AIRPORT OBSTACLE EXTRACTION BY AERIAL PHOTOGRAH STEREO MATCHING

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ABSTRACT

Terrain and obstacle detection is very important for the safety of aircraft operation. The International Civil Aviation Organization (ICAO) issued the requirements for electronic Terrain and Obstacle Data (eTOD) in 2004. The requirements request all countries to finish the survey of eTOD around large airports by 2010. Nevertheless, no traditional surveying approaches satisfy the required precision and resolution for the obstacle collection in any cost effective manner. In this paper, RealScape/Airport, a novel airport obstacle extraction system, is introduced. The RealScape/Airport system implements airport obstacle collection based on aerial photograph analysis. The system first creates the Digital Surface Model of the area covering an airport and its surrounding region from the aerial photographs of the area by a unique pixel-by-pixel stereo processing method. Then, the system compares the elevation of every pixel with that of the Obstacle Limitation Surface (OLS) on this location. The OLSs are 1.2% inclined surfaces starting from the endpoint of the runway all around until 10 km away, and from that point stretching outside horizontally as plane surfaces. An object that is higher than the OLSs is defined as an obstacle in the eTOD regulation. Based on this regulation, the system extracts the pixels over the OLSs as potential obstacles. Finally, the potential obstacle pixels are inspected visually under stereoscopic view to avoid missing projecting objects like lightning rods. From the final result, we find that the RealScape/Airport system achieves 50 cm vertical and 70 cm horizontal accuracy.

Key words: eTOD, stereo processing, DSM, aerial photograph

INTRODUCTION

The safety of flight is the top priority for aircraft operation, and terrain and obstacle detection are integral to that safety. Sufficient room is required between aircraft and the terrain or obstacles (such as buildings on the ground) especially during takeoff and landing. Even at other times, electronic Terrain and Obstacle Data (eTOD) data is important for en-route planning with the contingency procedure for emergency landing. As of now, some governments, including Japan, have already made it law that the location and height of every building over a certain height around an airport must be reported. However, this scheme assumes that all people will comply with the law; furthermore, under various circumstances, omissions in reporting or registering may occur.

The International Civil Aviation Organization (ICAO) issued the requirements for eTOD in 2004 (ICAO, 2004a) (ICAO, 2004b). The requirements request all countries to complete eTOD surveys around large airports by 2010. Nevertheless, no traditional surveying approaches satisfy the required precision and resolution for the obstacle collection in any cost effective manner, especially for the area surrounding an airport called area 2.

We have developed RealScape, a Digital Surface Model (DSM) generation system based on a stereo matching technique for aerial photographs. The Realscape system was first adopted as a change-detection system for fixed assets. (Koizumi, 2009). The system automatically detects changes in the height and color of buildings based on the analysis of DSM and orthophotos of aerial photographs taken in the current and previous years. The method was first adopted by the Tokyo metropolitan government in 2005 and has been used every year since.

We applied the experience in fixed asset change detection to airport obstacle extraction. This paper describes the Airport Obstacle Extraction system by an aerial photograph stereo matching technique. The system first creates a DSM of an airport and its surrounding region from aerial photographs by a unique pixel-by-pixel stereo processing method. Then, the system compares the elevation of every pixel with that of the Obstacle Limitation Surface (OLS) at this location. An object that is higher than the OLSs is defined as an obstacle in the eTOD regulation. Based on this regulation, the system extracts the pixels over the OLSs as potential obstacles. Figure 1 shows the basic concept of the obstacle extraction by DSM. The system has been applied in practical airport obstacle extraction tasks for several airports in Japan for a total of over 4,000 square kilometers in area. The results of implementation show that this system reduces 60% of the labor costs and 40% of the required operation period compared with traditional approaches.

