3D URBAN AREA SURFACE ANALYSIS

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ABSTRACT Surface reconstruction is a very important step towards the automation of mapping process. Surface analysis is an important part of the OSU surface reconstruction system. In this paper we introduce a surface analysis approach for the surface reconstruction of urban area. The approach consists of hump detection, grouping of 3D edges, and classification of 3D edges. The outputs of the surface analysis include locations and boundaries of humps, properties of 3D edges(e.g. horizontal or vertical, and on the topographic surface or above it), and occlusion prediction. Experimental results demonstrate this surface analysis approach can substantially improve the 2D edge matching and interpolation of surface.

KEY WORDS: 3D, Surface Reconstruction, Surface Analysis, Hump Detection, 3D Edge Grouping, 3D Edge Classification

1. INTRODUCTION

Surfaces, their properties and characteristics are probably the most important intermediate representation for extracting useful 3D information from images. As pointed out in Schenk et al., 1991, surface analysis is a key step towards reconstructing the topographic surface of urban area. The goal of 3D urban area surface analysis is to extract primitives with early vision processes(e.g. boundaries and depths), as well as symbolic primitives(e.g. properties of edges, such as breaklines and ridges, and occlusions) for the purpose of surface reconstruction and object recognition.

In digital photogrammetry, many successful examples of topographic surface reconstruction have been published, but mostly for small scales. Large-scale urban area are posing major problems, regardless of the matching method employed. Area based matching methods suffer from foreshortening problem which is very much a factor in urban areas. Feature based matching methods, on the other hand, are affected by dislocalization when using edge operators of large spatial extent.

In the OSU surface reconstruction system(see Schenk et al. 1991), we use a feature based matching approach(see Zong, 1992). The main goal is to reconstruct the surface by its breaklines. Breaklines are likely to correspond with edges in the image. Figure 1 depicts an 3D urban area surface analysis module which plays an important role in the OSU surface reconstruction system. The surface analysis serves two purposes: guiding the matching process and surface interpolation.

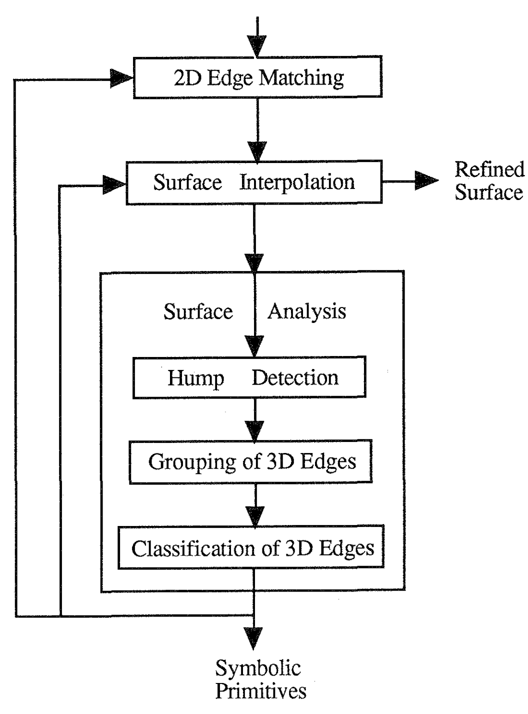

Figure 1. 3D urban area surface analysis module

As can be seen in Figure 1, surface analysis consists of three parts: hump detection, grouping of 3D edges, and classification of 3D edges. In the following sections, we will explain the algorithms made for the three parts, report about experimental results, and conclude with suggestions for future research. The 2D edge matching and the interpolation are treated in the papers of Zong, 1992 and Al-Tahir, 1992, respectively.

2. BACKGROUND

A great deal of research in digital photogrammetry is devoted towards the automation of photogrammetric processes. It is a very difficult problem, far from being solved. The goal is to produce map as automatically as possible. Obviously, automation includes recognizing objects which then have to be digitized. Questions like how many objects there are and where they are in a given scene must be answered. To answer these questions, a reconstructed topographic surface is needed.

