Automatic Real-time Mapping Using a Multi-sensor UAV System For Effective Emergent Decision Making

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ABSTRACT: For effective and timely decision making in an emergent situation, it is important to understand the current situation of the target area using up-to-date information about the area. Such up-to-date information must be efficiently derived by a UAV multi-sensor system and automatic fast processing software. In this study, we thus develop an automatic real-time mapping system which produces individual geo-rectified images such as ortho-images almost in real-time from the input images acquired and transmitted by a UAV multi-sensor system. While the UAV system is acquiring sensory data with on-board sensors such as a digital camera and a GPS/IMU system, it transmits the sensory data to the processing software on the ground in real-time through LTE communications. Using the sensory data, the software generates individual orthophoto rectified from each input image rapidly and visualizes the orthophoto on a map such as Google Earth. The entire system has been tested in a test site established at a rural area. From the test results, it is successfully demonstrated that whenever an UAV acquires an image in the air, the system on the ground generates and visualizes its rectified ortho-image over the existing map almost in real-time. The proposed system can make it possible to grasp the current situation in real-time particularly in disaster monitoring and damage assessment.

1. Introduction

These days disaster such as earthquake in Italy and Korea have occurred frequently. In urgent situation like those, it is necessary to response efficiently at appropriate time to minimize damage. For that, it is important to grasp field situation such as the location of disaster and the extent of damage in real time. Up-to-date geospatial information of target area enables decision makers to make accurate decisions rapidly. Using existing methods, the information of target area is acquired from satellite images. Satellite images are efficient in data acquisition as they cover broad area. On the other hand, data acquired from UAV (Unmanned Aerial Vehicle) is more efficient at local area. What is more, it takes less time to acquire data with UAV than with satellite. UAV can acquire up-to-date data more quickly than existing ways. Another advantage of UAV images compared to satellite images is the ability to obtain higher resolution images with more detailed information in low altitude. Due to improvement of sensors and UAV, the sensory data acquired from UAV can be used in various field. Many studies have been published on the use of aerial imagery for different applications, such as estimating riparian zone impact, vegetation mapping, damage assessment after a disaster, such as a strong typhoon, monitoring of wetland ecosystem and coastal management (Exequiel. C. at al, 2014). UAV can acquire the sensory data from the area which people are hard to go. There were researches that UAV obtain sensory data from disaster site for disaster assessment. In south Napa, UAV was used for supporting immediate post-earthquake perishable data collection and damage assessment (Meyer. D. at al, 2015). In ITHACA, the sensory data acquired from low-cost UAV was used for damage assessment on disaster (Bendea. H. at al, 2008).

As UAV applications constantly evolve, many geospatial data generation software have been developed. These software can process the data which is acquired from UAV as well as manned aircraft. They can reflect the characteristic about the sensory data of UAV. The image processing software which is developed currently produce geospatial information rapidly and precisely. For accurate decisions, the sensory data acquired from UAV should be processed to geospatial information because the geospatial information can be analyzed in GIS system. In the past, the person who was specialized in photogrammetry or image processing could use image processing software. Nowadays the person who is not a specialist in this field can use image processing software developed recently because they are automatic. Using these software, decision makers can obtain necessary information automatically and rapidly without professional knowledge. These software allow to make accurate decisions in shorter time. There were researches about automatic mapping system. For damage assessment, rapid mapping system based on micro UAV is developed. It can acquire multi-sensory data in the air and generate ortho-images from the data on the ground in a rapid and automatic way (Jeon. E. at al, 2013). For supporting UN field operations, automatic mapping system is being developed. The developing system can operate in a fully automatic way from the data acquisition of sensory data to the data processing for the generation of the geospatial such as a mosaicked ortho-image of a target area (Choi. K. at al, 2016).

In this paper, we present intermediate results of automatic real-time mapping system which we are developing. We introduce the prototype of mapping system which include aerial segment and ground segment. With the mapping system developed currently, we examine simulation test and present the results.