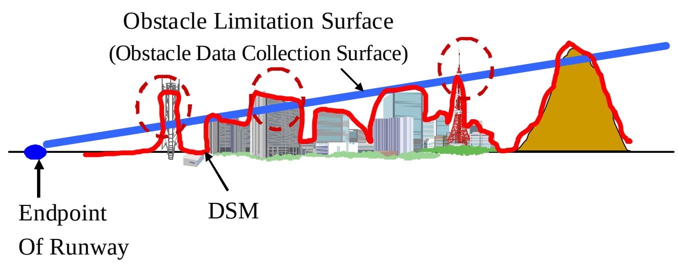

Figure 1. Basic concept of obstacle extraction by DSM.

OBSTACLE DEFINITION IN eTOD AND ITS PROBLEM

ICAO updated their document called Annex 14 in 2004. In the document, a new section that describes the requirements of eTOD is inserted. The request defines four types of areas. Basically, an area that is farther away from an airport requires lower spatial resolution and less accurate data. Table 1 shows the horizontal/vertical accuracy and resolution requirements for each area.

Table 1. Terrain and Obstacle data numerical requirements

Areas/Attributes	Area 1 the State	Area 2 Terminal Control Area	Area 3 Aerodrome/ Heliport Area	Area 4 CAT II/III Operation Area
Horizontal Accuracy	50.0 m	5.0 m	0.5 m	2.5 m
Vertical Accuracy	30.0 m	3.0 m	0.5 m	1.0 m
Vertical Resolution	1.0 m	0.1 m	0.01 m	0.1 m
Horizontal Resolution	3 arc seconds (100 m)	1.0 arc second (30 m)	20 m	0.3 arc second (10 m)

In these areas, areas 3 and 4 are both in the airport and are able to be measured by land survey. The digital elevation data published by national geographical survey institutes almost comply with the requirement of area 1. In between these two areas, area 2 is the area covered by a radius of 45 km from the ARP (aerodrome reference point). The OLSs for the area are 1.2% inclined surfaces starting from the endpoint of the runway all around until 10 km away, and from that point stretching outside horizontally as plane surfaces. Figure 2 shows the shape of area 2. The area is over 6,000 square kilometers and is difficult to cover by land survey. It also requires 0.1 m vertical resolution, which is not satisfied by existing data. Therefore, a novel method to cover this area is needed.

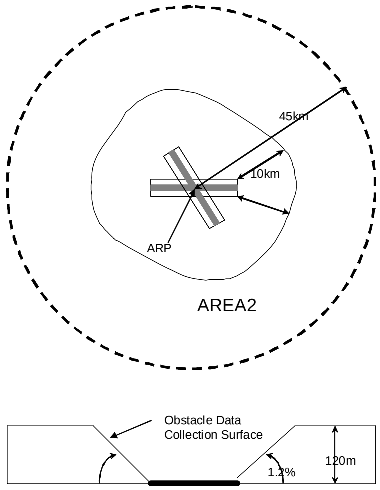

Figure 2. Obstacle data collection surfaces of Area 2.

APPLICATION DESCRIPTION

The major component of the RealScape/Airport system is RealScape/DSM. Because RealScape/DSM is a general-purpose software package for generating DSM data, the RealScape/Airport system is customized for the use of the civil aviation bureau, for such tasks as obstacle extraction and verification.