To reconstruct a topographic surface and recognize objects on the surface, edges are the main input. Physical boundaries of objects play a very important role in the human visual and recognition systems. Some psychological studies about the human visual and recognition process indicate that physical boundaries are the fundamental feature to graphically represent or describe objects[Attneave, 1954]. In Marr's paradigm for a machine vision system, which is the most advanced approach to date, edges (intensity changes) form the primal sketch[Marr, 1982]. Of course, surface reconstruction is a very complicated process, and to get a complete surface solely from edges is obviously not enough. To create a robust approach, we need to incorporate other information, such as texture and shape.

The edges detected in 2D images are intensity changes. They are caused by physical boundaries, but also by other phenomena like depth discontinuities between surfaces, shadow boundaries, changes in reflectivity, orientation, and texture of a surface. As known, the human visual system has an astounding perceptual classification and grouping ability to partition an image and to find associations among the various parts of the image. Grouping and classification make some property explicit in the whole process of object recognition, image understanding and image interpretation [McCafferty, 1990]. For surface reconstruction, we conclude that to find explicit properties of surface, grouping and classification must performed.

3. ALGORITHMS

3.1 Overview

For the surface reconstruction process, surface analysis should have the capacity of grouping 3D edges into humps or topographic surface, and further classifying them into horizontal and vertical edges. Horizontal edges are either on topographic surface or above it. Also surface analysis should be able to provide information about the boundaries and elevations of humps. The results of grouping and classification are used to complete the surface reconstruction process and later to aid object recognition, particularly the recognition of buildings.

Hump detection is the first step of the surface analysis. By a hump we mean something that clearly stands out from the topographic surface. Hump detection is important for several reasons:

-- Humps may be the reasons for occlusion. Their detection can be used to determine occlusions in the image.

-- Humps may cause problems for surface interpolation. Their known locations can positively influence the surface interpolation.

-- Hump detection is a requisite for the grouping and classification of 3D edge.

-- Finally, humps may aid object recognition, particularly recognition of buildings.

Once humps are detected, their boundaries are known. Based on the hump information, all 3D edges are divided into groups, and then all the edges in each group are classified. In the process of classification, all edges are classified into horizontal and vertical edges. Further all horizontal edges are classified as edges on the topographic surface or above it.

After the classification, the results are used in the matching part and interpolation part. The information fed back to the two parts includes locations, boundaries, and elevations of humps and predicted occlusions. Additionally, information about the properties of 3D edges(e.g. horizontal, vertical, and on the topographic surface or not) is available for the interpolation

3.2 Hump detection

3.2.1 Generating DEM from matched 2D edges

The position of matched edges in object space is computed with exterior orientation parameters. A DEM surface is generated by interpolating the 3D edges.

3.2.2 Transforming DEM surface to gray-value image

To detect humps, the DEM surface is transformed to a gray-value image. This gives us all the advantages of 2D image processing techniques. The formula used to transform a digital elevation value to a gray value is as follows:

$$g = 255*(\frac{Z - Z_{min}}{Z_{max} - Z_{min}})$$

where g is the transformed gray value, Z_{max} and Z_{min} are maximum and minimum elevation values of DEM surface respectively, and Z is elevation value to be transformed. After the transformation, humps show up as bright clusters on the gray-value image.

3.2.3 Image segmentation and boundary formation

In Figure 3a we notice some bright clusters correspond to the humps of the DEM surface shown in

Figure 2c. In order to find all the humps, we segment gray-value image to form contour lines. In this step, the interval between adjacent contours is a key parameter. In order to detect all humps, the interval should always be smaller than the lowest height of the humps in a given scene. In the contour image, humps are characterized by closed boundaries. See Figure 3b.

3.2.4 Eliminating non-hump boundaries and redundant hump boundaries

In Figure 3b some non-hump boundaries as well as redundant boundaries can be seen. To eliminate all non-hump boundaries, two generic properties are used. Closure property: a boundary for a hump is always closed. Length property: a hump boundary should not be too short or too long. By choosing the most outside boundary, redundant boundaries are eliminated.

3.2.5 Eliminating blunders

After all bright clusters in a gray-value DEM image are determined, they must be examined for blunders, such as some high peaks caused by wrong matching and bunkers. Shape operators may be useful to detect some blunders. An example for a simple shape operator is the ratio of length and width of a hump. For a complicated one, central moments may be used[Bian, 1988]. For instance, the second and third order central moments will tell the shape of an object and its symmetry. For bunkers, an elevation operator may be implemented to check all detected humps. If the gray value(elevation) inside a hump is lower than its surroundings, then it is not a hump, but a bunker. After all blunders have been eliminated(Figure 3c), the remaining humps are stored, together with shape information, such as average height, length, width, and volume.

