A Novel Building Change Detection Method Using 3D Building Models

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Abstract—The traditional procedure for the building change detection is subjective to user’s knowledge of the involved data. The complexity increases further due to unavailability of a public data set that is scanned on two different dates. Therefore, the manual changes in the reference data are more common to generate modified data. This paper first presents a strategy to introduce five types of changes in the reference data. Next, the proposed robust building change detection method runs analysis on planes’ connectivity to represent the 3D building models of the reference and modified data. Based on the plane connection information, the 3D building models are compared for identification of the building changes and classify them into unchanged, demolished, new, modified, and partially-modified planes. The experimental results show that the proposed building change detection method successfully detects all introduced changes in the test data set.

I. INTRODUCTION

A rapid growth of the cities, economy and population causes destructions of the old buildings, and developments of new buildings and transport infrastructures. Based on these changes, the city maps must be up-to-date to assist the users in finding the exact location of new or modified buildings. The updated city maps are also important for the disaster management during any natural disaster. Building change detection plays a key role in updating the map databases. In the literature, many building change detection methods have been proposed that can be categorised into two groups. The first kind of methods use 2D information such as the spectral information from the aerial image [1], [2]. Due to lack of height information these methods are unable to detect the height changes in a modified building. While the second kind of building change detection methods use both the 2D and 3D data information, e.g., spectral and height information from aerial images and LiDAR data respectively. However, these methods require human interaction for performing the building change detection task. Therefore, they become highly dependent on the user’s knowledge and understanding of the involved data and buildings.

Champion et al. [3] used Digital Surface Model(DSM), Digital Terrain Model (DTM), and multi-spectral information from the aerial images for detecting building changes. The resulting building changes were labeled as demolished, new or changed. These changes were manually introduced in the reference data set. This study also evaluated the impact of the DSM and DTM images on the change detection results and found that the use of the DSM and DTM had a great impact on the performance of change detection. The authors

further suggested that the use of raw LiDAR data would be more beneficial as compared to the DSM and DTM images. However, the method could not identify the modified building portions. Other change detection methods using images and DSM for building detection mainly focused on the interpretation of the height and textural difference, and then applied vegetation index information from the images to eliminate unwanted changes [4], [5]. However, they were sensitive to the resolution of the aerial image and the DSM. In addition, their accuracy suffered due to unavailability of vegetation index information of the test data set. Therefore, their performance was limited to the particular data set.

Machine learning methods were also applied for building change detection. Zong et al. [6] proposed a change detection method that used the aerial image and LiDAR data through a hierarchical machine learning framework. Next, a homogeneity and shadow information from the aerial image, while size and shape information of buildings from LiDAR were applied to refine the detected changes. Although it performed better on eight small test areas, but its performance was limited by the training data set. On the other hand, Qin and Gruen [7] applied the support vector machine (SVM) classification method to aerial and DSM images for extracting the building segments. The segments were then used to detect the changes by analysing the correlation between the reference and modified data. The results were refined by applying the height information extracted from the LiDAR data. Finally, a decision tree analysis was employed to classify the changes into three groups, i.e., demolished, new and uncertain changes. However, modified, unchanged and partially-modified planes were not detected by this method.

Another class of building changes detection methods are the threshold-based techniques. Vu et al. [8] proposed a change detection method that used several thresholds. Initially, the height thresholds were applied to the height histogram generated from the difference DSM image. Next, the point density threshold was used to remove the artefact. However, this method was able to categorise the changes into new and demolished groups only. Therefore, it could not identify the modified and demolished building portions. Awrangjeb [9] proposed a change detection method that used 2D building footprints to detect the building changes. The 2D building footprints were generated by extracting the building boundary from LiDAR data and aerial image. However, this method could not identify the changes in height of the buildings, e.g., rise in building storeys.

Fig. 1: The flow diagram of the proposed method.

