MATCHING-TREE

- A NOVEL DATASTRUCTURE FOR GLOBAL AUTOMATIC MATCHING

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Abstract: Matching of multiple views is normally consists of coarse matching, fine matching, and a bundle adjustment at the end. Coarse matching, that is the pre-alignment of the surfaces of the complex forms, which can be positioned far away from each other in 3D space, is a difficult problem to solve. Fine matching on the other hand can be performed accurately using either the ICP (iterative closest point) method or the least square surface matching method. At the end, a bundle adjustment aligns the multiple views exactly.

To perform the automatic coarse matching, this paper presents a fast algorithm to construct the "matching tree", which was innovated by the authors in the earlier paper [1]. The complexity of the algorithms is dropped from $O(n^4)$ to $O(n^2)$, and the real run time is accelerated by factor 100. Validation of the method has been performed based on reconstructing the Castle Neuschwanstein out of laser range scanner data.

1. Introduction

Matching multiple views is an interesting but hard problem for the reconstruction of historic buildings. The existing matching techniques are insufficient for automatic matching of scans for building reconstruction. Therefore, in industry, the typical solution to this problem is to use artificial markers.

We attempted to solve this problem by introducing a novel data structure, called "matching tree" [1] to pre-align two scans automatically. The systematic process can be divided into three steps: firstly, it performs segmentation of the laser range scan data according to the geometric characteristics; secondly, a coarse matching is conducted to solve the pre-alignment problem; and finally, an efficient fine matching aligns the models accurately. The coarse matching is not affected by the position of the models, because it is generated from a matching tree using invariant relationships from the models themselves. But the runtime is fairly high, that is $O(n^4)$, and n is the number of the correspondent pairs. To solve this problem, this paper presents a fast algorithm to construct a group of matching trees incrementally, and the most optimal tree will be used to calculate the transformation matrix between views. By this method, the runtime is reduced to $O(n^2)$.

The paper is organized as follows. In section 2, previous work is briefly summarized. Then, section 3, describes the details of the main method. The construction of the matching tree is described here in details. And the experimental results are shown. At the end, the possible improvements in the future are addressed.

2. Related Work

Automatic Matching without an additional tracking system has always been a hot topic in the 3D modelling field. The research can be categorized into: coarse matching and fine matching, two views matching and multiple matching.

Coarse matching, namely pre-aligning, is usually the precondition of fine matching. It does the global registration task. The preparatory works for the fine matching, such as automatically allocating of the correspondent relationship, aligning views approximately et cetera belong to this step.

For single-object views, one normally utilizes "principal axis transformation" [2]. For multi-object views, the objects' global registration problem must be solved. A possible technique is skeleton based matching [3], which encodes the geometrical and topological information in form of a skeletal and uses graph matching techniques to achieve the destination. Since the construction of skeleton and the matching algorithms of it are sophisticated, we did not choose this method for our application, but used a novel data-structure, "matching tree"[1], which was introduced in the earlier paper of the authors. And in this paper, we accelerate the process by a incremental construction method of the matching trees, which will be shown in the next section.

Fine matching is a fairly adult field in science. The most robust and frequently used method is ICP (Iterative Closes Point) [4] and numerous variants of it: ICCP (Iterative Closest Compatible Point) [5][6][7], ICPIF (Iterative Closest Points using Invariant Features) [8] etc. The basic idea of ICP is treating the nearest point in the other view as correspondent point. SVD (Singular Value Decomposition) is used to deduce the transformation-matrix during iterative steps to align the views to each other. The nearest point can in distance field (original ICP), or in diverse feature field (ICPIF), and by weighted correspondent pair or by reducing the search space (ICCP) to accelerate the convergence. The limit of these ICPs is that they only reach local minima. That is, if most of the nearest points just lie in the false direction of the true correspondent points, they will converge to a false result. This problem can be solved either with dynamic programming or by a reasonable pre-alignment. Adaptive least square matching [9] is an effective method for matching of 3D surface patches. However, it is not suitable for multi-object scenes, because it does not deal with the automatic correspondence problem, but needs an initial approximation.

Multi-view matching can be solved either incrementally or simultaneously. The paper[10] of Cunnington and Stoddart gave a detailed comparison of three n-view point set registration algorithms. Typically, man uses a bundle adjustment to homogenize the whole point clouds of the multiple scans.