2. Automatic real-time mapping system

Automatic real-time mapping system consists of aerial segment and ground segment. The aerial segment consists of platform, sensors, and control board. Platform loads sensors and control board. Sensors which include digital camera and GPS/IMU sensor are used to acquire sensory data. Control board is to save and transmit sensory data. The ground segment consists of server, image processing software, and visualization software. Server saves the sensory data which is transmitted from control board through LTE communication. The software processes sensory data and visualizes processed data on the map. UAV acquires the sensory data along the arranged route and immediately transmits the sensory data to the server. The transmitted sensory data is processed by the software and is visualized on the map. The whole system overview are shown in Figure 1.

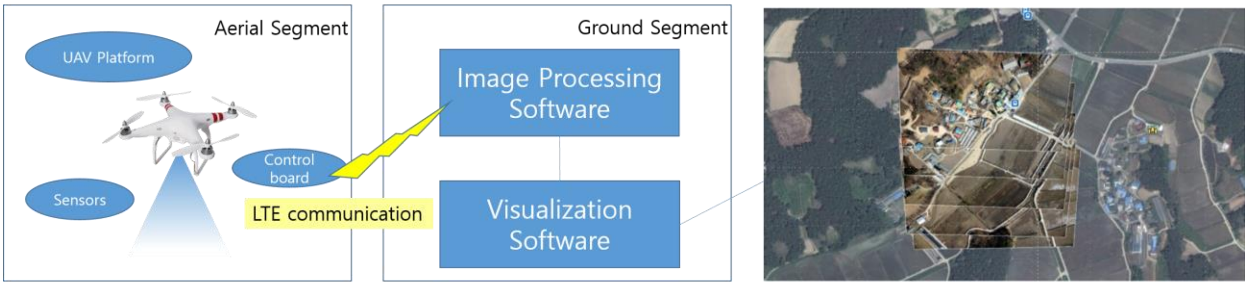

Figure 1. System overview

2.1 Aerial Segment

The aerial segment is to operate UAV according to flight plan and to acquire sensory data. We will select the platform and sensor for the experiment based on previous research. In 2.1.1–2.1.3, we introduce the components and specification of the aerial segment.

2.1.1 Platform

We will select the platform which is suitable in urgent situation such as disaster. Selected platform should be allowed to load the sensors and the control board. As weather conditions are unpredictable in urgent situation, the platform should fly automatically in any weather conditions. In this study, we select two platform for the experiment. One is MD4-1000 made in Microdrone Company. It is rotary wing aircraft. Its weight is 2.65kg and its maximum allowance weight is 1.2kg and operation height is 1,000m. It flies during about 45 minutes. The other model is the UAV which has tilt rotor developed by Sungwoo Engineering. As this UAV is being developed, detailed specification is not arranged. As this model can change the type of wing, it can fly using rotary wing in landing or taking off and fly using fixed wing in moving at certain altitude. So, it can acquire more sensory data in broaden area than MD4-1000. The appearance of UAV is shown in Figure 2.

Figure 2. Appearance of UAV (MD4-1000 / Tilt Rotor UAV)

2.1.2 Sensors

Sensors include digital camera which acquires the images and GPS/IMU sensor which acquires the position/attitude data of UAV. As the sensors are carried on the platform, its weight should not exceed the maximum allowed weight. The specifications of the sensors are summarized in Table 1.

Table 1. Specifications of sensors

Sensor	Model	Specification
Camera	Sony A7 Ⅱ	Resolution : 6000 x 4000 Pixel Size : 5.97um Weight : 599g
Lens	Sony E 24mm F1.8ZA	Focal Length : 24mm Size : 63 x 65.5 mm Weight : 225g
GPS/INS	APX-15	Dimension : 67 x 60 x 15 mm Weight : 60g Position Accuracy (DGPS) : 0.5~2.0 m Roll & Pitch accuracy (DGPS) : 0.03 deg Heading accuracy (DGPS) : 0.28 deg

2.1.3 Control board

Control board is used to save and control the sensory data, to synchronize the time as GPS time and to transmit the acquired sensory data to the server. According to flight plan, control board gets transmitted flight plan configuration and controls the sensory data acquisition cycle. After that, it save the acquired images and the position and attitude information of UAV which is synchronized as GPS time. As the control board is a plug-in board, it can be carried on any platforms. Control board is shown in Figure 3.