3.3 Grouping of 3D edges

All 3D edges are now grouped into humps based on their locations under the condition that all edges in one group should belong to one hump. The number of groups is identical to the number of humps. Edges which do not belong to any hump are grouped into an extra class: topographic surface edge.

3.4 Segmentation and Classification of 3D edges

In this step hump edges are segmented into horizontal and vertical edges, and further horizontal edges are classified into edges on the topographic surface or above it.

3.4.1 Classifying 3D edges into horizontal and vertical edges

In the 3D space, an edge can be a 3D curve. For such an edge, some segment(s) of it may be horizontal and other segment(s) are vertical. Horizontal edges are composed of horizontal edge segments, and vertical edges are from vertical edge segments. To get the segments, every point of a 3D edge is classified as horizontal point or vertical point based on an angle defined by the following formula:

$$angle = \arctan(\frac{z_i - z_{i-1}}{d_{xy}})$$

where z_i and z_{i-1} are two elevation values of the two adjacent points, p_i and p_{i-1}, and d_{xy} is the distance between the two points on horizontal plane. If the angle is greater than a threshold, the point p_i is classified as vertical. After all points of an edges have been classified, by simply connecting the adjacent points of the same class, horizontal and vertical edges are generated.

3.4.2 Classifying horizontal edges belonging to the topographic surface

To classify horizontal edges in a hump as edges on the topographic surface or above the surface, first it is necessary to find the minimum elevation of the edge points of a hump. Once the minimum elevation is found, according to the average elevation of a horizontal edge, the edge is classified as edge on the topographic surface or above it.

4. EXPERIMENTAL RESULTS

We tested our approach on several stereo pairs ot urban area image patches.

4.1 Source Data

The image patches used in the experiments were selected from aerial images(model 193/195) of The Ohio State University campus, a good example of a typical urban scene. The scale of the photographs, from which the digital images were digitized, is about 1:4000. The experiment was performed on the images with a 2k x 2k resolution. Each pixel in the images represents a square 44cm x 44cm. For the experiment two image patches were selected with a size of 512 x 512.

Figure 2a shows the two image patches used in the experiment. The matched edges are shown in Figure 2b, and a DEM surface generated from the matched edges is shown in Figure 2c. The two figures in Figure 2c are two different view angles for same one DEM surface. The DEM surface was generated by using Interhraph's modeler software. We recognize from Figure 2c that the buildings are distorted by the interpolation process.

4.2 Experimental results

Figure 3a is the gray-value DEM image for the DEM in Figure 2c. In this image some bright clusters are recognizable, which indicate potential humps. Comparing this figure with Figure 2a, we see that areas with buildings are obviously brighter than their surroundings. Figure 3b shows a contour image of Figure 3b. Th contour interval used was 4 meters. Figure 3c depicts all detected humps. At this stage the number of humps, the locations and boundaries of the humps become known. Additionally, the elevations and shapes of the humps are determined as well.

After the hump detection, all edges are associated to humps or topographic surface based on their geometrical locations. To test the results of this grouping process, a DEM was generated for every hump using only the edges belong to the hump. Figure 3d and 3e are two samples of them. One of the two humps is OSU library, and the other one is University Hall. The two humps have the same shape as they are in the DEM surface in Figure 2c, which indicates the result of grouping is correct. Finally the Figure 3f shows the DEM of the topographic surface after all the humps have been removed, with the exception of two incomplete humps(the contours of these two humps are not closed).

Figure 4 shows the results of classification. Based on the derived information of edge properties, we generated the top of OSU library in Figure 4a by using all horizontal edges which are above the topographic surface in the hump "library". Figure 4b is a combination of vertical edges and horizontal edges which are above the topographic surface.

The derived hump information and edge properties are made available to the matching and interpolation processes. With this information, the matching improved considerably[Zong, 1992]. The improvement of the interpolation part is shown in Figure 5. Here we show the DEM after a new interpolation took place with hump information. The result in Figure 5 demonstrates that the building walls in Figure 5 are more vertical than those in Figure 2c.