This paper proposes a building change detection method that uses the LiDAR data and the 3D building models of a site as the input data, whereas the aerial image is only used to introduce some changes in a site of the input data. Generally, the changes in the site are generated with respect to the time, but such data is unavailable. Therefore, the changes in the reference site are manually incorporated to test the performance of the proposed method. After generating a modified data from the reference data, the plane connection information between the neighbouring building roof planes is measured. Initially, all neighbouring roof planes are labelled as sibling planes and then parent-to-child planes are separated from them using visual analysis of the neighbouring planes. Finally, all the wall plane connections are labelled as sibling planes. After generating the plane connections, the 3D models from both the data are reconstructed using plane connection information. The 3D building models are cross-correlated by using size and height information of building planes. These correlated changes are finally classified into five groups, i.e., unchanged, new, changed, modified, and partially-modified planes. The experimental results show that the proposed building change detection method is successful in detecting all the changes in the two test sites in Australia.

In this paper, a new robust building change detection method is proposed in Section II. In Section III, the data set, parameter settings, experimental setup and result analysis are discussed. We finally present a conclusion in the last section.

II. PROPOSED METHOD

Fig.1 shows the flow diagram of the proposed building change detection method. The inputs to the proposed method are 3D building models, aerial image and Digital Elevation Model (DEM) of the test data set. The proposed method has three major steps, (i) modification of input data, (ii) creation of building data structure, and (iii) change detection.

The 3D building planes, which contain X, Y, and Z coordinates of building roof planes, are extracted by following the procedure proposed in [10]. Based on a roof plane intersection

analysis, the wall planes of a building are extracted that complete a 3D building model. For creating the building data structure from the 3D building model, the relationship/connection between any two connected planes is generated. Three types of plane connections between the roof planes of a building are possible, i.e., parent-to-child, parent-to-parent, and child-to-child connections. Last two types of roof plane connections are also known as the sibling connection. While sibling connection is the only possible connection between two wall planes, and roof and wall planes of a building. The plane connection step is a semi-automatic step, where the sibling connection is automatically generated and the parent-child connection is manually introduced. Based on the plane connection information, the planes of the 3D building model are updated or represented.

Finally, the plane equation, plane type (roof or wall plane) and its connected planes' numbers with connection types are structured. This procedure is performed with both the reference data and the modified data in order to generate the plane data structure. As we mentioned earlier, the data set with both the reference and the modified data are unavailable. Therefore, the 3D building model of reference data is manually changed to produce the modified data of a given site. In order to identify the building changes, the data structure of the reference data and the modified data are compared in the change detection process. Later, the planes of both data are classified into five groups, i.e., unchanged, new, modified, demolished and partially modified changed planes.

A. Modification of Input Data

The inputs to the proposed method are 3D building models, aerial image and DEM of the test data. In the proposed method, the 3D building model is generated by using 3D building roof planes. The 3D building roof planes are extracted by using the method proposed in [10]. This method initially classified the LiDAR data into the ground and non-ground LiDAR points by using a height threshold. Next, a Delaunay triangulation algorithm was applied to the non-ground points and classified

(a) Reference data

(b) Addition of height in buildings

(c) Addition of a veranda

(d) Removal of verandas

(e) Addition of a new building

(f) Relocation of buildings position

Fig. 2: Introduction of five different changes in the reference data.

these points into coplanar and non-coplanar points. Based on the coplanar points and building planes' equations, the coplanar segments of building planes were extracted. Then, the coplanar segments (i.e., planes) were refined by applying six rules, i.e., merging planes, finding parallel planes, finding non-parallel planes, finding planes' locations, finding planes intersection, and merging and splitting of planes. Tree planes were removed from the refined planes by using mean and average height difference, area, and boundary of planes, used LiDAR points, and unused LiDAR points of a plane. The resultant planes were labelled as the 3D building roof planes.

Our proposed method measures the plane intersection analysis to classify the sides of extracted roof planes into two groups: wall side and non-wall side. For example, if a plane is intersected with its neighbouring plane, then its intersecting side is considered as a non-wall side and the remaining sides are labeled as wall sides of a roof plane. The wall side of a roof plane and bare earth information from the DEM are employed in order to generate wall planes around the extracted roof boundaries, thus, the 3D building model and its plane equations are measured.

