Objects Matching Improvement using Optimization Techniques in a Geometric Modal Methodology

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ABSTRACT

This work was based on a previously developed methodology using shape modal description for matching image objects. With this methodology, the objects points were matched using a local search approach. This paper presents a global search methodology using optimization techniques to establish the correspondences between two objects. It was also developed a solution to match excess points after the usual "one to one" matching, if the number of nodes that compose both objects is not the same. It is also briefly presented the method used for the determination of the rigid transformation between two objects, which facilitates the results analysis.

Keywords

Computational Vision, Objects Matching, Modal Analysis, Optimization Methods.

1. INTRODUCTION

The determination of correspondences between objects is a useful process in some domains of computational vision, as for example: tracking and analyzing objects motion/deformation, image segmentation, reconstruction of 3D objects, etc.

Usually, the resolution methods for the matching problem include restrictions that prevent inadequate matches according to the considered criteria [Mac03a]. The matching problem can be interpreted as an optimization problem, with an objective function and restrictions that must form a non-empty space of possible solutions for the optimization problem.

The base methodology used in this work for the matching process, was adopted from [Sha92a, Tav00a] and briefly it consists in the construction of a (affinity) matrix that relates the two objects points, involved in the matching process. This matrix is constructed from the shapes modal description and relates the two objects by the displacements analysis of each point in the respective modal space. This way, as lower is the value of an affinity matrix element, higher is the probability of the match associated to that element being adequate. The previous matching strategy uses a local search: each point's pair match is established if the affinity value is the lowest for both points. This methodology can be used to match either 2D or 3D objects. However, such as it was proposed initially, it presents two considerable disadvantages: 1) the matching is done only in a local standard, this is, the points are considered as independent elements and not as belonging to a global model; 2) when the objects to match are composed by a different number of elements, the points in excess are not matched, since the correspondence type considered in this approach is the usual "one to one".

This work overtakes these disadvantages [Bas03a] using global optimization techniques in the search matching process, which highly improves this phase with a low computational cost and increments the geometrical methodology (shape modal description) potential. The excess points problem is solved with matches of type "one to many" and vice versa, based in neighborhood and affinity criterions.

Through this developments, the rigid geometrical transformation between two objects shown to be of

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interest when some correspondences between the objects points were already known. Therefore, a previously developed method [Hor87a, Tav00a] was employed for that purpose. This method uses quaternions and the existing geometrical transformation is calculated through the least squares minimization of the determined transformation error.

2. SHAPE MODAL DESCRIPTION

In the adopted base methodology, for two objects matching (where each object is composed by a set of points), a matrix that relates the two sets of points is constructed using the modal description of the shape [Sha92a, Scl95a, Tav00a, Tav02a].

This method [Sha92a, Tav00a] analyses each object individually for the extraction of its shape modes (eigenvectors) and subsequently uses them to establish the matches. Essentially, the eigenvectors codify the object shape based on the distances between its points.

Fig. 1 summarizes the global methodology for the determination of correspondences, using the shape modal description.

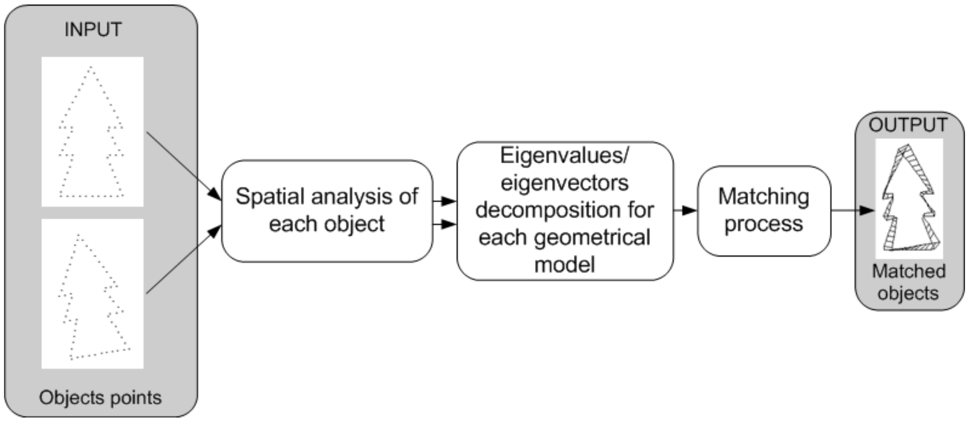

Figure 1: Resumed diagram of the adopted geometrical methodology. (The main objective of this work is the matching process improvement using optimization techniques.)

