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8—25 Robust Extraction of 3D Structures by Fusion of Intensity-Based and Contour-Based Junction Features

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Abstract

This paper describes a new method for validating and classifying 3D junctions by combining detected intensity-based junctions and contour-based junctions. The resulting algorithm is divided in four steps: (*i*) the pairing of junctions according to proximity criteria, (*ii*) the matching of branches/segments of paired junctions, (*iii*) the validation of isolated junctions according to paired junctions and finally, (*iv*) the validation of branches/segments to complete the junction characterization. Preliminary experimental results are presented which show the effectiveness of the method to infer in a robust manner the description of 3D objects.

1. Introduction

Many vision systems imply 3D object description and recognition from a single 2D grey level image. The aimed application involves an interior scene composed of various curved and polyhedral 3D objects. The extraction and classification of 3D junctions play an important role in the object description process since these features provide information about the object shape and pose. Two fundamental approaches prevail in the literature for detecting and classifying junctions: the intensity-based approach and the contour-based approach.

The first one uses small regions of interest and apply either an edge clustering approach to form junction branches [2] or a fitting method which incorporates a parametric model [1][7] for each type of junction to be detected. These methods provide a good proportion of detection of real versus false junctions and a precise estimation of the junction position and characterization. Nevertheless, they suffer from the lack of information of the global 3D structures. Some junction branches classified as straight lines may indicate a structure locally linear although it is globally curved. Moreover, spurious branches issued from shadows can lead easily to a bad junction classification.

In the case of edge-based extraction methods, a segmentation of edge contours into straight lines [4][5] and circular arcs [5] is first applied before determining the co-terminating segments to identify the possible junction areas. These methods provide in output a good classification of junctions due to the global information on 3D structures that participating segments convey. However, this scheme suffers from the errors resulting from the approximation of curves and the difficulty of defining an intersection point leading to an imprecise junction position. Besides, gaps between segments which are frequently encountered nearby junctions can prevent the association of segments to an existing junction or more dramatically the junction detection.

The study on junction extraction and classification shows that no existing scheme provides off-the-shell junction extraction and identification under sufficiently robust conditions. It appears that only a new combination of intensity-based and edge-based methods could limit the number of spurious/missing junctions while improving the junction position and its identification. Such an approach is proposed here which attempts to take advantage of each method performances.

The following section gives a brief introduction to the two junction extraction methods which are adopted before describing in details the procedure of fusion of these two approaches.

2. Detecting Potential Junctions

2.1. Intensity-based junctions

The intensity junctions are extracted from regions of interest identified in the intensity image [2]. The method is based on a binary splitting process applied on vectors associated to edge points lying in the region of interest. The combination of these vectors, each element of which is the gradient response to an oriented mask, allows to cluster edge elements which present similarity of amplitude and orientation into junction branches. Topological constraints are added to better control the edge clustering process. The absence of use of parametric junction models allows to detect junctions of various types in an unified way. Thus, no specific assumption has to be made about the shape of 3D objects to be considered. The algorithm provides the refined and validated position of intensity junction with subpixel

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accuracy as well as its branches which are approximated by straight and curved lines (see results on Figure 2a,c).

2.2. Contour-based junctions

The second source of information, the contour junctions [6], is obtained using contour information extracted from the intensity image. Contour information is obtained by segmenting and approximating contours into constant curvature segments (straight line segments and/or circular arcs). MuscaGrip, a multiscale segmentation and 2D contour approximation algorithm defined by two grouping processes (polygonal and constant curvature approximations), leads to a multiscale covering of each contour with a redundant set of segments with possible overshoot/overlap. Intra- and inter-scale classification of this multiscale covering, managed by *heuristically-defined qualitative labels*, leads in turn to a single non-redundant subset including no overshoot and no overlap [5]. This method aims at finding a set of adequate pairs (*scale, set(s) of constant curvature segments*) to best describe the shape of the contour. Contour junctions are defined as the intersection area between two or more constant curvature segments according to co-termination and proximity principles between extremities (see results on Figure 2b,d).

These two sources of information used independently would hardly lead to a complete and adequate description of the scene due to several errors such as false/missing junctions, spurious/missing branches/segments (compare the detected junctions in the two sources in Figure 2). In order to overcome limitations of the two methods, a fusion of the two types of junctions is attempted, leading to the elaboration of a new hybrid method.

