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DEVELOPMENT OF UAV AIR ROADS BY USING 3D GRID SYSTEM

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ABSTRACT: 500~1000 WORD

With the drastic development of low-altitude UAV (Unmanned Aerial Vehicle) technology, UAV will be used for long-distance logistics in the near future. Many countries begin to develop UTM (UAV Traffic Management) system, and one of the objectives for the system is preparation of UAV-logistics era. In that era, hundreds of drone will simultaneously fly at one area. To prevent UAV collision in the air, UAV air road should be designed. The Korean government have supported research projects related with UAV air roads. This paper deals with development of UAV air roads by using 3D grid system. First, detail 3D spatial information for UAV air roads is constructed. In many cases, 3D digital map does not include transmission towers, utility poles, power lines, or trees, since the interests of 3D digital map are focussed on digital elevation model and digital surface model with buildings. The transmission towers, utility poles, and power lines could be obstacles when UAV perform its logistics mission. Therefore, detail 3D information should be constructed for UAV air roads. We constructed such detail 3D information by using MMS (Mobile Mapping System) and aerial survey with Lidar and digital photograph. Next, 3D grid system is proposed to present such detail 3D information. Usual object based 3D information is huge size and hard to control. To provide 3D information to a flying UAV, data should be light. Therefore, light-weight 3D grid system is effective to provide air road information to UAV. Proposed 3D grid based air roads can be used for UAV flight plan, traffic management etc.

1. INTRODUCTION

1.1 General Instructions

Logistics is an area with great potential for unmanned aerial vehicle (UAV) application, with the rapid advances in UAV technology. The US electronic commerce company Amazon announced its successful delivery of the first order using a UAV in 2016. In a reference video released by Amazon (Amazon, 2016), a British resident Richard orders an Amazon Fire TV and popcorn on his tablet PC. As soon as the order is received, Amazon dispatches a UAV carrying the items, and the package is delivered to the backyard of the indicated address in 13 minutes. Japan's biggest open market, Rakuten, announced its plan to commercialize a UAV parcel delivery service in 2016 (Drone Starting, 2016). CJ Logistics of Korea also initiated the development of delivery drones, and completed a test delivery in Gangwon Province in November 2016 (Drone Starting, 2016).

One of the priorities to be addressed for the application of UAVs in commercial delivery service is establishing a traffic system to prevent collisions. The US Federal Aviation Administration (FAA) has been conducting the Unmanned Aerial Systems Traffic Management (UTM) project since 2015. The UTM is a cloud-based unmanned aircraft control system that is currently under development by NASA with the support of the FAA. The UTM provides pilots with the information required to secure space for configured routes and to maintain distance from other flying objects. This management system takes spatial limitations and bad weather conditions into account to guarantee the safe operation of private drones in low-altitude airspace (Kopardekar et al., 2016). In this project launched in August 2015 and schedule to be completed in March 2019, more than 125 major American companies and universities are currently participating, including Google, Amazon, Verizon, and Stanford University. Amazon suggested a vertical airspace system for low-altitude UAVs in 2016. This system designates the region under 200 ft for low-speed localized traffic according to the airspace altitude; it is allocated to UAVs for surveillance and filming, not transport. The system designates the region from 200 to 400 ft for high-speed transit and limits its use only to package delivery (KAIA, 2017). Figure 1 shows Amazon's proposed vertical airspace design for small drone operations. The Ministry of Land, Infrastructure, and Transport (MOLIT) of the Korean government presented the "Fundamental Plan for Advancing Drone Industry" in 2017. In this plan, the MOLIT would design a drone-highway, which would be an exclusive route for drones intended for long-distance and high-speed delivery.

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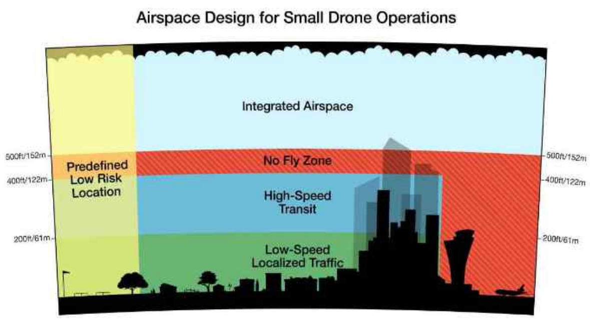

Figure 1. Amazon's vertical airspace design for small UAV operations (source: Amazon)