Fig. 3: Extracting X and Y coordinates of a point of the cyan plane, where X and Y values are highlighted by a purple box.

The aerial image contains sharp boundaries of objects including the buildings. While the DEM and plane equation contains bare earth and height information of building, respectively. Therefore, the DEM, plane equation and aerial images are collectively used to produce changes in the reference data. The changes in the reference data are performed by moving a cursor at boundaries of building planes in the aerial image and import values of X and Y at the cursor point. This procedure is also shown in Fig. 3. Based on the X and Y coordinates of the point, the Z value of the point is measured by using the respective plane equation. For the wall planes, the Z value at a ground point of the wall plane is directly extracted from the DEM. The extracted information of planes is later used to modify the 3D building model of the reference data. For example in Fig. 2, some changes have been made: remove verandas of buildings, add new verandas in buildings, add a new building, add height in buildings and interchange buildings position.

B. Plane Connection

A plane connection is a relationship between the two connected planes of the 3D building model, where the connected planes are either intersected or overlapped to each other. The 3D building model consists of roof and wall planes. The relationship between the connected roof planes can either be a parent-to-child, a parent-to-parent, or a child-to-child connection. The parent-to-parent and child-to-child connections are also known as sibling connection. Therefore, all connected roof planes are initially labelled as siblings. Then, the parent-to-child connection of two connected roof planes is manually

Plane 1	Plane 2	Plane 1 Type	Plane 2 Type	Plane Connection Type
14	11	Roof	Roof	Parent-to-Child
14	6	Roof	Roof	Parent-to-Child
14	32	Roof	Roof	Parent-to-Parent (Sibling)
14	28	Roof	Roof	Parent-to-Parent (Sibling)
14	23	Roof	Roof	Parent-to-Parent (Sibling)
11	1	Roof	Roof	Parent-to-Parent (Sibling)
6	1	Roof	Roof	Parent-to-Parent (Sibling)
32	28	Roof	Roof	Parent-to-Parent (Sibling)
28	23	Roof	Roof	Parent-to-Parent (Sibling)
6	11	Roof	Roof	Child-to-Child (Sibling)
3	10	Wall	Wall	Wall-to-Wall (Sibling)

Fig. 4: The relationship between the connected building planes.

labelled. Whereas, the relationship between the connected wall plane and any other plane is a sibling connection. An example of plane connection is shown in Fig. 4, where few roofs and wall planes are marked and their connection to each other are displayed as well.

C. 3D Model Representation

Based on the plane connection, the 3D building model is updated and represented in a structural format, where each plane of a building is structured as a separate node. A node contains complete information of a plane e.g., plane ID, plane equation, 3D plane points (i.e., polygon), plane type (i.e., roof or wall plane), and it's connected planes.

D. Automatic Change Detection

In the proposed method, the change between the 3D models of the reference and the modified data is measured by correlating their structural information. The building structure of both models are correlated based on the size and height difference of the connected planes. The size difference identifies the change in buildings' shape, while the height difference identifies the change in buildings' volume. Both changes are collectively used in order to detect all kinds of changes and classify the building planes into five groups, i.e., unchanged, demolished, new, modified, and partially-modified planes. For this purpose, the building roof planes are mainly used to detect changes in a building structure. The difference in a building's size is

(a)

(b)

(c)

(d)

(e)

(f)

Fig. 5: Measure the size and height difference between the reference and modified data, where (a) building area in reference data (b) building area in changed data (c) building height in reference data (d) building area in changed data (e) size difference and (f) height difference.

(a) Roof planes

(b) Roof and wall planes (3D building model)

Fig. 6: Classification of building planes into five groups, i.e., unchanged (yellow), new (red), modified (blue), partially-modified (cyan) and demolished (green) planes.

measured by excluding the building area of modified data from reference data. The resultant regions of a building are labelled as new building planes which are shown in Fig. 5. While the remaining four groups, i.e., unchanged, demolished, modified, and partially-modified planes, are detected by differentiating the building height and area of the modified data and of the reference data.

