Segmentation of Range and Reflectance Images with an Expert System

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Abstract - We propose a new image segmentation technique based on a combination of both global and local segmentation methods applied to range images and those applied to reflectance images. A high level image processing based on an expert system CLIPS combines all the information produced by the different segmentation methods and gives a good parameterization of all object surfaces included in the images. We show the contribution of such a system with respect to image segmentation.

Keywords: expert system, rules, range image, image segmentation.

1 Introduction

In machine vision, there is a growing interest in range imaging. This is mainly because, in contrast to the traditional reflectance images, range images give the true geometric shape of the object surface, which is an intrinsic feature of the object. Object recognition is one of the primary goals to consider. Since every object can be decomposed into a set of surface patches, object recognition can be reduced to recognize individual surfaces.

Several solutions for range surface segmentation have been proposed in the literature, but few have focused on surface classification, especially for non planar surfaces [1, 2]. Range surface segmentation methods fall into three classes: 1) region growing or clustering [3-6]; 2) edge detection [7-9]; 3) hybrid [10-13]. Region growing techniques attempt to group pixels into connected regions based on similarity of the surface properties. Clustering methods divide the image into several clusters of connected pixels based on the similarity of face properties. Both approaches require a priori knowledge about the number of surfaces present in the image. Edge detection techniques locate pixels that lie on the boundary between two regions. There are three basic primitive types of edges in range images: step, roof and smooth edges. Most of the research work has been focused on the first two types of edges. Step edges correspond to points where surface normals are discontinuous. Detection of roof and smooth edges is very difficult as they do not correspond to large depth variation and tend to hide in noise. Hybrid methods refer to the combination of region-based and edge-based methods in order to overcome the problems of over-segmentation and under-segmentation. An exhaustive overview and comparison of range image segmentation methods can be found in [14].

Our segmentation approach is based on a combination of both global and local segmentation methods applied to range images, and global segmentation method applied to reflectance images. The global segmentation method is based on a detection method of 0th order and 1st order discontinuities, applied to range and reflectance images. The local segmentation method is based on a local inspection of the average curvature of each pixel in the original range image [15].

As we have several results, obtained from the methods of segmentation, we must use a system which makes it possible to fusion these results. To improve the results of the segmentations we use an expert system and describe the strategy employed. The rules used for supporting active capability are expressed as an Event-Condition-Action (ECA) paradigm which are termed production rules in expert systems. The Event of an ECA rule determines when the rule should be evaluated. The Condition of an ECA rule determines whether the action should be executed. The Action of an ECA rule determines how to react if the condition is evaluated true [16]. We show the contribution of such a system with respect to image segmentation [17].

This paper is organized as follow: In section 2, the low level image processing which correspond to the segmentation method of both range and reflectance images is developed. In section 3 we present the expert system, CLIPS [18]. The high level image processing based on this expert system, to combine all the information produced by the different segmentation methods to classify the regions correctly, is presented in section 4.
2 Low level image processing

The segmentation approach is based on a detection method of 0th order and 1st order discontinuities. It is a local method characterized by the three following features. First, a unique detector is used for detecting both 0th order and 1st order discontinuities. Second, the noise, which disturbs the detection of discontinuities, is damped by combining smoothing with discontinuity detection. Third, discontinuity detection and smoothing are smoothed more than necessary. The method we used, is called Minimal Detector Minimal Smoothing (MDMS) [15]. Compared to other methods, which also combine discontinuity detection with smoothing, the MDMS method is original in regard of two aspects. First, it is the only one that takes into account an estimate of noise level to control discontinuity detection and smoothing. Second, it is the only one that combines the detection of 0th order and 1st order discontinuities with the use of diffusion for smoothing.

A similar approach is used to extract 0th order discontinuities of reflectance images, by applying gradient masks. Figure 2 shows the results of this operation.

In the following a short description of the various methods is given, detailed information is found in [18].

2.1 Global segmentation of range images

For the global segmentation of the range images three different types of object surfaces were taken into account:

- planes with $z = ax + by + c$
- curved areas with $z = ax^2 + bx + cy^2 + dy + exy + f$
- balls with $(x-x_c)^2 + (y-y_c)^2 + (z-z_c)^2 = r^2$

In the discontinuity points image (figure 1b) germ areas for a region growing method are produced by computing a distance transformation first (distance of each “black” pixel to the closest “white” pixel). After applying a threshold to the distance image for getting a binary distance image and performing a connected components analysis areas with a distance to the nearest contour line above the threshold are gained, that means that these areas are located in the middle of each surface. These areas are used as germ areas (figure 3a).

