static/dynamic obstacle of the grid through which the link passes in proportion to a distance including the grid.
At this time, Node and Link, which pass through the no-fly zone and Geo-fencing school, should be deleted so that they are excluded when selecting the best route as follow Figure 5 and Figure 6.

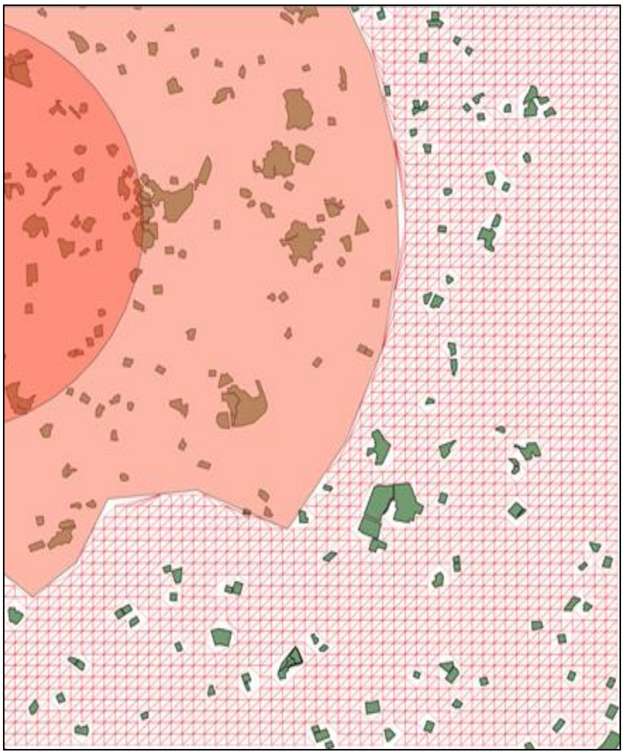

Figure 5. Node link excluding no-fly zones and educational Facilities

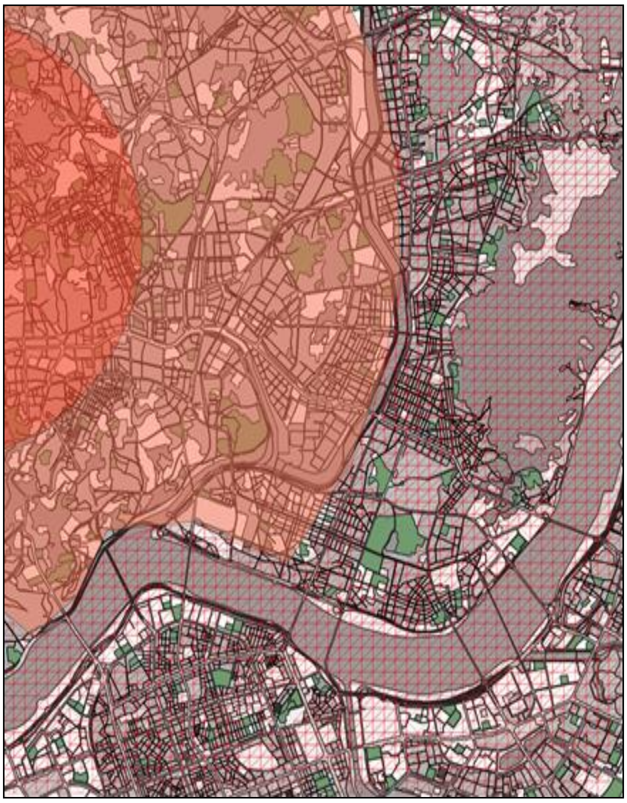

Figure 6. Weighted links based on suitability

The suitability of the dynamic/static obstacle (110) is calculated by combining the suitability of land use (100) and the suitability of population density (10). Figure 7 and Figure 8 are the degree of suitability of day time/night time manufactured by the method.