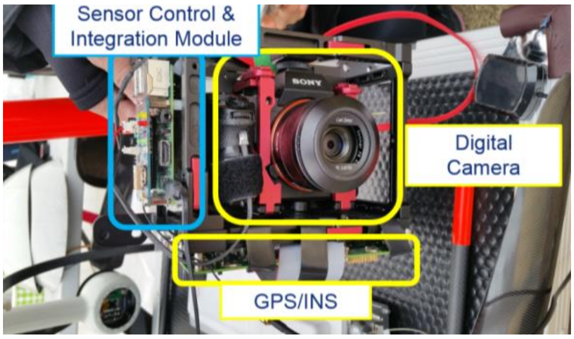

Figure 3. Control board

2.2 Ground Segment

The ground segment is used to save and process the transmitted sensory data from the aerial segment through LTE communication and to visualize the processed images on the map. The sensory data which is transmitted from control board in real-time consists of an image and a position/attitude data of UAV acquired from GPS/IMU sensor. As the position/attitude data of UAV convert the position/attitude data of camera in image processing software, exterior orientation of the image is determined. Using the image and the exterior orientation of the image, the individually geo-rectified image is produced through geometric correction process. In visualization software, the individually geo-rectified image is visualized on the map such as Google Earth.

2.2.1 Image processing software

In the digital camera and GPS/IMU sensor of the aerial segment, the image and the position/attitude data of UAV is acquired. The sensory data is transmitted to the server by LTE communication in real-time. For producing individually geo-rectified images in image processing software, the initial exterior orientation of the image is necessary to obtain by converting from the position/attitude data of UAV to the position/attitude data of camera. For the position/attitude data of camera, system calibration should be performed. System calibration is to set the mounting parameter in 3D rigid transformation which indicates the relation between GPS/INS data and the exterior orientation of the image. With the acquired image and ground control points, the estimated exterior orientation of the acquired image is determined by bundle block adjustment. The mounting parameter is determined by comparing the estimated exterior orientation and GPS/INS data. Using the parameter from system calibration process, the position/attitude of camera is determined. With the parameter and the position/attitude data, the exterior orientation of the image is determined.

Using the image and the exterior orientation of the image, geometric correction process is performed. Using the exterior orientation of the image and collinearity equation, the edge of the image projects onto the ground for determining the ground coverage of the image. Within ground coverage, internal-given grid is set up and the pixel is rearranged according to the grid. Through the process, the individually geo-rectified image is produced.

2.2.2 Visualization Software

Visualization software is to visualize the individually geo-rectified image on the map such as Google Earth. In this study, the individually geo-rectified image is visualized on the MAGO3D which is live 3D geo-platform based on WebGL developed by GAIA3D. MAGO3D which is geospatial information platform based on Cesium can process image from drone, point cloud, sensory data, weather information in real-time. Based on this platform, we can visualize the individually geo-rectified image on MAGO3D.

3. Experiment & Result

In this study, we performed simulation test for automatic real-time mapping system we are developing. As we didn't confirm model of the hardware, we performed simulation instead of the main experiment. In simulation test, we conducted the experiment with the images which were acquired in rural area in Korea using UAV. Whenever an image and the position/attitude data of the image was uploaded on the server every 5 seconds, we checked the individually geo-rectified image on the map which was processed and visualized by the software every 5 second.

3.1 Data acquisition

We acquired UAV images over rural area which was with dimension of 600m by 600m. The flight height was 200m, the ground resolution was 5.1 centimeter, overlap was 80%, and sidelap was 20%. With this configuration, we confirmed the flight plan. The flight plan is shown in Figure 4. For data acquisition, we selected MD4-1000 for as UAV platform and sensors same as stated above section 2.
For system calibration, we acquiree GCPs (Ground Control Points) with RTK-GPS. The 96 GCPs were acquired with 1.5 centimeter precision. The distribution of GCPs was shown in Figure 5. With these GCPs, we could perform system calibration to obtain the position/attitude data of camera.