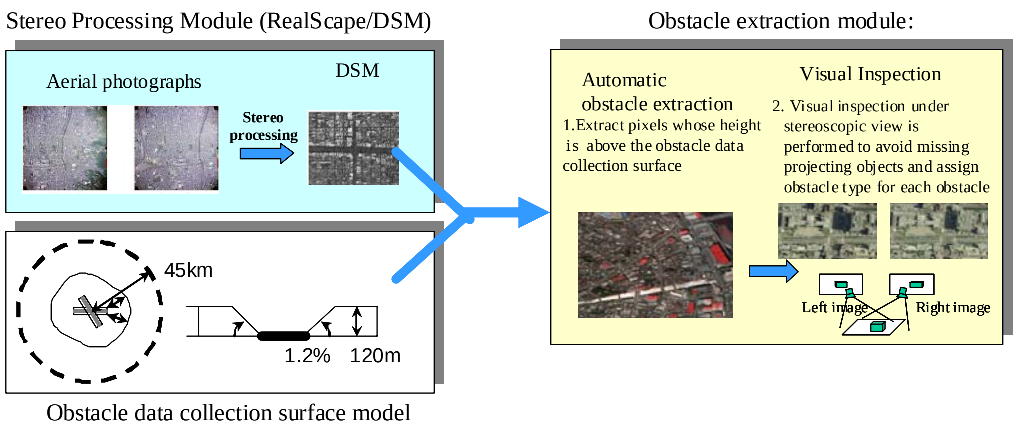

Figure 3. System Configuration.

Stereo Processing Module (RealScape/DSM)

This module inputs two aerial photographs into the computer, converts all its pixels into 3D information and calculates the building height information (DSM) within an accuracy of one meter. At the same time, it applies true orthorectification processing in order to correct for the inclinations of buildings in the photographs and to enable a precise overlapping of the photo and maps.

Obstacle Candidate Extraction Module

This modules inputs DSM data and orthophotos produced from the stereo processing module and obstacle data collection surface model designed for each airport to comply with the restriction and runway shapes. Both data are strictly aligned with geographical location, that is latitude and longitude. Therefore, a pixel in DSM that is higher than the OLSs at the same location is extracted as an obstacle candidate in the eTOD regulation. The obstacle candidate data is checked by visual inspection using stereoscopic view. Each obstacle is classified into various obstacle types such as buildings, trees or poles.

The target we set before designing this system was to improve both the performance and accuracy of extraction by automation. Even with the current technology level, it is difficult to achieve a perfectly error-free extraction and type assignment automatically. In particular, obstacle type classification is almost impossible by machine.

Therefore, we decided to apply obstacle candidate extraction using automated software in the primary reading and to provide the visual inspection support to eliminate false extraction and decide obstacle type.

STEREO PROCESSING OF AERIAL PHOTOGRAPHS

The stereo processing module produces dense pixel-by-pixel resolution DSM data from a set of aerial photographs that covers an airport and its surrounding region. In the module, various image processing techniques such as customized DP matching are adopted. Figure 4 shows the outline of the stereo processing module.

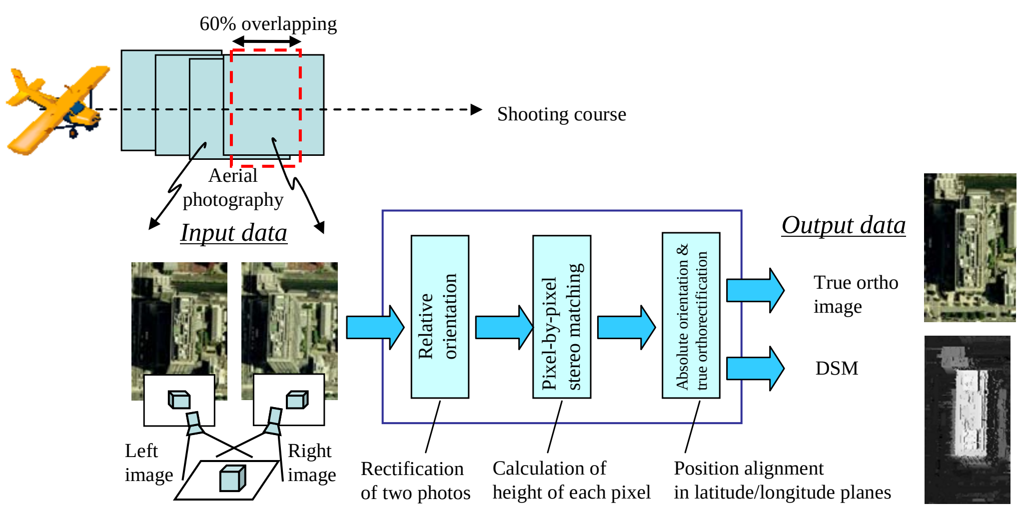

Figure 4. Outline of stereo processing module.