Each of these germ areas is approximated by the three types of surfaces separately by choosing the parameters to get a minimum quadratic distance error for all points of the germ area to the approximation. In the growing phase pixels are added to a germ area when the following conditions are fulfilled:

- the pixel is a direct neighbour to the area
- the pixel has the same properties as the area
- the pixel is not yet assigned to an area
- the pixel is not a NIL pixel.

Area number, parameters of the surfaces, size and a measure of goodness are stored in a list and in a first evaluation step surfaces with low measure of goodness and surfaces without a marked growth are deleted. Figures 3b-d show the result. In these figures and in the following figures as well white areas represent regions being detected with respect to the category mentioned (e.g. plane area), black areas are not belonging to that category and for grey pixels no measurements are available (NIL pixels).
2.2 Local segmentation of range images

This segmentation is based on a local inspection of each pixel in the original range image (figure 1a). Two approaches have been implemented:

**Local curvature evaluation:**
The local curvature $H$ of each pixel $(x,y)$ is calculated using the following formula:

$$H = \frac{(1 + z_y^2)z_{yy} + (1 + z_x^2)z_{xx} - 2z_xz_yz_{xy}}{2(1 + z_x^2 + z_y^2)^{3/2}}$$

with $z_x$, $z_y$, $z_{xx}$, $z_{yy}$ and $z_{xy}$ as first and second local derivatives of the function $z = f(x,y)$. These curvature values are used to produce three binary images:
- convex: all pixels with a positive curvature greater than a threshold
- concave: all pixels with a negative curvature greater than a threshold
- plane: all pixels with curvature close to zero.

After a dilatation-erosion-process and a connected component analysis the new areas including with their properties are added to the region list. Figures 4a-c show the result.

**Figure 4: Local curvature evaluation**

**Local plane and ball approximation:**
The local environment of each pixel of the original range image is approximated by a plane and a ball. Based on the approximations three binary images are generated:

- local plane: the measure of goodness of a pixel is above a threshold
- ball convex: the local positive curvature (1/radius of the ball) is above a threshold
- ball concave: the local negative curvature (-1/radius of the ball) is above a threshold

After dilatation-erosion and connected component analysis the new areas including with their properties are added to the region list. Figures 5a-c show the result.

**Figure 5: Local plane and ball approximation**

2.3 Global segmentation of reflectance images

The treatment of the reflectance images for the global segmentation is realised in the same way as for the range images.
images. Only a median filter is used for noise reduction and the germ areas are generated using contour lines on the basis of the first derivative in stead of discontinuity points. Figures 6a-d show the result.

![Germ areas and plane reflectance areas]

![Areas of curved reflectance and ball type reflectance]

**Figure 6:** Global segmentation of reflectance images

As we have several results, given by the methods of segmentations, we must use a system which makes it possible to fusion these results. To improve the results of the segmentations we use an expert system and describe the strategy employed.

3 **Expert system CLIPS**

Expert systems have the deductive capability to support production rule processing and to deduce new knowledge or new data from them.

The expert system CLIPS [18] is a program which can process rules and which can be integrated into existing program in C language code. The goal is to combine the two programs into a program, where the expert system interacts with the image processing system and improves its results. During that process the information of processed range images, processed reflectance images, of global and local segmentation is used and combined to get a complete description of the regions of the image. CLIPS has become freeware and can be obtained at their companies web page [www.ghgcorp.com/clips](http://www.ghgcorp.com/clips).

3.1 **Description**

There are three basic parts to an expert system; facts (Fact_List), rules, and control strategy. The facts represent the data upon which the expert system is acting (i.e. modifying, deleting, creating). An initial base of facts has to be presented to the system. Beside the database there exists also a rule base, containing all rules. The rules determine together with the conflict resolution strategy the actions of the expert system. When the conditions of a rule are satisfied and the actions take place it is said “the rule fires”. Each rule consists of a condition part (called left hand side - LHS) and an action part (called right hand side RHS), where the action is executed if the condition is satisfied. They are always expressed in the following form: if [LHS] then [RHS].

\[
\text{if} \left[ \text{condition}<1> \text{ and condition}<2> \ldots \text{ and condition}(n) \text{ are met} \right] \Rightarrow \text{then} \left[ \text{do action}<1>, \text{action}<2>, \ldots \text{ action}<m> \right]
\]