The UAV traffic system should be established in accordance with the detail spatial information infrastructure. This kind of spatial information should be lightweight enough that the ground control system (GCS) and central control system (CCS) can handle it. Theoretically, a digital surface model (DSM) should present all the elevations including the ground, buildings, and other objects. However, most 3D digital maps do not include transmission towers, utility poles, power lines, trees and so forth because the main purpose for which 3D digital maps are generated is to present the ground, roads, and buildings. However, transmission towers, utility poles, and power lines could be obstacles when UAVs perform their logistics missions. Therefore, detailed 3D information should be constructed for UAV air roads. We constructed such detailed 3D information by using the Mobile Mapping System (MMS) and aerial survey with LIDAR and digital photographs in this work. Most spatial information established so far is based on objects. Objects include points, lines, or polygon types, which are suitable for accurately representing spatial information. Although object-based spatial information is able to accurately represent spaces and attributes, its data size inevitably becomes too cumbersome to guarantee accuracy. Therefore, such data are hard to handle in computing environments that do not have sufficient memory. For the pilot to know whether a flying UAV is on the assigned route, or to verify other obstacles that are not easily identifiable with the naked eye through the camera of the UAV in flight, the detailed spatial information should be lightweight enough to be handled by the UAV GCS. In this context, the present paper suggests a 3D grid system based on a data structure satisfying the data size requirement.

The remainder of this paper is organized as follows. The next section deals with construction of the detailed 3D spatial information. Then, the 3D grid system for UAV air roads is proposed, followed by the conclusion.

2. DETAIL 3D SPATIAL INFORMATION CONSTRUCTION

The main purpose of constructing detailed spatial information is to predict all obstacles, which include buildings, bare ground, transmission towers, utility poles, power lines and so forth, during UAV flight. Therefore, this section is divided into traditional digital surface model (DSM) construction and obstacles model (OM) construction. First, we need to define DSM and OM. Maune (2001) defined a DSM as a data model that depicts the elevation of the top surfaces of buildings, trees, towers, and other features elevated above ground level. Theoretically, a DSM includes the bare ground, buildings, trees, transmission towers, utility poles, power lines and so forth. However, we differentiate the DSM and obstacles, since each of the features could not be constructed by using only one surveying tool. In this paper we define a DSM as a data model that depicts the bare ground, buildings, and trees. An OM is defined as a data model that depicts traffic signals, transmission towers, utility poles, and power lines. In this study, the target area for DSM and OM was around Junju-si, Junrabook-do, Korea. Figure 2 shows the target area for DSM and OM. In Figure 2, the yellow rectangle represents the DSM construction area, and the yellow lines represent the OM construction area; the models were constructed by using MMS.

Figure 2. Target area for DSM and OM

2.1 Generation of DSM by Aerial LIDAR

The DSM was constructed by aerial LIDAR. The aircraft used was a Cessna 208B, and the LIDAR system model was an ALS50-II. To process the LIDAR data, Socetset SW, Granfnav, IPAS Pro, ALP PP, and TerraScan SW were used. The detailed specifications of the ALS50-II are listed in Table 1. The SW application flowchart is presented in Figure 3. The aerial LIDAR procedure was classified into 6 stages. Stage 1 establishes a measuring plan; stage 2 conducts aerial LIDAR; stage 3 conducts data pre-processing; stage 4 produces a DSM; stage 5 runs a product quality test; and the final stage produces the final outcome.

Maximum pulse rate	150 kHz
Maximum scan rate	90 Hz
Number of returns / intensities	4 + 3 with last return
Intensity digitization	8 bits + 8 bits AGC level
Operating altitude (m AGL)	200 ~ 6,000
Max FOV (degrees)	75
Rack operating temperature	0–40 °C
Scanner operating temperature	0–40 °C cabin-side temperature
Real-time digital camera	1280 × 1024 pixels

