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Recognition of occluded objects using curvature

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ABSTRACT

New approaches of object representation reliable for partially occluded objects recognition are introduced in this article. Objects are represented by their boundaries, which are deformed by the occlusion. The boundary representation was made by approximation with circle arcs. The representation was designed to be local and robust to occlusion. The curve approximation with circle arcs is equivalent to the curvature representation with respect to noise. The algorithm is simple and easy to implement. Experimental results are presented.

Keywords

occluded object, dominant points, minimal and maximal curvature points

1. INTRODUCTION

Recently, many papers about partially occluded object recognition have been published. The objects are supposed to be planar and represented just by their binary pictures. Moreover, we assume the objects are compact, that means each object consists of one part only, the boundary of which is a closed curve. We also assume the object may undergo some spatial transformations: translation, rotation, scaling, affine transformation or perspective transformation. Even in this simplified specification, the recognition problem has not been efficiently solved yet. In this article we assume the occluded object undergo just three basic transformations: translation, rotation, scaling.

The key point is to find a reliable description (the method for features extraction) of the object. To be robust to occlusion and to be invariant to the implicit transformations, the description should have local characteristic. Moreover the description should represent the object as accurate so that two different objects would have different features.

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When it is not the case, and we do not have any database, the object could be reconstructed due to its specifications.

There are three basic approaches, which are used to handle the objects description. The first approach is: object string features characterization (the string contains some features for every point). The well known local differential invariants [Weiss92] or total curvature description [Pikaz95] belong to this category. The second approach is the object description by important points such as extreme curvature points [Han Jang88], [Tsang94], or curvature points of inflection. The third approach is the boundary approximation for example by splines [Cohen95]. There are also some publications, in which the authors suggested algorithms which didn't belong to any of these three approach classes for example saliency descriptor [Turney85]. There were some other experiments, for example genetic algorithms [Kawaguchi98].

This work contains two new algorithms, which stem from the Jia's idea [Jia92], for partially occluded objects recognition. Both of them have the same base - new approximation method of digitized curve by circle arcs. The methods differ by approximation progress i.e. construction of the object representation.

In the second chapter we show two ways to obtain the boundary representation, from the circle arcs curve approximation. The segment description is explained in the third chapter. Experimental results are mentioned in chapter four.

2. CURVE REPRESENTATION

In this section we focus on curve description by osculating circles. Let us assume, that we can obtain, for every point of digitized curve, an osculating circle and the surroundings of validity, i.e. the surrounding of the current point, where the curve is well approximated with a predefined accuracy by the osculating circle. The description of the algorithm for obtaining osculating circles can be found for example in [Worring94]. Let us denote *repr* $B^a{}_i$ the representation of osculating circle and the surroundings of validity ($B^a{}_i$) at the point B_i. The description of the structure *repr* $B^a{}_i$ is written in the next section.

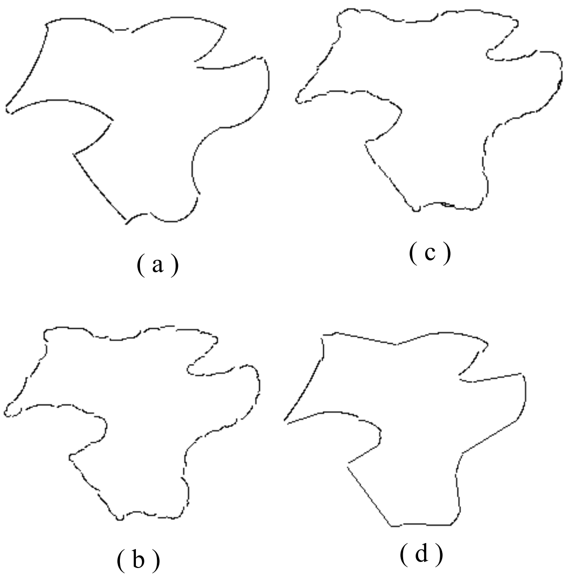


Figure 1: *Curve split into parts by different V feature (a) The biggest curvature (b) The smallest curvature (c) The shortest surroundings of validity (d) The longest surroundings of validity*

Non sequential description

The algorithm for object description should be robust to errors, i.e. any error, which can appear in the process is not distributed into other parts.

Algorithm description:

1. M = {set of points, which belong to the curve};
2. R = {};
3. **While** M is not empty **do** {i-th loop};
   a. Find out the point B_i from M which has a V feature;
   b. Find out the set of points $B^a{}_i$ which are in the B_i's validity region and which belong to M.
   c. $M=M - \{B^a{}_i\}$;
   d. $R=R$ + *repr* $(B^a{}_i \cap M)$;
4. **endwhile**

Set R is the desired representation. V is the feature of point, for example we can put V equal to the biggest curvature.