For example, the modified planes are detected by finding the area having positive height difference region at the modified 3D building model. Similarly, the area of positive height difference region at the reference 3D building model is labelled as demolished plane, whereas the remaining area having no height difference region at the reference 3D building model is labelled as unchanged plane. The building planes, which are (1) partially new and modified in the modified 3D building model and (2) demolished in the reference building model, are labelled as partially-modified planes. All these groups of planes in the reference and in the modified building models are shown in Fig. 6, where the unchanged, demolished, new, modified and partially-modified planes are marked by yellow, green, red, cyan, and blue colour, respectively. The new, modified and partially-modified planes are refined by applying area tolerance threshold. The area tolerance threshold is the only threshold used in the change detection step of the

TABLE I: Modification or changes in the AV1 and AV2 sites, where a tick is showing a particular change in tested sites.

Reference site	Modified site	Add Height	Add Building	Add Veranda	Remove Veranda	Interchange the position of	
						3 buildings	5 buildings
AV1	Scene 1	✓					
	Scene 2		✓				
	Scene 3	✓	✓				
	Scene 4	✓	✓	✓			
	Scene 5	✓	✓		✓		
	Scene 6			✓			
	Scene 7				✓		
AV2	Scene 8					✓	
	Scene 9						✓
	Scene 10	✓					
	Scene 11	✓				✓	
	Scene 12	✓					✓
	Scene 13		✓				
	Scene 14		✓			✓	
	Scene 15		✓				✓
	Scene 16	✓	✓			✓	
	Scene 17	✓	✓				✓
	Scene 18			✓			
	Scene 19			✓		✓	
	Scene 20			✓			✓
	Scene 21	✓		✓			
	Scene 22		✓	✓			
	Scene 23		✓	✓		✓	
	Scene 24	✓	✓	✓		✓	
	Scene 25		✓	✓			✓
	Scene 26	✓	✓	✓			✓
	Scene 27				✓		
	Scene 28	✓			✓		
	Scene 29	✓		✓		✓	
	Scene 30	✓			✓		✓
	Scene 31		✓	✓			
	Scene 32		✓		✓	✓	
	Scene 33		✓		✓		✓
	Scene 34	✓	✓		✓	✓	
	Scene 35	✓	✓		✓		✓

(a) Scene 4

(b) Scene 5

(c) Scene 24

(d) Scene 34

Fig. 7: Qualitative results after applying the proposed building change detection method, where unchanged, new, modified, partially-modified and demolished planes are marked by yellow, red, blue, cyan and green colour, respectively.

(a) AV1

(b) AV2

Fig. 8: Selected sites to evaluate the performance of the proposed method.

proposed method. After classifying the roof planes, the wall planes are also classified into the five group according to their connection with the roof planes.

III. PERFORMANCE STUDY

A. Study Area

Due to unavailability of public data set for the building change detection, many researchers used their own data set to evaluate performance of their proposed methods [3], [9], [11]–[14]. Two sites of an Aitkenvale area, i.e., AV1 and AV2 as shown in Fig. 8, are selected to evaluate the performance of our proposed change detection method. The AV1 site has a point density of 40 points per metre square and it covers 66×52 metres square. The AV2 has a point density of 29.3 points per metre square and it covers 108×80 metres square. The AV1 site has only one building and very low vegetation, whereas the AV2 site has five buildings and comparatively high vegetation. For change detection, a site has to be scanned on two dates with a few years gap. The data set from the first date can be used as the reference data and from the latter as the modified data. However, due to an unavailability of such a particular data set from two dates, the only scanned site of data set (i.e., reference site) is modified manually to generate the modified site. As shown in Table I, 35 changes have been made in the AV1 and AV2 sites by adding a new building, verandas, height in buildings, removing verandas, and interchanging the position of three and five buildings on the site. The AV1 site has only one building, therefore, interchanging the position of buildings could not be made in the site.

