LIDAR-based Change Detection of Buildings in Dense Urban Areas

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***Abstract*— An automatic method for LIDAR-based (Light Detection And Ranging) change detection is proposed. Highly dense LIDAR point clouds are recommended as the most suitable gathered data for dense urban areas. The main goal is to develop an up-to-date building inventory database, which is in great demand for the earthquake-prone areas like Japan, using LIDAR as primary data. Two LIDAR surveying flights in 1999 and 2004 provide the test data over Roppongi, Tokyo, Japan. Detected results are visual evaluation using ortho-photo produced by LIDAR surveying flights. The highly automated processing proved the efficiency of using LIDAR for a quick and reliable updating. Moreover, it also implies the feasibility for detection of damaged buildings due to earthquake.**

Keywords— ***Building inventory database; LIDAR; change detectio;, updating; dense urban area.***

I. INTRODUCTION

An up-to-date building inventory database is crucial requirement for a reliable damage assessment, especially for the earthquake-prone and dynamically changing urban areas like in Japan and other nations in Asia. Even though the aerial photograph has been conventionally employed for map compilation in the updating process [1-3], the characters of the aerial photograph cause several unavoidable problems. Firstly, casting shadows dominate in the scenes acquired over dense urban areas with many skyscrapers. Secondly, the spectral information of buildings in aerial photographs is diverse and ill-defined [2]. Thirdly, perspective projection causes the leaning of buildings, which requires the height information to correct. Therefore, we proposed the employment of LIDAR [4] rather than spectral information derived from the aerial photograph as primary data in updating.

A LIDAR (Light Detection And Ranging) surveying flight equips a laser scanner, a Global Positioning System (GPS) receiver and an Inertial Navigation System (INS). It is an active sensor emitting the infrared laser pulses at a high frequency and then recording the reception of the reflected pulses. A surveying flight can quickly collect the dense cloud points (more than 1 point per square meter) with X, Y, and Z coordinates. The intensity of reflected laser pulses can also be recorded in the latest LIDAR systems. Change detection of buildings using LIDAR data in Japan was carried out [5]. That study was just a simple comparison between two data sets. Our final goal is to implement a complete system processing for updating building database mainly based on LIDAR data. The previous study [4] was updating a GIS database from recently acquired LIDAR data. It aims to be employed in current updating status when GIS building database is still not very outdated and LIDAR data is limitedly employed. If LIDAR data is widely available in the future, updating database will be applicable by detecting the changes between two LIDAR surveying flight data. It is the main objective of this study. Moreover, the proposed method in this study can be applied in another scenario. Two LIDAR surveying flights could be carried out before and after an earthquake. The change detection can show the collapsed buildings. Since the pulse intensity is recorded only in the latest LIDAR systems, it has not been concerned in this study. The following sections describe the proposed automatic processing and its testing for Roppongi, Tokyo, Japan.

II. METHODOLOGY

Three-stages processing is described as follows.

A. Pre-processing

This step merges laser points from all flight strips of each data set and extracts two data sets into the same extent. Moreover, the portion in GIS building inventory database, which is covered by a new surveying flight, is also extracted for the preparation of updating. It can be simply carried out by any GIS package such as ArcGIS.

B. Main-processing

To speed up the processing, a grid format is preferred rather than a raw point format. The nearest neighbor interpolation is chosen to preserve the sharp leap in elevation along the edges of buildings. Depending on the density of laser points from two surveying flights, the cell size of the grid is determined.

Let *pre* and *post* are names of two grid-based LIDAR data sets. A simple calculation on grid, i.e. *post – pre*, is carried out and forms the difference grid. Observing the histogram of the difference grid, possible changes are located far away from the average (or mean) value (Fig. 1). To extract the possible new construction and demolition, a histogram thresholding is applied as follows.