Input Data

The input images can be analog or digital aerial photographs similar to those used in the traditional change judgment system. Each of these photographs consists of a series of picture frames taken by overlapping around a 60% area between the frames. This system executes stereo processing by assigning two adjacent picture frames as the left and right images and obtains the height information on all pixels in the overlapped area.

Relative Orientation

Unlike photographs in which images are taken using a stereo camera that can be calibrated every time before use, aerial photographs are taken using various camera attitudes. This procedure makes it necessary to perform image rectification, which is a method for parallelizing a pair of images. For this purpose, the system rectifies input images by using the external orientation parameter. Then, orientations of the input images are aligned.

Pixel-by-pixel Stereo Matching

The main task in stereo matching is to identify the corresponding points in the left and right images. When the left and right images are paralleled with relative orientation, all of the subjects are located on the same scanning line number in the left and right images. Therefore, the search for corresponding points can be limited in a single dimension. We adopted the DP (Dynamic Programming) matching method for the search that uses the cross-correlation as the evaluation value and outputs the DSM after the processing. In order to obtain high-quality DSM, it is necessary to select the cross-correlation parameters, such as the window sizes and threshold values, optimally according to the scales and types of input images. As their selection necessitates experience, we provided the system with parameter settings that are optimized according to the types of processed images, so that the user can perform optimum processing simply by selecting one of the parameter settings.

Absolute Orientation

Since processing for the above is performed in the image coordinate space, it eventually becomes necessary to compare the matched correspondence of the photograph and the DSM with the latitude and longitude of the land location in this procedure. At the same time, a conversion of the parallax values obtained by the stereo matching of the altitude value is also performed.

True Orthorectification

Since stereo processing requires a large amount of calculations, traditional aerial survey software generally obtains the altitude information only for the characteristic points and the contour lines of topography and buildings, and applies interpolation to other points. This has resulted in problems such as dealing with buildings that lack contours and are undistinguishable from the ground and consequently remain inclined in/with the images. On the other hand, RealScape can determine the absolute positions of all pixels because the stereo processing it applies offers the height information of all pixels without a need for contour information. We call this processing method the “True Orthorectification” method. True ortho images show the roof surfaces of all buildings in their real positions without tilting (Figure 5). This makes it possible to overlap a photograph precisely onto a map or to overlap two photographs taken under different shooting conditions.

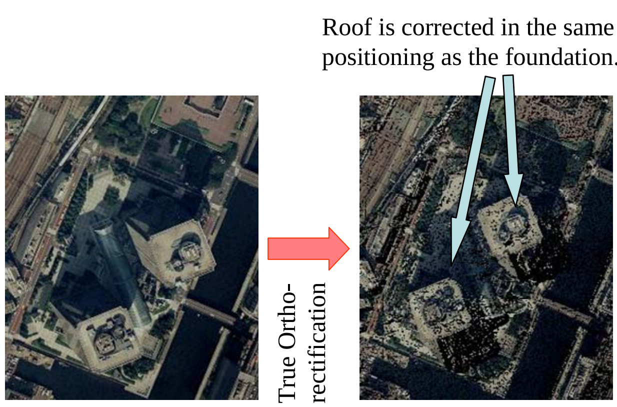

Figure 5. True orthorectification.

OBSTCLE EXTRACTION AND INSPECTION

As already described in Figure 3, we can extract a building that is over the OLS by comparing the DSM produced from a set of aerial photographs and a three-dimensional model of the OLS created according to the runway shape and position of each airport. The DSM data has height information for each pixel. Therefore, if the original aerial photograph is taken in 14-cm horizontal resolution, we can extract the obstacles as 14-cm resolution point groups. Figure 8 shows an example of extracted objects (point groups). The point group is shown in red and overlaid on the orthorectified image that is produced by using DSM and an aerial photograph.