3. OPTIMIZATION PROBLEM

Optimization problems involve maximization or minimization of functions of variables in a certain domain, usually defined by a set of restrictions applied to the variables. The matching problem can be written as an assignment problem, which is a particular case of an optimization problem. The classical assignment problem presumes the existence of n points in object t, n points in object $t+1$, and the assignment cost for each par (i, j), C_{ij}, where i is a point from object t and j is a point from object $t+1$. This assignment cost is equivalent to the value of the affinity matrix element corresponding to (i, j). In this type of problems, it's intended to determine the matches distribution, so that: Each point in t be matched only with one point in $t+1$; Each point in $t+1$ be matched only with one point in t; Be minimized the total costs of assignment/matching.

In the proposed methodology, for a global determination of correspondences were used three optimization methods [Bas03a, Löb00a, Vol96a].

In the implemented methodology, after obtaining the optimal solution of the assignment problem follows the rejection of the obtained matches that don't respect a pre-established threshold. This restriction prevents matching points that have a weak affinity between them.

4. MATCHING THE EXCESS POINTS

Case the number of points of the objects to match is different, with the usual matching restriction that allows only matches of type "one to one", will necessarily exist points in excess that won't be matched. The solution found was initially to add fictitious points to the model with fewer elements, this way solving the requirement of the matrix involved in the optimization process having necessarily to be square. After the optimization phase are considered excess points the ones matched with fictitious elements. These excess points are matched adequately, using a neighborhood and an affinity criterion. This way are allowed matches of type "one to many" or vice versa for the excess points. We will call this method algorithm: *ADCom*.

5. RIGID TRANSFORMATION BETWEEN TWO OBJECTS

The determination of the rigid transformation [Fol91a] between two objects is a common problem in several domains of computational vision. In this section is presented a method, initially proposed by [Hor87a], also described and implemented by [Tav00a, Tav02a] for the determination of the rigid transformation, considering a rotation around an axis that passes through the origin, a scaling relative to this point and a translation. The adopted method is based in the least squares minimization of the determined transformation error and at least it needs the matching between three pairs of points to estimate the involved transformation: For the rotation representation are used unit quaternions; The translation is determined by the difference between the centroid coordinates of object *t* and the centroid coordinates of object *t+1*, previously rotated and scaled; The scaling is determined by the quotient of the square root of the quadratic deviations of the objects coordinates relatively to the corresponding centroids.

6. RESULTS

In this section are presented some experimental results obtained with the developed matching methodology.

The adopted/developed algorithms were integrated in a development and test platform written in *Microsoft Visual* C^{++}, which contains various functions necessary for image analysis and processing and functions for computer graphics [Tav00a, Tav02a].

The results analysis present a comparison between the previously used search methodology in the matching process, based in a local approach ("without optim."), and the new proposed search methodology, based in a global approach using optimization techniques ("with optim.").

First 2D example is composed by two contours of a real pedobarography image [Tav00a]. The second contour was obtained by applying a rigid transformation to the first one. Figures 2 and 3 show the matching results with the methodologies briefly presented and the estimated rigid transformation. Table 1 presents some numerical results of the matching process. In this table the column labelled *Cost* has the cost value for all the found matches, for each search strategy, obtained from the sum of all corresponding affinity values.

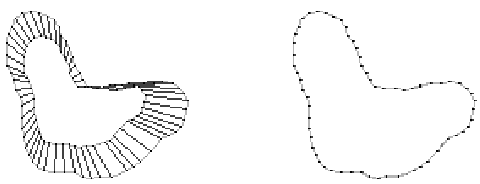

Figure 2: Matching between objects *Foot1* and *Foot2* using the local matching solution and applying the estimated rigid transformation without and with the scale factor, respectively.

The results show that, using an optimization algorithm, all matches were successfully found. Using the local approach, all of the matches were also successfully establish, but three pairs of points are unmatched. Figures 2 and 3 show the matching results after the estimated rigid transformation with/without applying the scale factor. These figures show that this estimation produced good results that can be satisfactorily used, for example, in objects alignment.