In this part we discuss advantages and disadvantages of V features, which we use as a decision rule to get B_i. We have tested four V features: the biggest and the smallest curvature, the largest and the shortest surroundings of validity.

The biggest curvature: The algorithm chooses the details, and so there is a big respect to the details. i.e. there is the respect to points with big curvature - corners describe the object very efficiently. The next advantage is, that the occlusion changes quite a small part of object description where the object was not occluded. The disadvantage is the number of parts, which the object is split in.

The smallest curvature: In fact we took points with the smallest absolute value of curvature - points with curvature near zero. If there were points of inflection, the algorithm chooses them at first. The advantage is that the parts, which the curve is split in, are quite long and there is a relative small number of them. The disadvantages are inaccurate detection of points of inflection and partial suppression of the curve details.

The shortest surroundings of validity: The algorithm picks up the parts of curve which are typically non circular and which are difficult to approximate in this way. At the border we can find corners and points of discontinuity. The meaning of circle approximation is nearly lost, but the important points can be found out very easy.

The longest surroundings of validity: That was the original Jia's idea[Jia92]. At first sight it seems to be natural and the best method. But we have to know that it is not true. The algorithm splits the curve into small number of long parts. The first disadvantage is that if we occlude a few points of one part, the whole part comes to be unusable i.e. the big part of object is lost. The second disadvantage is that specific details of the curve are partially suppressed.

The algorithm is not sequential. The areas are step by step chosen independently on each other. But we can find specific objects - or part of objects where the areas are chosen dependently. Let us look at the ellipse. We can damage two small parts of the ellipse and the object description would be absolutely different (if feature V is one of our four features), because of the monotonic change of ellipse curvature. We suggest an algorithm which can solve this problem.

Sequential description

The sequential algorithm we suggested and tested has the basic advantages of the previous algorithm and it solves the problem described above. The essential idea is almost the same: using the curvature to find the important points.

Algorithm description:

1. *Struct* = {};
2. Find the "important" points $B = \{B_i\}$
3. For every two following important points (B_{i1}, B_{i2}) on the curve make two structures *String*(B_{i1}, B_{i2}) and *String*(B_{i2}, B_{i1}). The structure *String*(B_{i1}, B_{i2}) create in this way:
   a. *String*$(B_{i1}, B_{i2})=\{\}$;
   b. $V=B_{i1}$;$M=\{$*points belong to curve between points* $B_{i1}, B_{i2}\}$;
   c. **While** $|V - B_{i1}| < | B_{i2} - B_{i1}|$ **do**
      I. *String*(B_{i1},B_{i2}) = *String*(B_{i1}, B_{i2}) + *repr*(*sur* $V \cap M$) where *sur V* are the points which belong to surroundings of validity of the point V.
      II. $M=M-\{sur\ V \cap M\}$;
      III. V= the closest point to B_{i2} of $\{sur\ V \cap M\}$
   d. **endwhile**
4. *Struct* = *Struct* + {*String*(B_{i1},B_{i2}), *String*(B_{i2},B_{i1})};

The final curve description is given by structure *Struct.*

The "important" points could be points of inflection or points where the curve reaches extreme curvature. In our experiment we used all points suggested above as the set of "important" points , because of minimizing sequential error distribution. All these points are invariant to rotation, translation, scaling.

Discussion

In this section we discuss advantages and disadvantages of both methods. At first we can see that both of them are based on the same curve property (curvature) and that implies the same robustness to noise and it implies similar computing completeness.

The size of curve descriptor - the structure *Struct* is four times bigger for sequential method. The matching algorithm will be much slower anywhere. But the size amplification makes the description robust to occlusion. Let's see why.

Let us assume curve, which has two important points B_i, B_j next to each other, and there are minima of the curvature. Herewith we think about smallest curvature like the V feature. If we occlude just one of these points, the first algorithm makes the description that is damaged by 50% compared to the original in the case that curve is an ellipse. But if we use the second algorithm, the *String*(B_i, B_j) will be wrong however the *String*(B_j, B_i) will be completely correct!

Here is one disadvantage of the sequential algorithm, which we have mentioned above. The approximation error is increasing and is distributed from the beginning point to the next one through whole structure *String*(B_i, B_j). Let's look closer at the first algorithm. If we choose two points on the curve, the curvature between them is a monotone function, the first algorithm is "sequential" between them. From this easy case, we can deduce that the sequential algorithm distributes the error in the same area as non-sequential algorithm.