Figure 6. Example of Extracted Obstacles.

The process up to here from creating DSM to extracting obstacles can be almost automatic once an aerial photograph is thrown into the system. However, thin objects like a lightning rod projecting from the rooftop may not be extracted from 14-cm resolution DSM even if they can be seen in the photo. Therefore, we need a visual inspection process. For this purpose, OLS is set 5 m lower than its original position because most lightning rods are shorter than 5 m. We call this a “secondary surface.” Then, visual inspection for the obstacle candidates extracted by the secondary surface under stereoscopic view is performed to prevent from missing such projecting objects. The operator, wearing special glasses, can see the photo in 3D and measure the height of each projecting object on the rooftop. Furthermore, the operator identifies the object shape by grouping pixels and also identifies the type. Table 2 shows an example of the types of objects.

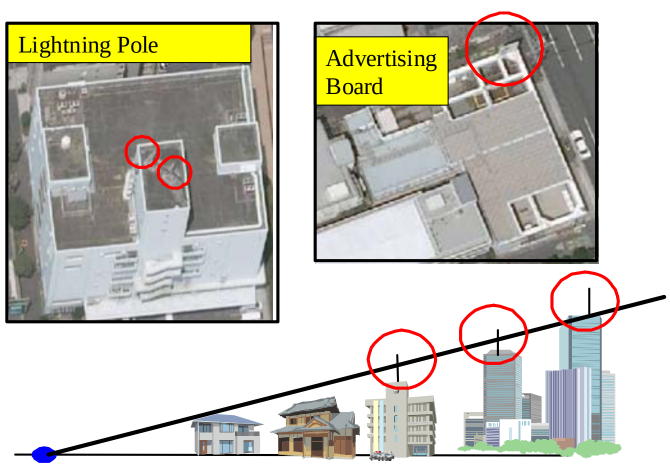

Figure 7. Thin objects on the top of buildings.

Table 2. Types of obstacles

1	AIRCRAFT
2	BRIDGE
3	BUILDING
4	CABLE WAY
5	CHIMNEY
6	CRANE
7	ELECTRIC LINE
8	MONUMENT
9	POLE
10	TANK
11	TOWER
12	TREES
13	TV TOWER
14	UNKNOWN

Figure 8. Final result of extracted obstacles.

TEST AND EVALUATIONS

Accuracy of DSM

We evaluated the vertical accuracy of DSM created from digital aerial photographs by comparing DSM with field surveys and laser profiler data. Table 3 shows specifications and Table 4 shows the results, which were 15.9 cm vertical accuracy for DSM and 12.4 cm vertical accuracy for laser profiler data. DSM was nearly equal to laser profiler data in vertical accuracy. On the other hand, the resolution of laser profiler data was only about 2 m, but that of DSM was 7.2 cm, which was equal to the resolution of an aerial photograph. Hence, DSM created by RealScape had much higher resolution than laser profiler data.

Table 3: Specification of aerial photograph, field survey and laser profiler data

Aerial photo-graphs	Camera	UltraCamD
	Scale	1/8,000
	Spatial resolution	7.2 cm
	Overlap rate	OL: 60%, SL: 30%
	Focal length	105.2 mm
Field surveys	Survey method	Mobile receiver by FKP
	Number of points	100 points
Laser profiler	Spatial resolution	About 2 m

Table 4: Accuracy of DSM created from digital aerial photographs

	Vertical accuracy	Resolution
DSM	15.9 cm	7.2 cm
Laser profiler data	12.4 cm	About 2 m