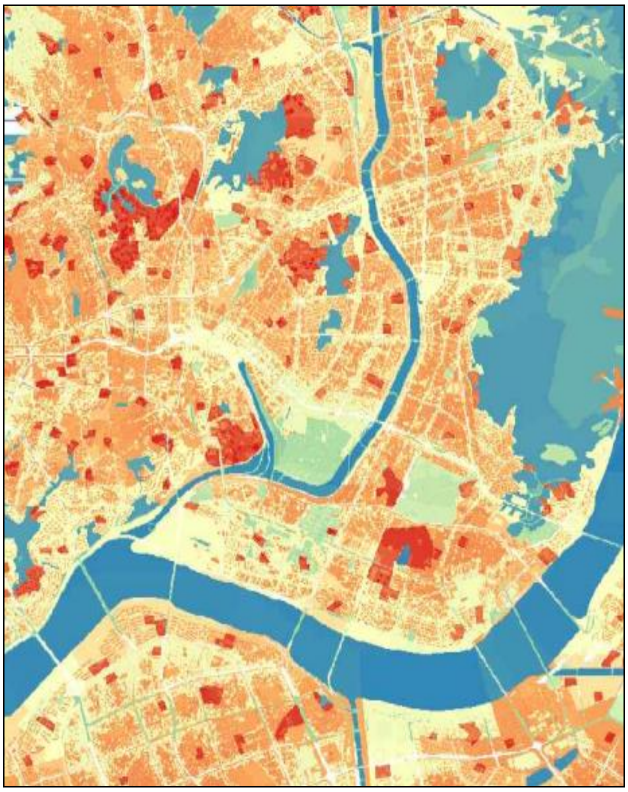

Figure 7. Suitability of dynamic obstacle in day time

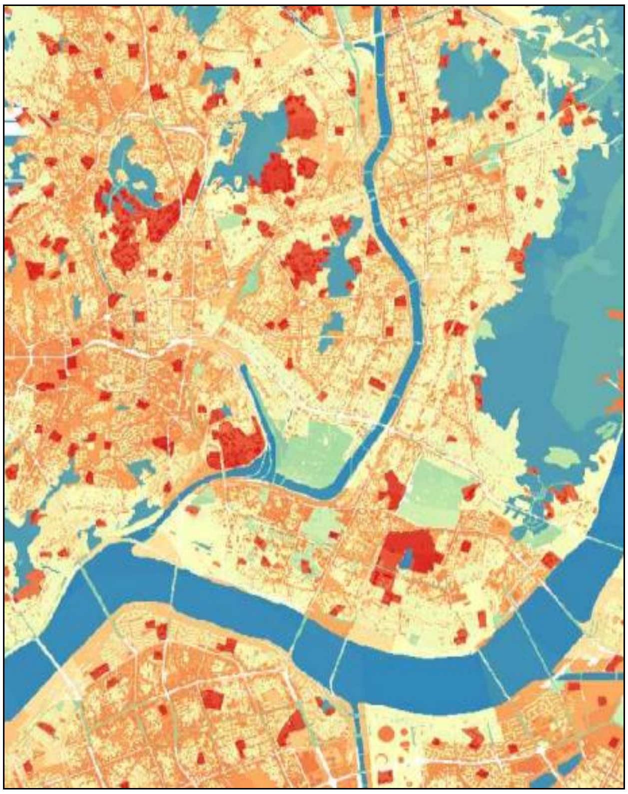

Figure 8. Suitability of dynamic obstacle in night time

In order to determine the effective dynamic/static obstacle suitability in flight path calculation, flight paths were calculated in various combinations. Flight routes were compared under the following conditions.

(1) Suitability of static obstacle (land use)
(2) Suitability of dynamic obstacle (population density of day time/night time)
(3) Suitability of static obstacle (land use) + dynamic obstacle (population density of day time/night time)

Figure 9 is the screen that sets the execution conditions for calculating the route of the drone. The system was developed as a result of an existing research project, and in this study, a route search algorithm considering ground suitability was additionally applied. In the relevant screen, the conditions can be set as options and selected.

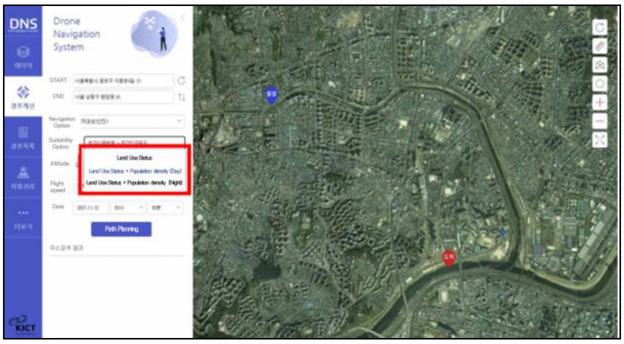

Figure 9. Select path navigation options screen

The optimal flight path results calculated by applying various conditions for the same starting point and arrival point are as follows.