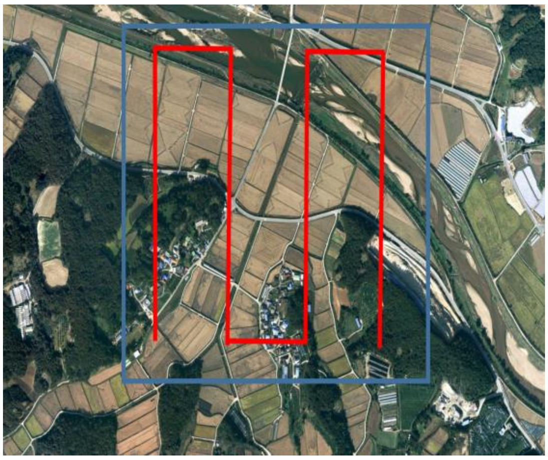

Figure 4. Flight Plan

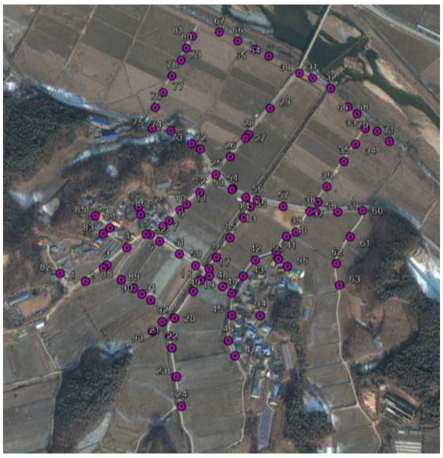

Figure 5. Distribution of GCPs

3.2 Simulation & Result

The main experiment was conducted according to the following steps. First, UAV acquires the sensory data according to flight plan. The data acquisition cycle is predicted as 5 seconds. Second, the sensory data is transmitted to the server in control board. Third, the transmitted sensory data is instantly and automatically processed in the image processing software and visualization software. The whole flowchart is shown in Figure 6. In our case, we performed simulation test as the hardware system was not arranged. The simulation test picture is shown in Figure 7.