Table 1. Specifications of ALS50-II

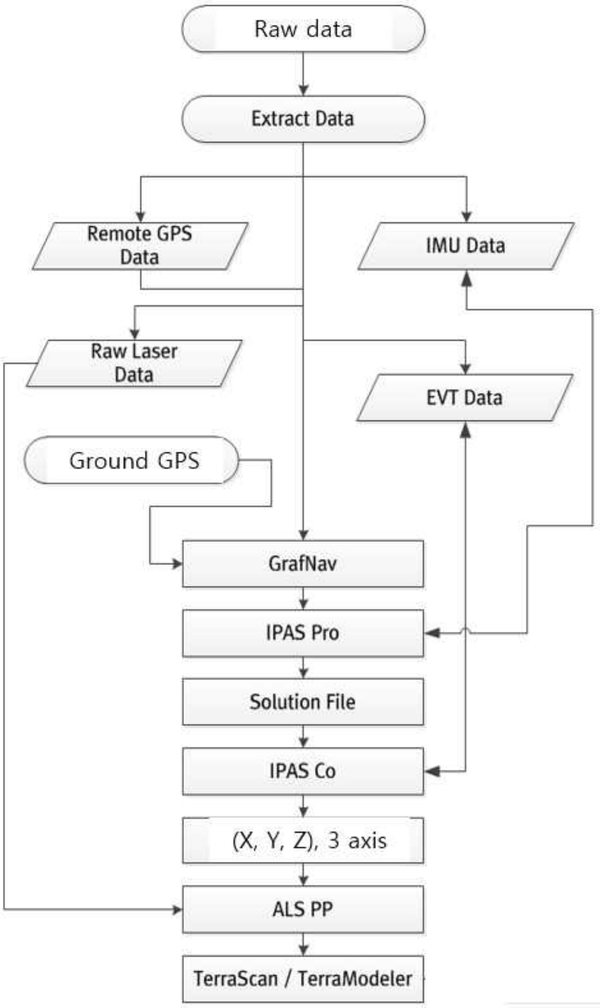

Figure 3. Flowchart for SW application

2.2 Generation of OM by MMS

The OM was constructed by MMS. The mapping system integrates various sensors to provide GPS, INS, LIDAR, and photogrammetry on a vehicle. The MMS measures locations of geographical features and objects along a road, and obtains information of an area while the vehicle is moving. The Mitsubishi X-320R model was used for the MMS in this study. The LIDAR equipment with a data obtainment rate of 300,000 points/sec was used for measurement. The maximum scanning distance was 500 m; the rotation rate was 100 hz, and the GPS/INS accuracy range was 6 cm. The software used for analysis was an MMS viewer and LandMark update. Figure 4 shows the obstacle extraction process. Point cloud data acquired by the MMS is presented in Figure 5. With the point cloud data, we extracted obstacles, including traffic signals, transmission towers, utility poles, and power lines through manual digitization.

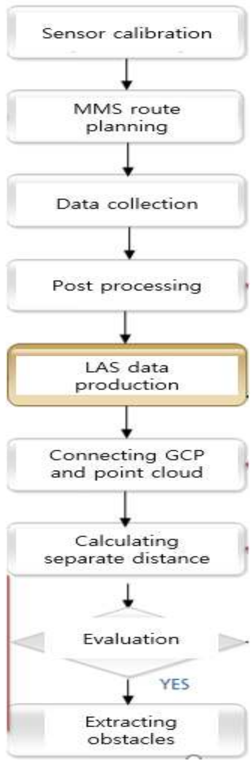

Figure 4. Process of extracting obstacles by MMS

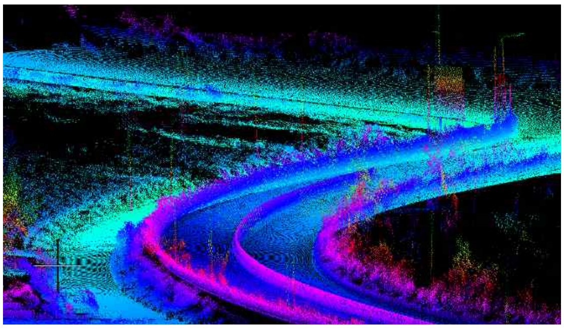

Figure 5. Point cloud data generated by MMS

3. 3D GRID SYSTEM FOR UAV AIR ROADS

To introduce the proposed 3D grid system, we must first define the grid and tile concept. A grid is defined as a tool for presenting objects. In the object-based spatial information system, objects are presented by using points, polygons, and lines. In the 3D grid-based spatial information system, objects are presented by using grids. The concept of a tile is a unit that groups a certain number of blocks because a grid consists of many grid blocks. In order words, a tile is a group of grid blocks, and is a key concept in grid management.

3.1 Definition of a tile

The production of tiles is defined in reference to the entire globe. The size of a quad tile is reduced in reference to the size of the initial Level 0. For example, the reference tile size of Level 0 is 20 degrees, and that of Level 1 is 10 degrees. The size of a Level 2 tile is 5, which is half the size of a Level 1 tile. This level size division continues until the level reaches the defined level. Figure 6 presents the concept of tile level division.

In this work, the tile size of the initial Level 0 was defined as 20 degrees for the simulation. When the entire world is divided into 20 degrees, the index is divided into 18 in length and 9 in width. The index in Level 1 consists of 36 in length and 18 in width. Figure 7 shows the tile degree for each level. The length and width of a tile are divided in reference to longitude and latitude as above. The z axis, the height, is divided in reference to meters. The division reference for the z axis is not specially defined, and the divided area may be modified according to data attributes or expressed altitude. For example, when one tile is defined with 30 grid blocks in producing a 10 m grid, the index for z axis tile division will be 300 m units. The numbers of length and width blocks in tile division always match, whereas the number of height blocks may not.

