Automatic Floor Matching for 3D Indoor Spatial Modeling

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Abstract. With the advent of a variety of indoor location-based services, the necessity of 3D indoor model construction has become a significant issue worth noting and following. The aim of this study is to propose an algorithm of floor matching to construct a multi-floor building model. In this case, the characteristics of shape and position of lift features are used to search matched pairs in the algorithm. In addition, the vertical connectivity information also can be generated through the process. The proposed algorithm was applied to the Seoul National University Library to verify its suitability. In the case of a high-rise building, it is expected that a multi-floor building model can be constructed efficiently by automatically aligning the data generated per each floor through the method developed in this study.

Keywords. Floor Matching, Floor Alignment, Vertical Connectivity, 3D Indoor Spatial Model

1. Introduction

As various location-based services of indoor are being provided, demand for three-dimensional indoor spatial information is steadily increasing. In fact, various studies have been carried out to generate a 3D indoor model such as with the use of geometric models or networks by utilizing CAD, scanned floorplans, or sensor data such as laser and LiDAR. Prior research related to the 3D indoor spatial information can be categorized into two categories: first, limited information is generated for single floor, and second, multi-floor buildings are reproduced by overlapping after data is built by layer (Dosch et al. 2000, Karas et al. 2006, Boguslawski & Gold 2016).

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Broadly speaking, the floorplans in various formats are drawn separately by floor, and sensor data can be collected per floor. Therefore, for the establishment of a 3D indoor model for multi-floor buildings, the data generated by each floor must be aligned vertically, and two or more inter-floor matched points and areas are required. Previous studies of multi-floor building modeling have been targeted at buildings with nearly the same floor shapes (Jamali et al. 2016, Zhu et al. 2013, Dosch & Masini 1999). In actual cases, the floor shapes of multi-story buildings can be identical, the upper floor may occupy only a portion of the lower floor, or floors may have completely irregular shapes. In such cases, the alignment of data by the floor is a complex problem, and even the use of manual alignment may also be limited without a basic knowledge of the building. Dosch & Masini (1999) developed the algorithms for matching floors using features of corners, staircases, pipes, and bearing walls as nodes. They configured the compatibility graph using nodes on the condition that the confidence rate is smaller than the fixed threshold. However, there is a limitation in that it is applicable only when the size of the building is small and the shape of the building is similar. In addition, Zhu et al. (2013) aligned data, built by floor based on a 2D vector floorplan, through the type classification of the axis and text. But this approach is applicable only to specific floorplans, because the axis and text used in the study are not in the general form. For the multi-floor model with different floor shapes, Dao & Thill (2017) dealt with a model with 3D indoor network based on floorplans. However, the study focused on accessibility evaluation rather than the process of creating 3D models.

In this study, we introduce a floor matching algorithm to set up a multi-floor building model, by aligning the individual pieces of data using the restricted information that is available in scanned floorplans. Also, in order to utilize the multi-floor building data constructed through floor matching, we generate connectivity information for inter-floor movement rest on matching between building installations such as the lifts and stairs.

2. Methodology

Since features that can be extracted and vectorized from scanned floorplans are not sufficient, miscellaneous feature information in the previous study of Dosch & Masini (1999) cannot be employed. The 3D spatial data is the combination of the horizontal and vertical connectivity relations, and the vertical connectivity relations among the floors can be defined by stairs and lifts (Lee 2004). The corresponding data for lifts and stairs are easy to extract, since they are expressed with a manifest symbol in the floorplan.

2.1. Lift Matching

The lift matching algorithm is described in table 1. The similarity index (*Sim*) can be calculated by combining the shape similarity (Kim & Yu 2015) and the door positional similarity. The shape similarity is calculated by standing on the shape index (Burghardt & Steiniger 2005) representing the shape characteristics of the two polygon objects. The door positional similarity is derived from the distance between measuring the lift-entrance and centroid. If the *Sim* is evaluated as less than the threshold, the two lifts can be regarded as a matched candidate pair. The weights and thresholds are empirically determined. The pair with the largest sum of overlapping areas per each lift feature can be detected as an actual-matched pair. The centroid of lift and lift-entrance centroid of the matched pair can be respectively extracted and stored as a matched point pair.