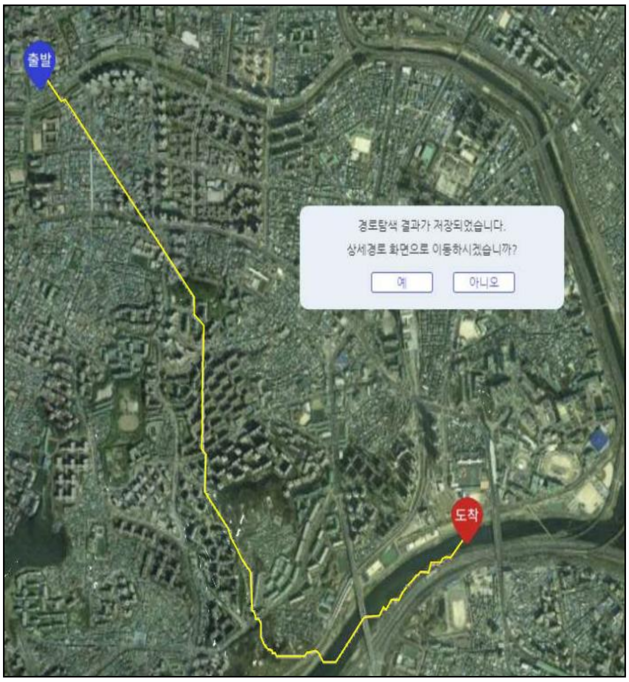

Figure 10. Result (1)

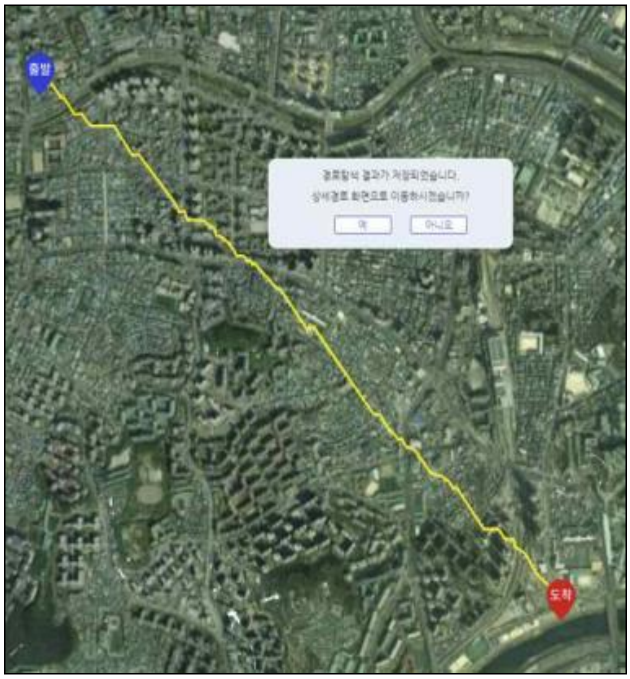

Figure 11. Result (2)

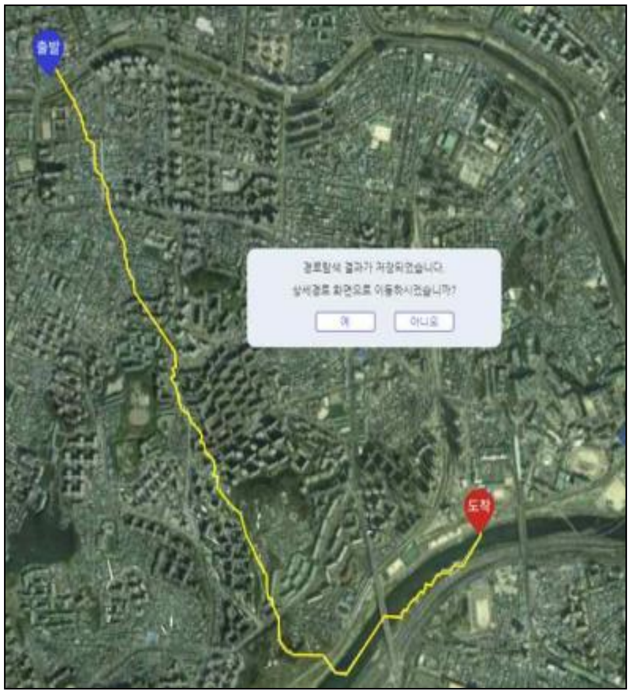

Figure 12. Result (3)

To calculate the optimal drone flight path, conditions (3) were applied separately during the day and at night. As a result, commercial facilities prefer night time to day time, and residential facilities prefer day time.

5. Conclusion

In this paper, we proposed UAV 2D path planning algorithm considering ground suitability for flying safety in digital twin. After define the dynamic and static obstacles for UAV safety flight, ground suitability values are derived. Ground suitability value for flying safety is calculated by proposed outdoor floating population estimation algorithm and land use data. Calculated suitability values are assigned to grid-divided test area. All grids are connected with line and suitability value is assigned to the lines at the location. The experiments show the optimal 2D UAV path plan for flying safety

In order to reflect more accurate spatial information in the future, it is necessary to subdivide dynamic obstacle information currently divided by day/night by weekday/weekend, day of the week, and time zone. In addition, various conditions are defined according to the purpose and optimal flight path derivation for each purpose is required by systemizing the flight purpose.

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