3. SEGMENT DESCRIPTION

In the previous chapter, we have mentioned structure *repr X* with the notice to be explained later. At first we repeat, that X is a part of the curve, which can consists of several continuous parts. Let us assume X is just one part. The extension can be done very easy as implies from our description.

Well, we have the part of curve X, which is continuous, we know the osculating circle, i.e. its center and radius. The representation of this information can be made in many ways.

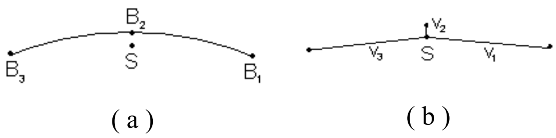


Figure 2: *Structure reprX*

We define S as a center of gravity of X. The point B_1 is the first point of X (clockwise), point B_3 is the last point of X and point B_2 is point which is lying on curve X and line from center of the osculating circle which halves the angle between B_1 and B_3. See fig. 2a. After that we can define three vectors v_1, v_2, v_3 see fig. 2b, which fully determine center and radius of osculating circle. But this representation has many advantages when compared to the first one.

1. The representation is robust to inaccuracy while finding the osculating circle.
2. The measure of error can be defined easily as a difference between three vectors.
3. This measure has good properties near zero curvature, the measure sufficiently defines the error.

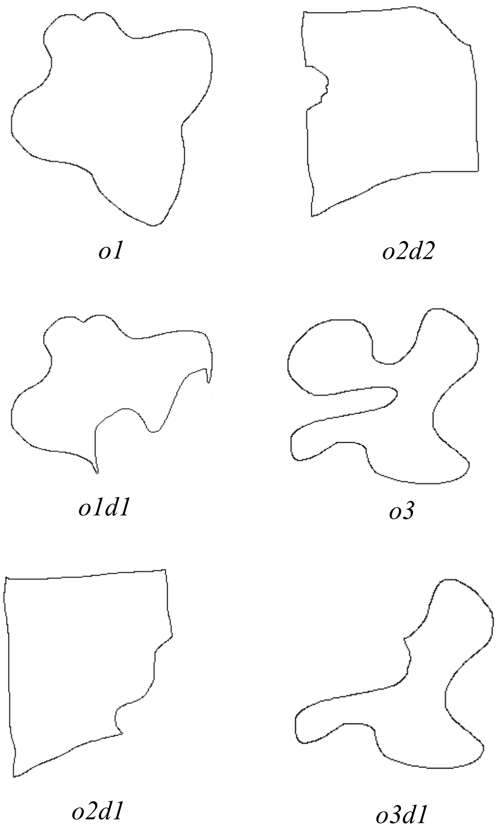
If the X consists of several continuous parts, we make these three vectors for every part.

4.RESULTS

We have tested these two algorithms at different types of curves which were rotated, scaled and occluded. In this section we show the robustness of these algorithms to occlusion, moreover the separability of types of objects is shown.

We designed simple matching algorithm to show object description properties. Match results are written in the tables. The numbers in the tables mean the similarity (percentage) of two objects. The names of objects are derived in this way: Name *o1* means first object. Objects were damaged by occlusion and so the name *o1d1* means first object that was damaged in the first way.

The computing complexity is $O(n)$ where n is number of points, which belong to the digitized curve.



	o1	o1d1	o2d1	o2d2	o3	o3d1
o1	xxx	61.3	14.4	19.9	22.5	21.6
o1d2	xxx	xxx	16.2	18.7	19.0	19.0
o2d1	xxx	xxx	xxx	32.8	14.0	10.2
o2d2	xxx	xxx	xxx	xxx	14.9	11.0
o3	xxx	xxx	xxx	xxx	xxx	64.0
o3d1	xxx	xxx	xxx	xxx	xxx	xxx

Table 1: *Similarity measure (in %) between the test objects for non-sequential method*

	o1	o1d1	o2d1	o2d2	o3	o3d1
o1	xxx	59.8	2.8	2.0	3.1	1.4
o1d2	xxx	xxx	0.8	2.7	3.0	1.4
o2d1	xxx	xxx	xxx	14.0	0.4	1.7
o2d2	xxx	xxx	xxx	xxx	1.6	0.7
o3	xxx	xxx	xxx	xxx	xxx	56.2
o3d1	xxx	xxx	xxx	xxx	xxx	xxx

Table 2: *Similarity measure (in %) between the test objects for sequential method*

5.CONCLUSION

Two algorithms for occluded curve representation were presented. Both of them were based on curve approximation by circle arcs. We showed the robustness of the representation algorithm and matching algorithm to occlusion and experimental results were presented.

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