Input : lift polygon layer L_A, L_B
1: For each lift j on floor i do 2: A_{ij} = area of Lift j on Floor i 3: ${C^X}_{ij}, {C^Y}_{ij}$ = centroid (X, Y) of Lift j on Floor 4: P_{ij} = perimeter of Lift j on Floor i 5: ${E^X}_{ij}, {E^Y}_{ij}$ = entrance centroid (X, Y) of Lift j on Floor i 6: $S_{ij} = 1 - (P_{ij}/2\sqrt{\pi \times A_{ij}})/\max(P_{ij}/2\sqrt{\pi \times A_{ij}})$ 7: $D_{ij} = 1 - (\sqrt{({C^X}_{ij} - {E^X}_{ij})^2 + ({C^Y}_{ij} - {E^Y}_{ij})^2})/\max(\sqrt{({C^X}_{ij} - {E^X}_{ij})^2 + ({C^Y}_{ij} - {E^Y}_{ij})^2})$ 8: End 9: For each lift j on layer A and lift k on layer B do 10: $Sim = w_1\lvert S_{Aj} - S_{Bk}\rvert + w_2\lvert D_{Aj} - D_{Bk}\rvert$ 11: if $Sim < threshold$ 12: Transform using $C_{Aj}, C_{Bk}, E_{Aj}, E_{Bk}$ as standard point 13: $A_{ov}(L_A, L_B) = A_{L_A \cap L_B}$ 14: candidates.append(j , k, $A_{ov}(L_A, L_B)$) 15: End 16: If candidates[2] = $\min(\sum A_{ov}(L_A, L_B))$ 17: pointA = [centroid of lift(candidates[0]), lift entrance centroid of lift(candidates[0])] 18: pointB = [centroid of lift(candidates[1]), lift entrance centroid of lift(candidates[1])]
output: Point layer including pointA, pointB

Table 1. Pseudo code of lift matching algorithm

2.2. Cross-floor Information

Since the scale of the floorplan for one building is the equivalent, the data by floor can be aligned through the rigid transformation which is composed of rotation and translation on the basis of the matched point. That is when the scales are identical, the coordinates of the upper point can be transformed according to the ones of the lower point as follows:

$$x' = cos\theta x - sin\theta y + T_x$$
$$y' = sin\theta x + cos\theta y + T_y$$

When the matched point pair is fixed through the algorithm illustrated in Section 2.1, the angle of rotation θ and the translation T_x, T_y can be calculated using the corresponding point as a reference point. After transforming, all matched pairs of lifts and stairs can be obtained by applying the position criteria and the overlap area criteria for the polygon matching (Kim & Yu 2015). Once matched pairs of all objects are identified, the alignment error can be reduced by re-transforming of the data using a number of centroid of all building installation features as reference points.

3. Results

The developed algorithm was implemented to the Seoul National University Library. The lower floor contains 2 lifts, and the upper floor contains 4 lifts. A total of 3 matched candidates were found, and one matched pair was determined through a comparison of the sum of the area of the overlaid parts. A reference point pair (matched point pair) was acquired for layout alignment. The results are shown in figure 1, and the ceiling of each layer was not expressed to show the suitability of aligning floors visually. After aligning, the connectivity information for the vertical movement in the building was retrieved through the matched pair searching between building installations among floors (table 2).

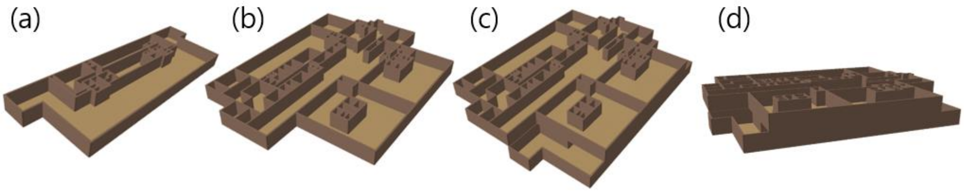

Figure 1. Floor alignment with SNU data; (a) B1 floor (b) 1st floor (c), (d) aligned floors

ID	type	up_connect_id	low_connect_id	floor
1	Lift	3	1	1
2	Lift	4	2	1
3	Lift	1	-	1
4	Lift	2	-	1

Table 2. The attribute of building installation layer with connectivity information

4. Conclusion

This paper presents a floor matching algorithm to establish a multi-floor building model from the scanned floorplan. Through the algorithm, it is noted that data by the floor can be automatically aligned using reference points, which is obtained from matching information between building installation such as lifts and stairs. Also, inter-floor connectivity information for vertical movement can be gained considering matched pairs.

In order to verify the appropriateness of the algorithm, indoor spatial data by the floor of Seoul National University Library were generated and the proposed floor matching algorithm was applied. As a result, the floors were appropriately aligned by the building installations, and the vertical connectivity information between the upper and lower lifts and stairs were obtained. The inter-floor connectivity information is stored in the form of an attribute table, and a vertical network with nodes and links can be formed reliably on the basis of the information. Since the current method can degrade performance when feature detecting and vectorizing results are inaccurate, it is necessary to improve the accuracy of those results. Moreover, it is expected that a vertical network will be formed from the application of connectivity information, thus utilizing in an effective indoor navigation system for the further study.

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