3. Proposed Hybrid Method

The resulting algorithm is divided in four steps. The first step consists into pairing junctions from the two sources. The paired junctions are then processed in order to match similar features (one branch with one segment) whenever feasible. According to features of paired junctions, isolated junctions from the two sources are validated. Finally, matched/unmatched features of each junction are validated in turn. Figure 1 shows the main steps of the algorithm, from 2D intensity image to 3D junctions leading to 3D structures included into this image. The following sub-sections present a more in depth description of the algorithm.

3.1. Pairing of junctions

At first, junctions issued from the two sources are grouped to form pairs (intensity junction, contour junction) if they are close to each other in the image, see Figure 2.

3.2. Matching of features of paired junctions

For each paired junction created, one try to match their respective features (one branch with one segment) according to a given set of constraints. A junction pair with at least one matching feature pair is considered as validated. Initially, pairs of straight features are searched. To be matched, they must show similarity of orientation, a low maximal deviation as well as an overlap of their bounding boxes or normal projections. Then, curved features are tested to verify that they present a similar curvature and center position as well as an overlap of their occupation sectors. Potential pairs composed of two features of different types (for example one curved branch with one straight segment) are treated as if they were straight due to the imprecision of the resulting type. To achieve this, the curved feature is replaced by its tangent at the nearest extremity of the junction. The remaining unmatched features are kept for the next processes. An example of matching of features of one paired junction is shown in Figure 3.

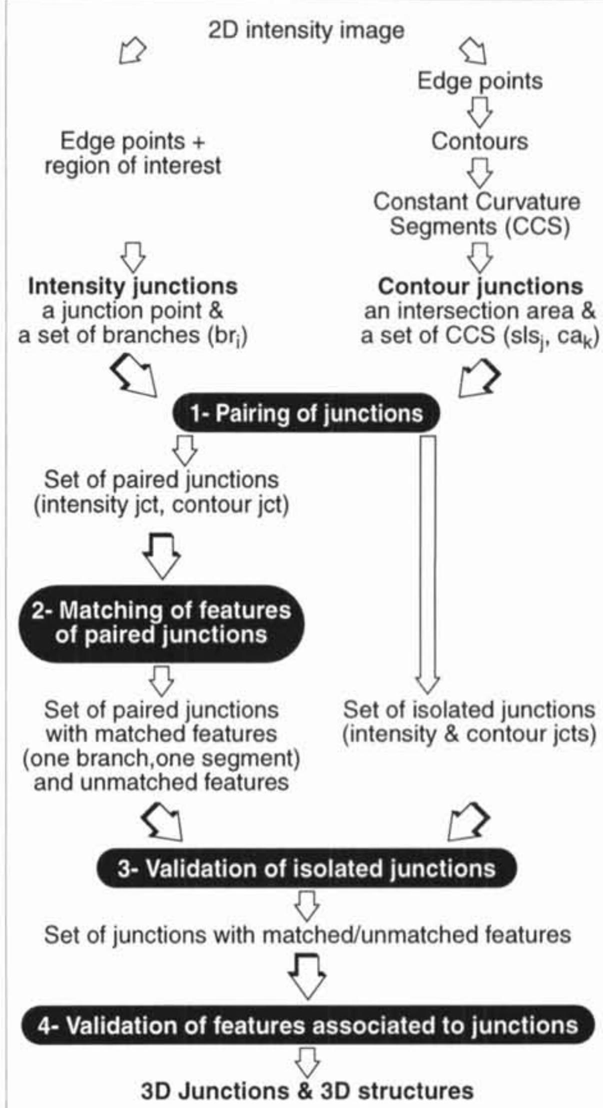

Figure 1 Main steps of the proposed hybrid method.