5. CONCLUSION

Surface reconstruction of urban areas is a very important step towards the automation of mapping processes. A complete surface is essential in order to recognize man-made objects and interpret images. Surface analysis is a key part of the OSU surface reconstruction system.

The experimental results demonstrate that the surface analysis can substantially improve the matching and interpolation of the surface of urban area. Additionally, the results od the hump detection can be used to recognize buildings.

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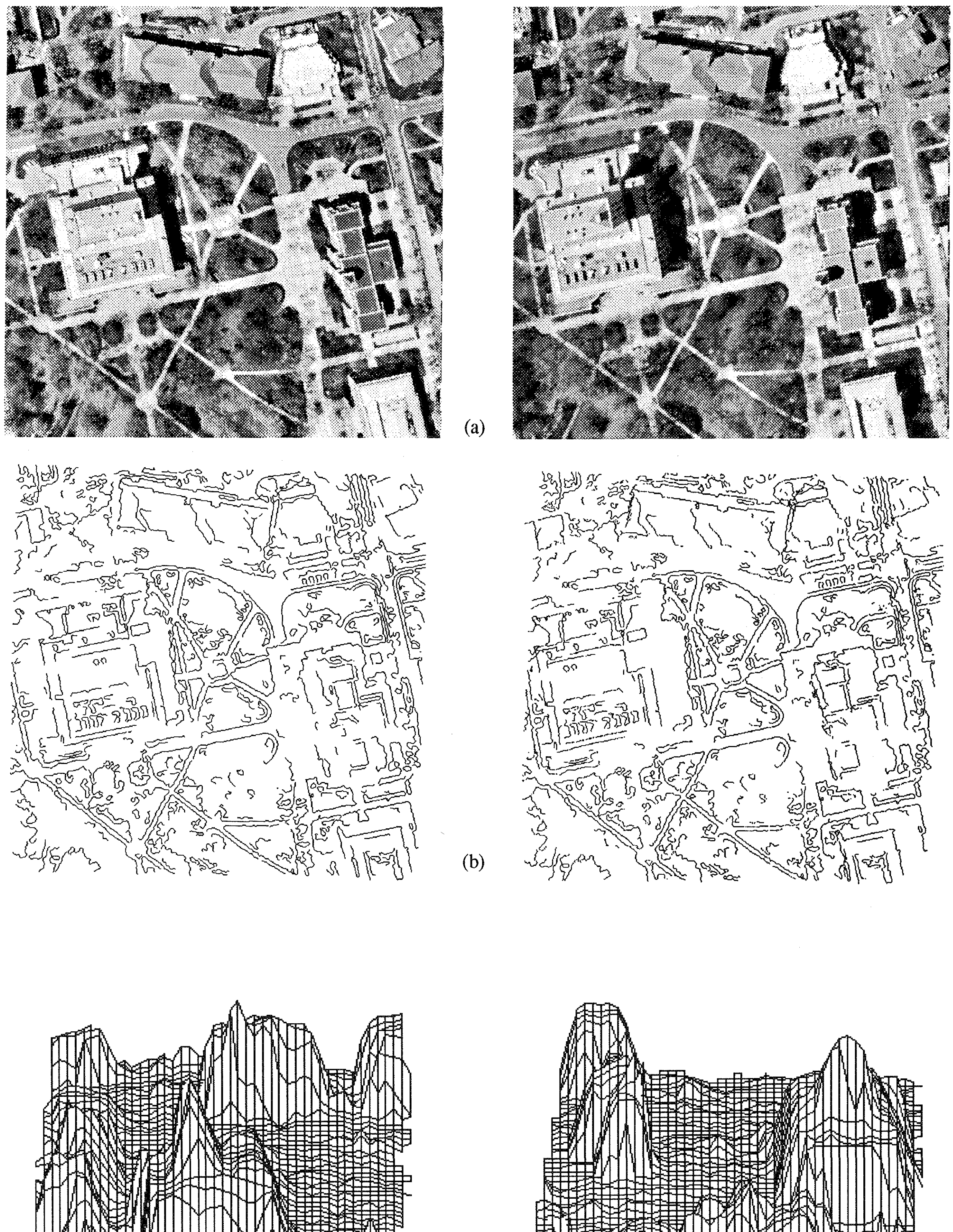


Figure 2. Source input data. (a) Two stereo image patches selected from OSU campus images. (b) Matched 2D edges for the patches in (a). (c) Interpolated DEM surface for the scene in (a)(two view angles).