The LHS contains the condition which need to be met in order for the rule to fire. The RHS contains all the actions that shall be performed when the rules fires. When a LHS of the rule is satisfied it does not automatically mean that this rule fires. The firing is controlled by the conflict resolution strategy. First all rules are evaluated and those whose conditions are met are placed on the agenda. Then the conflict resolution strategy is looking at all rules in the agenda and decides which one is firing next (Fig. 7)

![Simplified order of rule firing in CLIPS](http://www.ghgcorp.com/clips)
There are three major advantages of integrating CLIPS into our segmentation system. First, a condition and an action of ECA rule can be expressed via the CLIPS statements. If C code is used to define all ECA rules, recompiling the whole system cannot be avoided even though only the condition or action parts have been changed. Since CLIPS supplies an interpreted environment, recompilation is not required. Secondly, the CLIPS inference engine can be used to control both condition evaluation and action execution after an event occurs and is detected. Finally, the CLIPS Fact_List can be used to transfer parameters from an event to the corresponding condition. In the composite event detector, the CLIPS Fact_List can also be used to pass parameters of a primitive event to a composite event.

3.2 Implementation of rules in C and CLIPS

Different strategies exist and can be used. One way of controlling the order of rule firing is to assign salience values of the rules. A rule with a higher salience will fire before a rule with a lower salience. Only between rules with the same salience the conflict resolution strategy is applied. In Clips the salience of a rule can rank from lowest salience (-10000 = least important) to highest salience (10000 = most important). The default value is 0 when defining a rule without declaring it’s salience.

It is desirable to have certain rules executed before others, or there might be rules which should be executed on the very end only, so rules have been divided into following groups, with decreasing salience:

- **Main**: this group has the highest salience, rules belonging to it are executed first. Members: rule 21
- **SimpleRules**: there are simples rules, easy to evaluate and execute. The LHS as well as the RHS can be executed in the Clips environment alone, without going into the C program code. Members: rule 1, 2, 4, 5, 9, 10 and 19.
- **ImproveRegions**: these rules improve regions that already exist. Members: rule 6c and 13.
- **CheckLocal**: these rules try to find new regions in areas that are not yet assigned to any region. They cause additional image processing. Members: rule 7, 8 and 11.
- **BackgroundRules**: these rules are dealing with the background. Members: rule 15 and 16.
- **LastRules**: these rules are executed at the very end. Members: rule 6b.

Only the group of **SimpleRules** fires at the instances of the reflectance image as well as the range image. All other rules are only concerned with range image. The main focus of this image processing program is on the range images. Important information is needed and taken from the reflectance images, but it is not the goal to completely analyse the reflectance image.

4 High level processing

After the low level processing several lists with areas (together with their properties) being candidates for object surfaces are available. An evaluation of these results (figures 3–6) shows that

- some object surfaces are not detected at all
- some object surfaces are detected by several procedures with properties which do not always conform (surfaces are detected as balls and curved areas or as curved and plane areas)
- some areas are split into independent sub areas
- some object surfaces merge into one area
- some areas do not have the correct size (e.g. the growth stopped too early)
- dummy areas are generated.

4.1 Rules

To cope with these problems on a high level treatment a set of 21 rules was defined which could be grouped into 5 categories.

**Simple rules:**
The simple rules work only with the area lists. A typical representative of this group is the following rule:

IF a region is recognized as a plane and a curved area and not as a ball and the two measures of goodness for the plane and the curved area are equal and good and the coefficients a and b of the plane and b and d of the curved area are equal and the coefficients a, c and e of the curved area are close to zero

THEN the region is a plane.

**Rules for improving existing regions:**
Regions that already exist are checked and modified by repeating several low level procedures with modified conditions or parameters:

IF there remain pixels around a region which are not assigned to any region and there are no local regions or regions in the reflectance image in that part of the image

THEN repeat the region growing using the current region as germ area.
**Rules for checking local regions:**
These rules check the results of local treatment of range images and global treatment of the reflectance image in order to get more information about those regions:

**IF** a region is recognized as not a plane but a curved area and a ball
**and** the measure of goodness of the ball is better than that of the curved area
**and** the size of the ball is greater than the size of the curved area or equal
**and** there exists a local region with a very small variation of curvature

**THEN** the region is a ball.

**Rules for finding new regions:**
Image sections that are not assigned to any region are inspected:

**IF** there remain image parts which are not assigned
**and** there are no local regions at the same position in the reflectance image

**THEN** repeat the region growing process for these areas not yet being assigned by using a reduced distance threshold for the generation of the germ areas.