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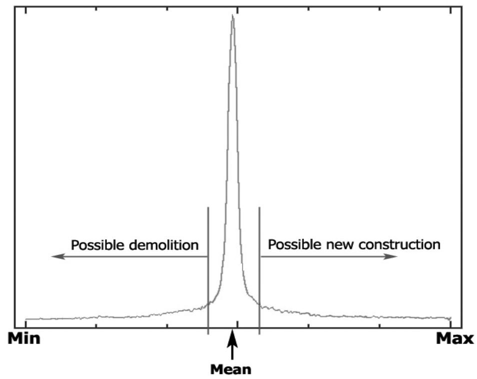

Figure 1. Histogram thresholding

$$PNC > Mean + i \times STD \quad (1)$$

$$PD < Mean - i \times STD \quad (2)$$

where

PNC = possible new construction

PD = possible demolition

Mean = the average value of the difference image

STD = the standard deviation of the difference image

$i = 1, 2, 3, \ldots, n \in \mathrm{N}$

Depending on the level of the change in the concerned area, which is shown in the histogram of the difference grid, a suitable threshold is chosen. As experienced, a threshold of one *STD* is enough for detection of completely new construction or demolition. Smaller change such as increasing or decreasing of one floor of a building locates nearer to the *Mean* value than one *STD*. Fine classification of changes will be considered in further studies.

It should be noted that skyscrapers locating at the edge of flight strips [6] create the narrow shadow areas, e.g. no LIDAR point. Very high density of LIDAR points and the overlaps between the flight strips can fill-in these shadow areas. However, to be used in any case, the shadows should be taken into account. If shadows exist, because of different parameters of two surveying flights, there will be some artifacts generated along the edges of these skyscrapers in the difference gird. They will be concerned for removal in the post-processing.

The above-mentioned global thresholding in the histogram can be applied not only to the new construction and demolition in the scene but also to other small-size differences along the edges of buildings which are not the real changes of buildings. That is because of the random reflectance of laser pulses and the differences of two surveying flights' parameters. These wrong masking can be removed by opening morphological filtering and reconstruction [7]. Briefly, let I is an original image and J is an opening filtered image from I, so masker $J \subseteq$ Mask I. The reconstruction of $\rho_I(J)$ of mask I from marker J is the union of the connected components I_k that contain at least one pixel of J.

$$\rho_I(J) = \bigcup_{J \cap I_K \neq \varnothing} I_K \quad (3)$$

where $\varnothing$ is an empty set.

Some of the above-mentioned artifacts could be removed by morphological filtering but not all. They need to be further verified in the following step.

C. Post-processing

Two images which include detected new construction and demolition have been generated. Post-processing investigates the status of those detected components to distinguish between real changes and artifacts. There is no laser point in those artifacts from one surveying flight but there exist laser points from the other flight. This observation infers that the density of laser points falling into the areas of those artifacts is less than those falling into the real changed areas. A technique named "density thresholding" is proposed for the discrimination. If artifact exists in the scene of new construction, density thresholding concerns the *post* laser point set. If artifact exists in the scene of demolition, density thresholding concerns the *pre* laser point set.

Let S is the set of detected demolition polygons $S = \{S_i\}$ ($i = 1, 2, \ldots, n$), the sum of area is

$$A = \sum area(S_i) \quad (4)$$

where $area(x)$ is the area of x.

Let P is the set of laser points falling into the detected components, the total number of points is

$$nP = count(P) \quad (5)$$

where $count(P)$ is the number of elements in P.

Thus, the density is

$$D = \frac{nP}{A} \quad (6)$$

Let P_n is the set of laser points falling into a demolition (or new construction) polygon S_n, real demolition (or new construction) is a set of S_n

$$\left\{ S_n : \frac{count(P_n)}{area(S_n)} \geq D \right\} \quad (7)$$

After the discrimination, the detected new construction and demolition masks are intersected with the building database to assign the new status of the building. It is classified into three classes in the database. They are unchanged, completely covered by new building, and demolished buildings. Firstly, detected demolished masks are intersected with building footprints in the database. The intersected buildings are labeled as "demolished". Secondly, those "demolished" footprints are intersected with detected new construction masks to reclassify again to be "covered by new building". The remaining footprints are labeled as "unchanged" buildings. Except, the "unchanged" buildings, there is ambiguity in classification of two other classes due to the complexity in urban areas. Regarding the newly constructed buildings, in this study, only location of new building is marked. Further processing for 3D reconstruction of new building will be presented elsewhere.