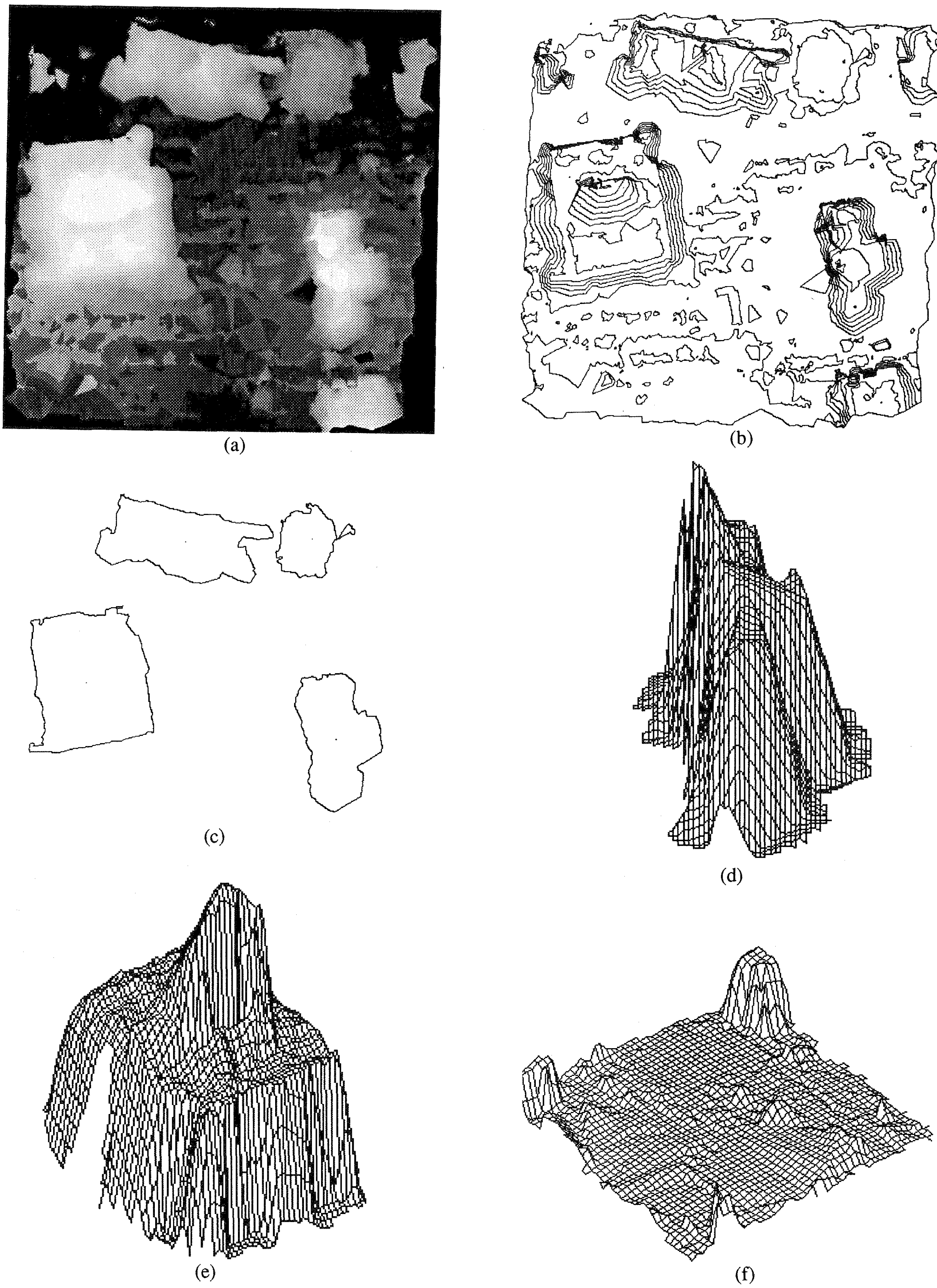
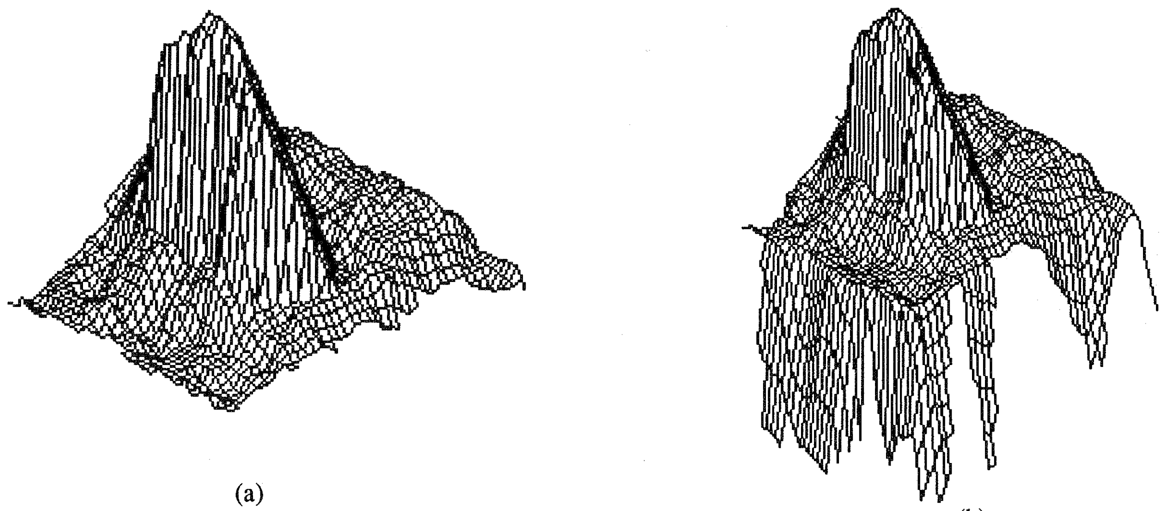
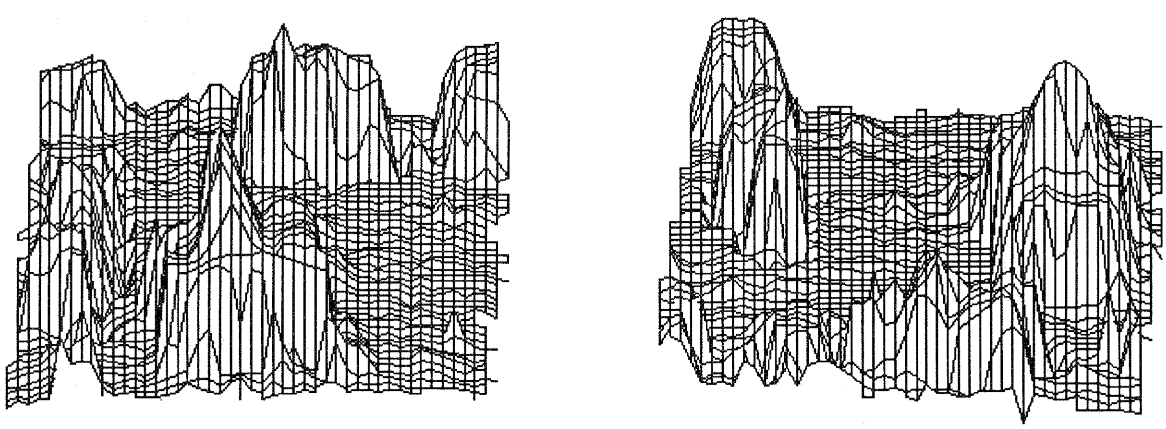


Figure 3. Detected humps and grouping examples. (a) Gray-value DEM image for the DEM surface in Figure 2(c). (b) Elevation contours for (a), the contour interval is 4 meters. (c) Detected humps for the scene in Figure 2(a). Each hump corresponds to one complete building in the scene. (d) and (e) Two hump DEM surfaces generated after grouping. The two humps are University Hall and library in OSU campus respectively. (f) The topographic surface after all humps were removed.



(a) (b)

Figure 4. Classification examples. (a) Top of the library in Figure 3(e) generated by only the horizontal edges which are above the topographic surface. (b) An incomplete library generated by vertical edges and horizontal edges which are above the topographic surface.



(a) (b)

Figure 5. The re-interpolated DEM surface. (a) and (b) Two view angles of the re-interpolated DEM surface. The building walls in this figure are more vertical than those in Figure 2(c).