3.3. Validation of isolated junctions according to paired junctions

At this point, there are still isolated junctions (as shown in Figure 2) from the two sources. An isolated intensity junction would be validated if at least one of its branches can be associated with a segment linking it to

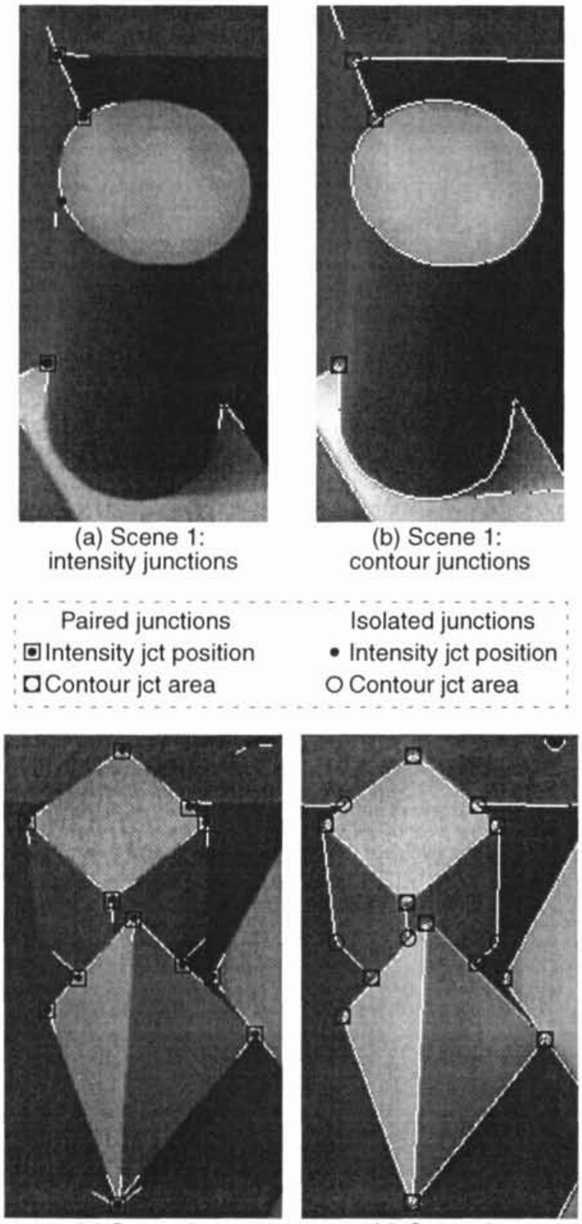

Figure 2 Pairing of junctions for two 2D intensity images: scene 1 composed of one cylinder and one box, and scene 2 composed of one box and one pyramid. (a,c) Paired and isolated intensity junctions, and (b,d) paired and isolated contour junctions.

another paired junction (see Figure 4a). Similarly, an isolated contour junction would be validated if at least one of its segments links it to another paired junction (see Figure 4b). Matched pairs (branch, segment) and unmatched features are also kept for the next process.

3.4. Validation of junction features

Next, unmatched/matched features of validated junctions must be validated in turn. This is based on the assumption that a valid junction is always characterized by at most three features. Consequently, the resulting validated junctions issued from the set of paired junctions and the set of isolated junctions are retained if

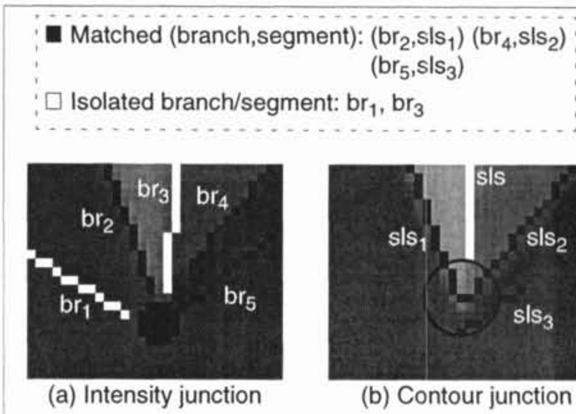

Figure 3 Matching of features for the paired junction on the bottom of the pyramid of scene 2. (a) Intensity junction and its branches $(br_1,br_2,br_3,br_4,br_5)$, and (b) contour junction and its constant curvature segments (sls_1,sls_2,sls_3). The segment sls is not associated with the contour junction.

they have three features or less. In the case of junctions with four features or more, spurious features are identified and eliminated. To achieve this, some rules are applied sequentially. At first, matched branches/segments are considered and validated if they are linked to another junction at their other extremity. Otherwise, these features are removed. If the number of validated features is still less than three, the remaining isolated features are then considered. In the case of isolated branches, an attempt of matching them with an existing segment linked to a validated junction is conducted. If this condition is respected, the feature is validated. The same holds true for an isolated segment which is linked to another validated junction.