3. Main Method

In this section, the proposed method is described in detail. The whole matching process can be divided into three steps: firstly, it performs segmentation of the laser range scan data according to the geometric characteristics; secondly, a coarse matching is conducted to solve the pre-alignment problem; and finally, an efficient fine matching with bundle adjustment aligns the models accurately.

3.1. Segmentation

By the characteristics of the surfaces, the model in one view is segmented into diverse objects. Here, the difference between normal vectors between adjacent points is treated as segmenting criteria. The details are described in [1]. Because the differences between normal vectors are identical in diverse views, segmentation of each view should be the same. After a successful segmentation, the invariant characteristics will be taken from the segments. We define a form-descriptor as a two-attribute vector consisting of the sine value of the angle between the normal vectors and the radius of the surface curvature. According to the form-descriptor-vector, a list of correspondent segment-pairs is established with a certain tolerance by calculating the normalized Euclidean distance.

3.2. Coarse Matching

In this step, the goal is to find the best allocation of the correspondent relationship between segments of different views automatically. We introduce a novel data-structure to achieve it: the "matching tree". Although the implementation of the alt method [1] is fairly simple, the complexity is very high, because there are many duplicate trees produced. That is, if we have a matching tree of n nodes, then, by the alt method, we calculated it C_n^3 times. To avoid the duplicate, we sort the nodes descending according to the weight and construct the trees incrementally. The principle is illustrated as following:

The weight of the tree is the sum of the weight all the tree nodes. The tree with a maximal weight will be chosen as the most optimal solution. The algorithm is showed as following:

1. Sort the nodes by he weight decreasingly (every node represents a correspondent pair)
2. Create the first matching tree from the first node
3. Process each node from the second to the last one
    a. Create a empty matching tree group MT
    b. For each node w before the actually processed node v
        i. if w and v fill the distance matching condition, then
            1. color w
            2. put the adjacent matching trees of w in MT
    c. for every tree t in the Group MT
        i. if all nodes of them colored, then
            put node v in the tree t
    d. if v was not put into any tree, then
        i. create a new matching tree which has only one node v
    e. uncolor all the colored nodes

Table 1: Generation of matching trees

If there are n correspondent pairs, it needs n iterations in step 3. And in this step, there are $\Theta(k)$ calculations, if the index of the actually processed node is k. So the whole runtime is $O(n^2)$.

Because our goal is to find the trees with maximal weight, if the nodes are strictly descending after the sort, then the maximal trees must be inside of the result set generated according to the above method. This can be proved by complete induction.

We have tested the same data set as them in the paper [1], and the real run time compare is showed in the following table:

Old Method		*New Method*	
generate roots	1656 ms	*sort nodes*	15 ms
validate other pairs and find maximum matching	37594 ms	*generate trees*	296 ms
		find maximum matching	1 ms
total time	39250 ms	*total time*	312 ms
acceleration factor 125.8			

Table 2: Compare with the old method

The correspondent pairs in the tree with maximal weight will be used to calculate the transformation between two views. This can be done in different ways. One way [11] is: translate the views to the centre of the correspondent pairs, and calculate the rotation matrix of the second view by singular value decomposition. The algorithm is as follows, with run time of O(n).

3.3. Fine Matching

The correct correspondent relationships between segments are decided in the first two stages. We can generate an arbitrary number of control-point-pairs by projecting the sampling points of one segment to its correspondent segment. And by the use of iterative actions, the result will be refined.

After the fine two-view matching, all the scans are in a common coordinate system of. So we can generate the corresponding point pairs of the multiple views, and make a bundle adjustment to homogenize the whole point clouds.

4. Conclusion

In this paper, an approach to accelerate the “matching tree”-algorithm is introduced to find the best pre-alignment between views.

As the quality and runtime of the coarse matching are decided by the initial correspondent segments, the advancing of the segmentation-technique and refining of the form-descriptor is also important work for the future.

Also the experiments were done by the 3D to 3D matching, this algorithm can also be extended to 2D to 2D matching and 2D to 3D matching.

5. Acknowledgements

Thanks to Johann Heindl, Bernhard Strackenbrock, Dr. Heiko Hirschmueller, Michael Suppa, Tim Bodenmueller and Wolfgang Sepp for the useful discussions and delivery of related data. Further thanks to the colleagues from Co. Zoller und Froehlich: Tomas Abmayer ,Dr. Christoph Froehlich, Franz Haertl for their support for our work.

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