III. TEST RESULTS

Two LIDAR data acquired over Roppongi, one of the busiest area in cenral Tokyo, in different occasions were available for our testing. Both surveying flights were carried out by Asia Air Survey Co. Ltd and in June 1999 and February 2004. Data was provided in 1-m grid format (Fig. 2). Thus, interpolation processing was not necessary.

The threshold of one standard deviation was chosen to apply to the histogram of the difference grid. Consequently, opening filtering and construction was applied to obtain the filtered images as shown in Fig. 3. Density thresholding was superfluous because both data was provided in the 1-meter grid format which shows no artifact in their difference. The detected changes include not only changed buildings but also the trees growth due to seasonal change or even newly planted trees because of city planning. Only using coordinates acquired by LIDAR, it was unable to discriminate between buildings and trees. A possible solution is to include the spectral information from aerial photographs. However, color aerial photographs were not available in this study. Another solution by employing the pulse intensity was also inapplicable since the pulse intensity was not recorded in the 1999 surveying flight.

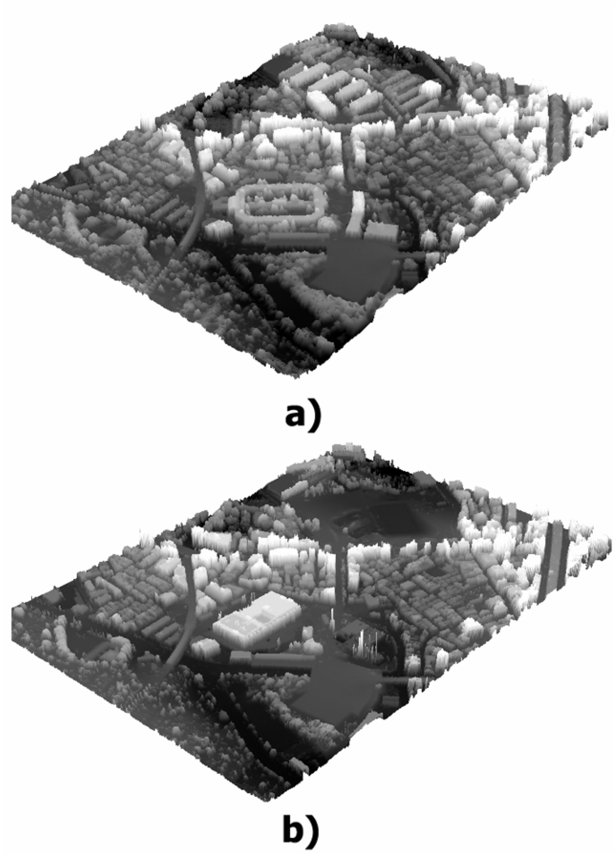

Figure 2. Acquire LIDAR data in grid format a) June 1999 and b) February 2004

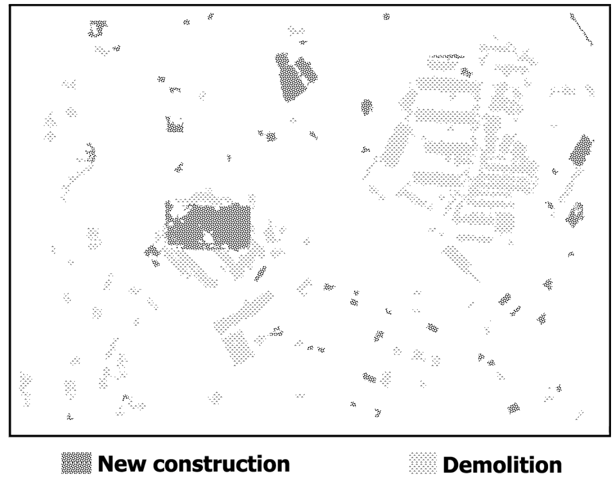

Figure 3. Detected new construction and demolition

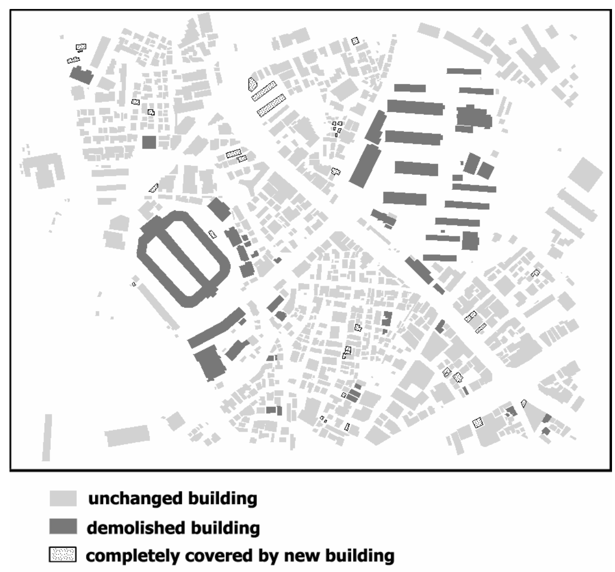

Figure 4. Updated building inventory database

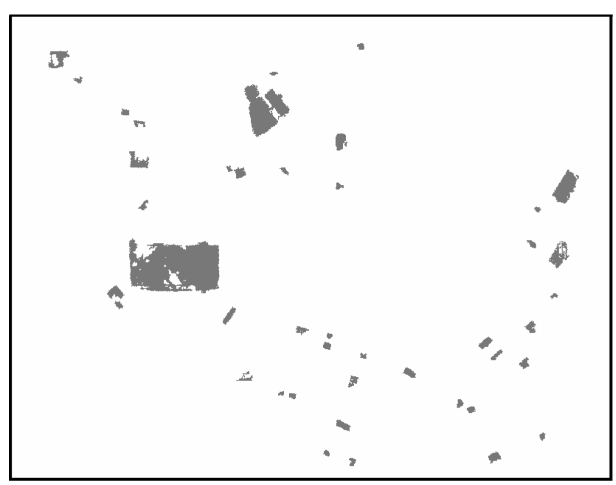

Figure 5. Masked locations of newly constructed buildings

Based on the detected results, the status of the building was updated. Wrongly detected demolition caused by trees could be eliminated by the mismatching with the building inventory database. But wrong detection in new construction could be only manually removed. Updated building database is shown in Fig. 4. The masked locations of newly constructed buildings are shown in Fig. 5. Fast computation is the first priority in developing the processing system. Grid-based processing of the whole area quickly located the "hot" spots, that were the changes. A more complicated processing such as morphological filtering and reconstruction or density thresholding focused in those several hot spots.