Obstacle Extraction Test

We evaluated obstacle extraction accuracy, in particular extraction of projecting objects, by field survey. First, we performed a field survey of an area about 1 km square near an airport and detected all of the projecting objects in the area. The total number of projecting objects included 397,240 electricity poles and 157 lighting rods. We extracted obstacle candidates in the area by the secondary surface, and identified 108 projecting objects, 32 electric poles and 76 lightning poles from the obstacle candidates by visual inspection without missing any objects. Figure 9 shows the comparison between the field survey result and the visual inspection result from the aerial photograph. These objects extracted by the secondary surface include those that are lower than the actual OLS. Therefore, as a final result, we extract only 17 lighting poles after measuring each object's elevation by stereoscopic view. This test shows that obstacle extraction time is greatly reduced by restricting visual inspection to the automated obstacle candidate area without reduction of accuracy.

Projecting objects by field survey (blue points) Obstacle candidates (red region) and projecting object on it (blue point)

Figure 9. Comparison of field survey and our method.

RELATED WORKS

The Realscape system was adopted first as a change-detection system for fixed asset change judgment (Koizumi, 2009). The system automatically detects the changes in the height and color of buildings based on the analysis of DSM and orthophotos from aerial photographs taken in the current and previous years. The fixed asset change judgment requires that the system detect horizontal or vertical changes of 2 meters or more and color changes in an area of about 2 × 2 meters, without exception. However, in actual cases, most vertical or horizontal shape changes entail color changes. Therefore, the system achieves fairly good results by combining color and shape chage.

In comparison with the change detection, obstacle extraction for an airport requires extracting much smaller projecting objects like lighting rods without color information. A much higher resolution aerial photograph is used for this purpose and we assume the highest height of such an object, and set the plane for obstacle extraction lower than the original height, extracting the candidate building that may have such an object on the roof. The final result is fixed by visual inspection using stereoscopic view.

Obstacle extraction for an airport is an important task but a definitive method has not been established. The eTOD Forum is a European initiative aimed at supporting those who are interested or involved in the implementation of the eTOD requirements. In Japan, the first meeting for eTOD was held in February 2009 by ICAO Asia Pacific. In the meeting, several methods for obstacle extraction were proposed such as LIDAR (Laser scanner), SAR (Synthetic Aperture Rader) from satellites or airplanes, though none of these is a definitive method basically because of cost and accuracy.

Forlani proposed a method for reconstructing buildings in an urban area from LIDAR data, but its laser spot spacing is about 1.6 m across track and 0.15 m along track, and roof shapes are extracted from the smoothed region (Forlani, 2003). Sites compared digital elevation data from airborn laser and an interferometric SAR system (Sites, 2000). In this case, point spacing of laser data was approximately 4 m and element grid size of interferometric SAR was approximately 5 m x 5 m. The resolution of both methods is too low to detect small obstacles like lighting rods. He also reported a cost issue. In Germany, the cost of acquiring a data set of coordinated elevation measurements in a single flight airborne mission with a laser scanner amounts to approximately US$ 200- per square km. This does not include editing operations. In this case, the cost may double to approximately US$ 400- per square km.

For the obstacle data management process, ClearFlite (Gordon, 2005), a product of BAE systems is an airfield obstruction software tool that allows operators to easily identify and collect vertical obstructions and manage them, but it does not support producing DSM around an airport.

CONCLUSION

This paper described an obstacle extraction system for airports. This paper described the definition and importance of obstacle extraction around an airport and showed a new method for extracting obstacles by DSM created from stereo matching of aerial photographs around the airport. This method was applied to several airport images to confirm its accuracy and reduction of manual work to extract obstacles.

As future work, a speed-up technique for processing a broad area around an airport is required. The system processes a circular area with a radius of 45 km, which is over 10 times larger than the Tokyo metropolitan area in the fixed asset change detection case. Currently, our system processes the area by using 48 PCs in parallel to reduce actual calculation time. A more sophisticated method should be introduced to reduce total calculation time, for example, by varying process data resolution according to the distance from the airport.

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