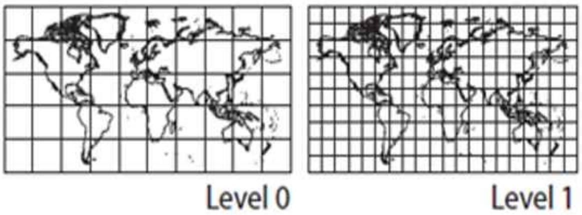

Figure 6. Concept for tile level division

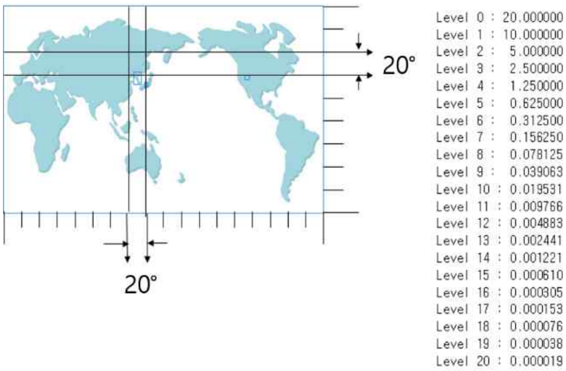

Figure 7. Tile degree for each level

3.2 Definition of a grid

The criteria for grid production are defined differently according to the properties of data. The length and width of a grid match with the appearance of reduced tiles. However, the height may not because the unit for height may be different from that for length and width. A grid has attribute values that are utilized in applications for various purposes. In this study, the grid attribute values were marked according to non-obstacle attributes and obstacle attributes, such as the ground, buildings, transmission towers, utility poles, power lines, or trees. Figure 7 presents the concept of a grid in a 3D tile. In Figure 8, the red cube represents the grid.

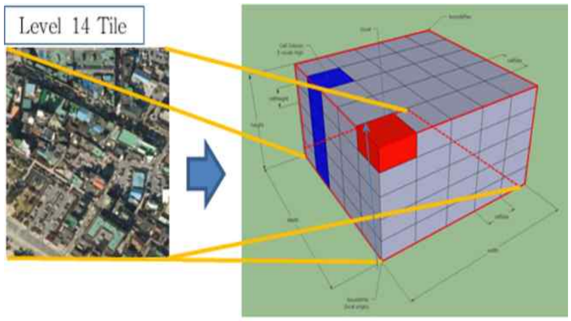

Figure 8. Concept of a grid in a 3D tile

3.3 Generation of 3D grid System

The grid size for air road for drones was configured as 5 m with 14 levels. A tile of 14 levels was designed to comprise 25 x 25 x 25 grid blocks to fit the 5 m size. The z axis index can be flexibly modified, but it is designed to consistently fit into 5 m. Grid data were produced based on detailed spatial information which was established as described in the previous section. We determined whether the defined grid system contains obstacle information, and x.cube files for each index are produced for output. The grid data extension is .cube, and the compressed model is in .cubz format. Grid data are compressed for fast transmission to the network. Simply put, grid data are generated in .cube, which are later compressed into .cubz using the zip algorithm for service. The file contains header information at the beginning of the process, and grid data at the end. Along with grid data of obstacle areas for UAV operation, warning grid data are expressed for flight warnings. Warning data are grid data with a warning function. They warn UAV controllers when a UAV passes through warning grid blocks, alerting the controllers regarding the entry and the fact that the vehicle may be approaching risk areas. Surroundings data are generated based on the data of flight obstacle areas when grid data are produced; they are assigned as attribute values to 26 grid blocks around the flight obstacle areas. Figure 9 shows the generated 3D UAV obstacle grid overlaid on an orthophoto. In Figure 9, red grids represent obstacles.

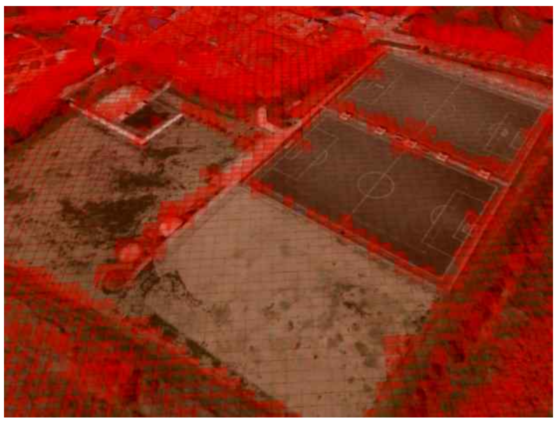

Figure 8. Generated 3D UAV obstacle grid overlaid on an orthophoto

4. CONCLUSION

In this paper, we dealt with development of UAV air roads by using 3D grid system. First, detailed 3D spatial information was constructed by aerial LIDAR surveying and MMS. Buildings, trees, and the bare ground were automatically extracted from aerial LIDAR data. Small obstacles including transmission towers, utility poles, and power lines were manually digitized by MMS data. Further, a 3D grid system was proposed. The 3D grid system is based on the concepts or tiles and grids. Because the proposed 3D grid system, which depicts the all types of obstacles for UAVs, is lightweight, it is suitable for UAV air road application.

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