Two aerial photographs acquired in 1999 and in the same 2004 surveying flight were employed for visual checking. The checking was carried out prior to match with a GIS-based building inventory database to observe how trees affect on the detection. It is shown in Table I. The ambiguity in visual checking was caused by the shadows in the aerial photographs. It also showed that the seasonal effect on trees in urban areas is the serious concern. Because the flight in 1999 was in summer season and the flight in 2004 was in winter season, lots of detected demolitions were trees. Thus, trees were the main cause of commission error. Regarding the omission error, there seems no mechanism to check it. The definition of change here was completely new construction or demolition. However, if a new building is exactly constructed in the same location with the same structure, it cannot be detected. That is the common problem of all kinds of acquired data.

TABLE I. THE RESULTS OF VISUAL CHECKING

	New construction	Demolition
Correct	44	42
Incorrect	4	55
Ambiguous	4	2

IV. CONCLUSION

The complete processing framework for change detection based on LIDAR data has been proposed, implemented and tested. It showed high level of automation in processing LIDAR data, which implies the fast computation. Changes of buildings will be classified based on multi-level histogram thresholding in further studies. Change detection employing LIDAR data could be useful for damage detection as well. The layer-collapsed buildings such as pancake-crush buildings could be easily detected from LIDAR-base change detection. A further study will integrate pulse intensity in processing and implement a complete processing system for both damage detection and updating a building database.

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