**Rules for background detection:**
Special rules are used for detection of the background:

**IF** a region is recognised as a plane or a curved area
**and** that region covers a big part of the image (big and small coordinates)

**THEN** the region might be the background.

For the implementation of this set of rules the expert system CLIPS was used in [17]. The rule of the example for a simple rule is transferred into the CLIPS language:

```
(defrule rule1 (declare (salience ?*SimpleRules*))
 ?region <- (object
 (plan_eval 1)(surface2_eval 1)(boule_eval 0)
 (plan_qualite ?plan_qualite &: (<= ?plan_qualite 0.03))
 (surface2_a ?surface2_a &: (<= (abs ?surface2_a) 0.06))
 (surface2_b ?surface2_b &: (<= (abs ?surface2_b) 0.06))
 (surface2_e ?surface2_e &: (<= (abs ?surface2_e) 0.06))
 (plan_a ?plan_a)(plan_b ?plan_b)
 (surface2_b ?surface2_b)(surface2_d ?surface2_d)
 )
 (test (<= (abs (- ?plan_a ?surface2_b)) 0.05))
 (test (<= (abs (- ?plan_b ?surface2_d)) 0.05))
 =>
 (modify-instance ?region (surface2_eval 0))
 )
```  

And retranslated into a common language:

**IF** a region is recognized as a plane (‘plan’) and a curved area (‘surface2’) and not as a ball (‘boule’)
**and** the measure of goodness for the plane is better than 0.03
**and** the coefficients a, c and e of the curved area are smaller than 0.06
**and** the difference between the coefficients a and b of the plane and b and d of the curved area is less then 0.05

**THEN** the region is not a curved area.

### 4.2 Segmentation results

Figures 8a-c show the result after a complete run of CLIPS. A comparison with the result of the global low level processing in figures 3b-d demonstrates the progress, which will be discussed by considering a few examples:

- The cylinder in the upper left part of the scene was detected by the low level processing as a thin plane area and a curved area (figure 3), as concave areas (figures 4 and 5) with ‘noise’ or border problems. With rules of the category ‘Simple rules’ the area was classified as a curved area and only as a curved area in the correct size (figure 8).

- The ball in the upper middle part was detected first as a curved area or a ball or a concave area with a size being too small. A rule of ‘Rules for improving existing regions’ adapted the parameters for the growth (in figure 3) so that the correct type of the area (ball) and the correct size could be extracted.

- The partially hidden ball in the left side of the scenario was not found with the processes of the low level steps. This area was found in correct shape and size by the rule given as an example for the category ‘Rules for finding new objects’. Only a discrimination between curved area and ball was not possible being due to the limited spatial resolution of the range data.
A total inspection reveals that
- no region rests undetected
- all regions are classified correctly as planes, curved areas or balls with one exception: the three thin plane areas in the middle of the image are classified as one curved area
- all regions have their correct size also with one exception: the ball at the right lower part of the image is split into two sub areas.

By optimisation of the rule set both failures can be avoided. The two sub areas for the one ball could be merged due to the knowledge that there exists one area with constant curvature in the local treatment of the range image (figures 4b and 5b). The one curved area in the middle of the image could be split into three areas by a rule which approximates curved areas by plane sub areas including a check of the quality of the sub areas or just by lowering the threshold for the germ area detection as an alternative after the first growing process. However, even after an optimisation of the rule set, some minor errors can not be totally excluded. Those errors have to be corrected in the next level of processing.

5 Conclusion

Based on the nearly correct classification of the three types of regions, in a next higher level of processing objects can be composed out of these regions using as a first step the information about the three-dimensional neighbourhood of the regions. In an iterative process a new set of rules has to be implemented into the CLIPS system. These rules check the geometric and radiometric relations between the areas being found with the first set of rules. For example, they are looking for areas being directly adjacent, for common border lines, for properties like above, below, right of, left of, partially hidden by. The results of this next step can be stored in a semantic network of areas being compared with a second semantic network for the structure of predefined objects. The emphasis will be finding the appropriate set of rules, a semantic network seems to be an adequate data structure but can be replaced by other structures.

References