The held features lead to the complete characterization of the junction. Besides, they may be used to update the junction position. A complete example is shown in Figure 5 for the paired junction from Figure 3.

4. Discussion

The merging of the two types of junctions is useful in at least two ways. Firstly, it allows to eliminate false junctions and spurious branches/segments, typically due to shadows or noise, leading to an adequate junction labelling. For example, it can be seen in Figure 2c that the false intensity junction at the upper right of the scene 2 will be removed by this way at step 3. Furthermore, a typical example of elimination of spurious branches/segments is shown in Figure 5.

Secondly, complementary information from these two sources allows to obtain a more complete description of the scene. For instance, the 3D structure of the cylinder of scene 1 is inferred by the intensity junction whose linear branch indicates the missing vertical edge of the cylinder (see Figure 4a). Moreover, the contour junction on the bottom left of the cube of scene 2 (Figure 4b) links two other junctions of the cube.

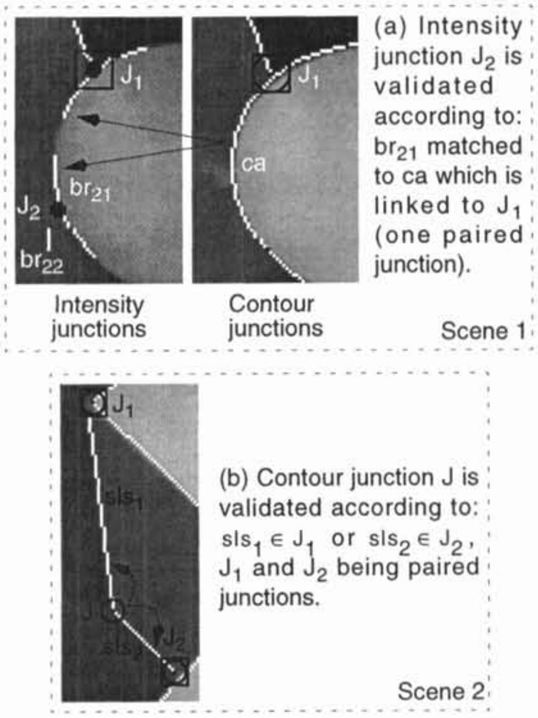

Figure 4 Validation of isolated junctions according to features of paired junctions. For (a) one isolated intensity junction, and (b) one isolated contour junction.

This allows to recover one missing face of the cube leading to the inference of its 3D structure. Finally, intensity junctions yield precise position of 3D junction points while contour junctions provide a more significant description of the 3D structure from its contours.

5. Conclusion

This article presented a new robust hybrid method, which combined intensity-based junctions and contour-based junctions in order to extract and validate significant 3D junctions. Junction positions are obtained accurately and segmented edge contours are associated to the final junctions leading to their complete characterization. The process could easily be completed by labelling the junctions according to Malik's dictionary [3].

The capacity of the method of removing false junctions and segments due to shadow or noise helps extracting 3D structures from single 2D intensity images in a robust way. This is particularly important in the real applications where controlling viewpoints and illumination is not possible and real-time reactions are needed.

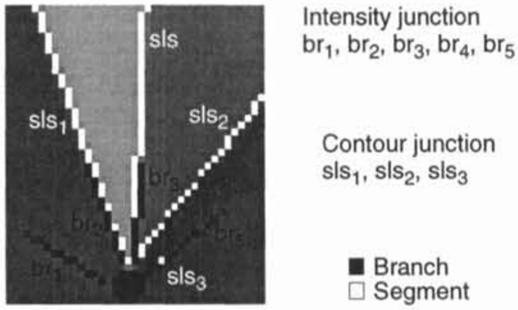

Figure 5 Validation of features for paired and isolated junctions. For the junction on the bottom of the pyramid of scene 2, matched feature pairs (br_2, sls_1), (br_4, sls_2) are validated due to their link with paired junctions. The pair (br_5, sls_3) is removed due to no link with a paired junction. br_1 is removed because no segment can be matched with it, and br_3 is matched with sls which is linked to a paired junction leading to the validation of the pair (br_3, sls). The final junction is then composed of three feature pairs (br_2, sls_1), (br_4, sls_3) and (br_3, sls), and its final position may be updated.

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