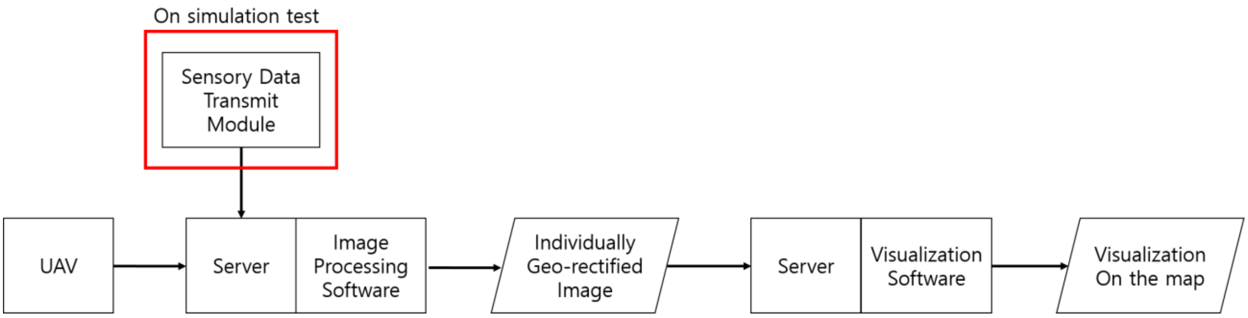

Figure 6. Flowchart

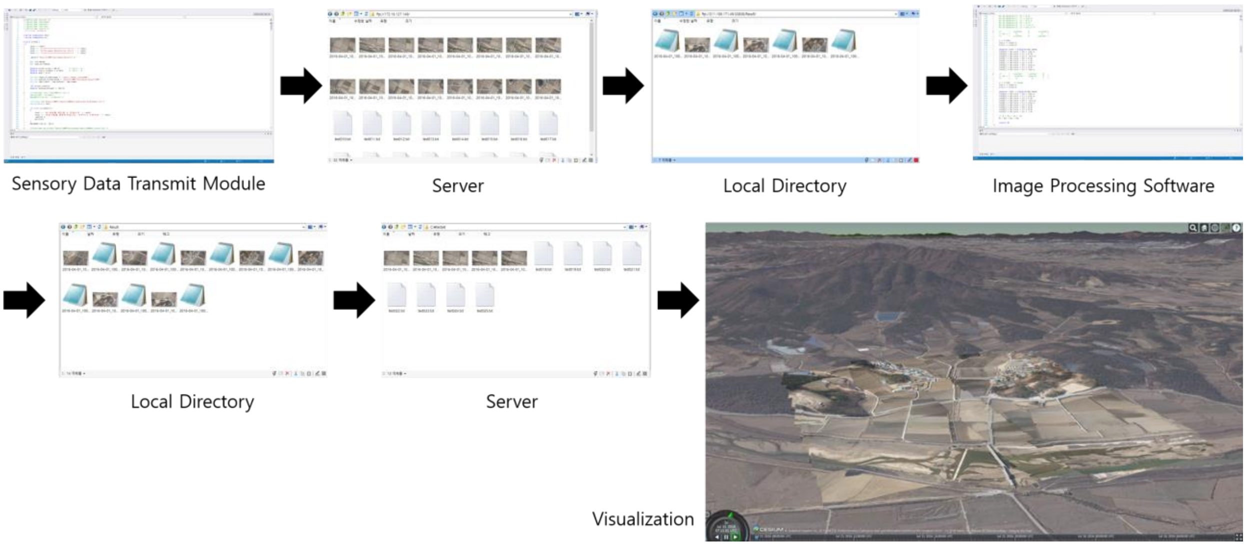

Figure 7. Simulation Test

For simulation, we examine the program which serve as UAV and control board. This program uploads an image and a position/attitude data of the UAV every 5 seconds. The resolution of each image is 6000 by 4000 pixels and the size is about 4.5 MB. Each position/attitude data of the UAV is text file format and indicates position and attitude of UAV when it captures the image. We examine simulation test with 10 pairs of two files.

A pair of data is uploaded on the server every 5 seconds. A pair of data is downloaded from the server to local directory. It takes 1 to 2 seconds to download files depending on the size of the image. The geometric correction process is performed with the image and the exterior orientation which are downloaded. The individually geo-rectified image from the geometric correction process is tiff for jpeg format. The difference between UAV image and the individually geo-rectified image is shown in Figure 8.

(a) UAV image

(b) Individually geo-rectified image

Figure 8. Difference between UAV image and the individually geo-rectified image

In the geometric correction process, there is a difference in the time required and in the size of the image depending on ground sample distance. In case of 30 centimeters at GSD, the image size is 2.5 MB and it takes about 2 seconds to process each image. The processed individually geo-rectified image is uploaded on the server. In case of 30 centimeters at GSD, it takes about 1 second to upload it. We examine simulation test as GSD changes. The results depending on GSD is shown as Table 2. The image which is on the server is visualized on the map immediately.

Table 2. Result

Download (Local Directory → Server)	Image Processing Software			Upload (Local Directory → Server)
Download Time	GSD	Size of the result	Processing Time	Upload Time
1 sec	30cm	2.1 MB	1 sec	2 sec
	20cm	4.4 MB	1 sec	4 sec
	10cm	14.3 MB	2 sec	11 sec
	6cm	22.6 MB	2 sec	16 sec

4. Conclusion

In this paper, we introduce automatic real-time mapping system based on a multi-sensor UAV system. The system consists of two part, aerial segment and ground segment. The aerial segment include platform, sensors, and control board. The ground segment include server, image process software, and visualization software. In the aerial segment, the sensory data is acquired from sensors on UAV. It is saved in control board by synchronizing GPS time and is transmitted to the server through LTE communication. In the ground segment, the transmitted sensory data is process to the individually geo-rectified image by image process software. The individually geo-rectified image is visualized on the map by visualization software.

With the software in development currently and sensory data, the simulation test was performed. The result show that the UAV image was processed and was visualized on the map. In case of 30 centimeter GSD, it expected to take 5 seconds to visualize the individually geo-rectified image on the map since UAV acquires an image and GPS/INS data. In case of 10 centimeters or 6 centimeters GSD, it took more time to upload it from local directory to the server because of the size of the image.

The proposed system can make it possible to grasp the current situation in real-time particularly in disaster monitoring and damage assessment. From simulation result, decision makers can see the geospatial information on the map in 5 seconds since UAV acquires sensory data. They can make accurate decision with the proposed system on urgent situation. In the future, we will perform the experiment in test site using UAV. After the experiment, we will check the whole processing time and the precision of the individually geo-rectified image.

5. Acknowledgement

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