B. Evaluation System

To verify the performance of our proposed building change detection method, the identified changes by the proposed method is automatically counted for each site and the results are manually tested. The results contain information about building planes which are classified into five groups: new, Partially-modified, demolished, modified, and unchanged planes.

C. Parameter Setting

In the proposed method, an area tolerance threshold is employed to differentiate the new, modified and partially-modified planes. These planes are located close to each other and differentiated by applying the area tolerance threshold. In this paper, the area tolerance threshold is set to 0.2 square metres. If overlapped plane area of the modified data with the planes in the reference data is 0.2 square meters larger than the non-overlapped plane area, then it is labelled as the modified plane.

D. Results Discussion

Two sites of an Aitkenvale area are selected to evaluate the performance of building change detection. In this paper, we are using Scene 4, Scene 5, Scene 24, and Scene 34 for qualitatively demonstration. The changes in building model are made in 2D space (i.e change in size or position) and 3D space (i.e., change in height). The addition of new verandas, building planes, and relocation of building planes in reference building model are known as 2D changes in the building model. As shown in Fig. 7, these changes are accurately detected by the proposed method. For example, new veranda and new building planes in red, partially-modified planes in cyan, unchanged planes in yellow are successfully detected from modified building

TABLE II: Evaluation for the AV1 and AV2 sites of the Aitkenvale area.

Modified site	Unchanged planes	Demolished planes	New planes	Modified planes	Partially-Modified planes
Scene 1	8	29	0	29	0
Scene 2	37	0	37	0	0
Scene 3	8	29	37	29	0
Scene 4	8	29	46	30	0
Scene 5	0	37	29	29	0
Scene 6	37	0	4	0	0
Scene 7	29	8	0	0	0
Scene 8	40	59	36	0	23
Scene 9	0	99	43	10	46
Scene 10	51	48	0	48	0
Scene 11	8	91	36	31	23
Scene 12	0	99	43	10	46
Scene 13	99	0	16	0	0
Scene 14	40	59	52	0	23
Scene 15	0	99	59	10	46
Scene 16	8	91	52	32	23
Scene 17	0	99	59	10	46
Scene 18	99	0	4	0	0
Scene 19	40	59	40	0	23
Scene 20	0	99	47	10	46
Scene 21	51	48	4	48	0
Scene 22	99	0	24	0	0
Scene 23	40	59	60	0	23
Scene 24	8	91	60	31	23
Scene 25	0	99	67	10	46
Scene 26	0	99	67	10	46
Scene 27	87	12	0	0	0
Scene 28	43	56	0	44	0
Scene 29	8	91	28	28	23
Scene 30	0	99	35	10	43
Scene 31	86	12	16	0	0
Scene 32	36	63	44	0	23
Scene 33	0	99	51	10	43
Scene 34	8	91	44	28	23
Scene 35	43	56	16	44	0

model. More precisely, an accurate detection of the partially-modified plane in cyan confirms the robustness of the proposed method in detecting 2D space changes. In addition, the green demolished building planes from the reference building model are also successfully detected by the proposed method.

A height change in the building model (i.e., change in 3D space) is also used to test the performance of the proposed method. The adding height to building planes produces the modified planes in the modified building model and the demolished planes in reference building model. Both types of planes are successfully detected by the proposed method, therefore, there are few demolished planes which are completely overlapped by modified planes in the resultant image (see Fig. 7 for illustration). This confirms that the proposed method is also capable of identifying the change in building height. The quantitative one-to-one mapping results for all the changes made in the AV1 and AV2 sites are tabulated in Table II. It is found that the proposed method is accurate in detecting all types of changes in buildings.

IV. CONCLUSION

This paper has presented a new method for detecting the building changes. It employed the 3D building model and its plane connection analysis to classify the building planes into five groups, i.e., unchanged, new, modified, demolished, and partially-modified planes. In this research, the aerial image and LiDAR data are used to introduce the changes in the reference

3D building model. The proposed method is evaluated using two sites situated in Aitkenvale, Australia, i.e., AV1 and AV2. The experimental results dictate that the proposed method identifies all types of changes that were introduced in the reference data.

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