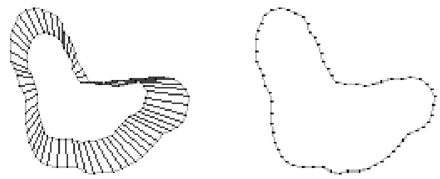

Figure 3: Matching between objects *Foot1* and *Foot2* (65 points) using the proposed matching solution and applying the estimated rigid transformation without and with the scale factor, respectively.

Matching Algo.	Nr Match.	Cost	Fig.
"without optim."	62 (95%)	14.5275	2
"with optim."	65 (100%)	15.7452	3

Table 1: Matching results of the first 2D example.

The second 2D example is composed by two contours obtained from two real heart images, obtained in two different time instants. Fig. 4 and Table 2 present some matching results.

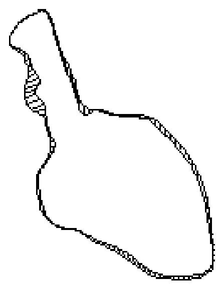

Figure 4: Matching between objects *Heart1* (139 points) and *Heart2* (136 points) using the proposed matching solution and *ADCom* algorithm to match *Heart1* excess points.

Matching Algo.	Nr Match.	Cost	Fig.
"without optim."	102 (75%)	10.2489	-
"with optim."	136 (100%)	14.4285	-
ADCom	139 (100%)	14.8855	4

Table 2: Matching results of the second example.

The matching results show successful matches between *Heart1* and *Heart2* contours. With the local matching search approach was obtained only 75% of the possible "one to one" matches. With the proposed matching search solution was successfully obtained 100% of those matches. *ADCom* algorithm efficiently matched all the excess points of *Heart1*. In this example only 20% of the eigenvectors were considered in the affinity matrix construction process. To achieve 98% of satisfactory matches using the local matching search we will need 75% of these vectors. With this experimentation, and with others that we have done, we can verify that the proposed search strategy can be more efficient than the previous one.

The last experimental example, considers two 3D objects, obtained from the same synthetic object using different resolutions. Table 3 shows some numerical results of the matching process using both search strategies. Figure 5 illustrates these results.

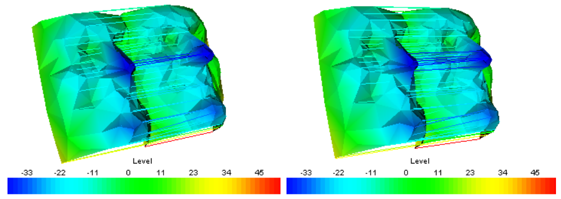

Figure 5: Matching between objects *Francut1* and *Francut2* using the local matching search and the proposed one, respectively.

Matching Algo.	Nr Match.	Cost	Fig.
"without optim."	109 (68%)	8.35145	5
"with optim."	161 (100%)	12.3884	5

Table 3: Matching results of the 3D example.

The results from Table 3 indicate that the purposed global matching search methodology, based in optimization techniques, is more efficient than the local search methodology, previously developed, since the first obtained 100% of the possible matches. As a consequence of the larger number of matches, the total cost associated is higher.

7. CONCLUSIONS

The several experimental tests carried through, some reported in this paper, allow the presentation of some observations and conclusions.

The proposed matching search methodology, based on optimization techniques, when compared with the one previously developed, based on a local search, obtained always a higher number of satisfactory matches.

In some experimental results, when the previously developed local matching search was applied, the parameters of the affinity matrix process must be carefully chosen in order to obtain a higher number of satisfactory matches. With the proposed search strategy, based on optimization techniques, the overall methodology becomes easier to used and easily adaptable to different types of applications.

To obtain a higher number of satisfactory matches, the number of eigenvectors used in the affinity matrix construction process to was dependent of the search strategy used. In the various experimentations considered, if we use the purposed search technique, this number can be lower. This suggests that the total computational effort can diminish for the overall methodology if optimization techniques are employed in the matching phase.

In the several performed experimental tests, the implemented *ADCom* algorithm, for the determination of correspondences of the excess points, finds satisfactory matches.

8. ACKNOWLEDGMENTS

Our thanks to Professor A. Volgenant for making available his article [Vol96a] and source code of his optimization algorithm, used in this work.

9. REFERENCES

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