A New Proposal to Register Range Images

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Abstract

Reconstruction of three-dimensional models is an important topic in computer vision. Range finders only let to reconstruct a partial view of the object. However, in most part of applications a full reconstruction is required. Many authors have proposed several techniques to register 3D surfaces from multiple views. The principal problem is to obtain the transformation matrix that aligns all views. This paper briefly comments the most important Range Image registration techniques. Furthermore, a proposal to fusion several range images is presented, including experimental results.

Table 1: The proposed classification

Fine Registration	ICP	Besl92	√			√		
		Kapoutsis98	√		√	√		
		Yamany98	√			√		
		Trucco99	√			√		√
		Greenspan01	√			√		
		Jost02	√		√	√		
		Sharp02	√			√		
		Zimber03	√		√	√		√
	Chen	Chen91	√				√	
		Gagnon94		√			√	
		Eggert98		√	√		√	
	Signed Distance Fiels	Masuda01		√		√		√
		Masuda02		√		√		√
	Genetic Algorithms	Chow03	√		√	√		√
		Silva04		√		√		√

Registration strategy	Pair-wise registration
	Multi-view registration
Efficient search	k-d trees
Minimization distance	distance point-point
	distance point-surface
	Robustness

1 Introduction

Three-dimensional reconstruction is an important topic in computer vision with many applications, such as reverse engineering, robot navigation, mould fabrication, visual inspection among others. However, most recent methods to get 3D models may only reconstruct a part of the object from a mechanical scanning. In order to get a complete model, multiple range images of the same object must be fused. Range image, also called 2 $^1/_2$D image, is composed by a 2D image with some additional information which leads to compute directly the 3D surface. A 2 $^1/_2$D image is given by laser scanning [1], pattern projection [4] or stereovision [3]. In order to register multiple images, Euclidean motion between views must be determined. Some authors had supposed that initial approximation of this motion is given. In such situation, the problem is solved by minimizing the distance between consecutive range images, with the aim of obtaining a *Fine Registration*. However, in most applications the initial motion is not available. In this case, a *Coarse Registration* must be previously solved to compute an initial estimation of the motion between views.

In fine registration methods, the goal is to get a better solution minimizing an initial guess usually provided by coarse registration method or by a positioning system. A classification of these methods is presented in table 1.

Table 1 also classifies the Fine registration methods in terms of: a) registration strategy (Pair-wise or Multi-view registration) depending on the number of views that are aligned in each iteration; b) use of efficient search such as k-d trees in order to speed up the algorithm; c) distance used to minimize the registration error; d) robustness of the method.

One of the most important characteristics of a fine registration method is the registration strategy. Pair-wise registration methods can only register simultaneously a pair of images, whereas Multi-view registration techniques use all views at once to obtain the final 3D model. Usually, Multi-view ones are preferred, because better results are obtained. However, these methods are more complex and require more computing time than Pair-wise ones.

This paper is focused on the main drawbacks of Pair-wise Registration strategy presented in section 2.

Our proposal to solve these drawbacks is presented in section 3. A comparative of classical Pair-wise and our proposal is presented in section 4. The article ends with conclusions.

2 Pair-wise registration drawbacks

Pair-wise registration methods only register simultaneously a pair of range images. This restriction causes some difficulties when more than two views have to be integrated within the same view.

Connection between range images

One of the problems of Pair-wise registration is knowing which range images contain significant overlapping region in order to register them. Usually this process is performed manually before determining the initial estimation of the motion or consecutively acquired views are considered as connected views. To solve this problem, the proposal of Ho [2] can be applied. All pairs of range images are registered and then the registration error is computed as the product between the point-to-point distances and the sinus of the registration rotation angle (the author uses a rotation table so that only one degree of freedom is considered). However, the author used this technique for coarse registration applications, where an initial estimation of the motion is not required.

Error propagation

During the process of modelling an object, several range images need to be registered in order to obtain the motion that transforms all views to the same coordinate frame. However, most part of range images have no connectivity with the reference frame. Hence, some auxiliary range images are used in order to find the motion between the views that are connected. The transformation matrix is computed as a product of the different auxiliary motions. This process implies that the error is propagated in every transformation. It usually causes that the model is not closed, because the first and last range images not match. Furthermore, if one of the intermediate transformation matrix is incorrect (because there is insignificant overlapping region or the surface is continuous and have not sufficient shape for the registration), all views that use this matrix are incorrectly integrated.

Minimization of the error

When all pairs of range images that have significant overlapping region are registered, there are different ways (combinations of matrix products) to transform all the views to the reference frame. The error of the global registration depends on the chosen combination. In the following section, a proposal to solve this problem is presented.

3 A new algorithm to fusion all views

In this section, we present a technique to minimize the global registration error detecting the best path to transform all views to the reference frame. The proposal is to compute the transformation of each image with the reference frame throughout the path with minimal residual error. This error is computed as the mean of the distances between point correspondences of both range images for every Pair-wise registration.

$$err_i^j = \sum^{N} [p_i - (R_j^i \cdot p_j + t_j^i)] \qquad (1)$$

Where p_i and p_j are both set of registered clouds of points, R_j^i and t_j^i are the Euclidean motion parameters and N is the number of point correspondences.

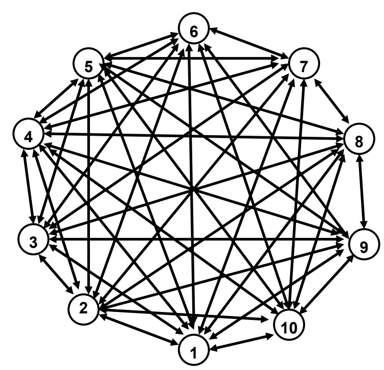

Figure 1: Exemple of an initial connectivity graph

As the connections between views are unknown, all views are registered, obtaining a transformation matrix between all of them. We obtain a connectivity graph between all views, where the cost of the path between views i and j is the registration error obtained in the registration (see Fig. 1). In this situation, we obtained a full connectivity graph, where each view can be transformed to the reference one (first view) using different paths between views. In order to obtain the best possible model, we have to determine the path that transforms all views to the reference frame related to the minimum cost. Dijkstra algorithm is applied to determine optimal path in graphs to solve this problem, obtaining a reduced graph (see Fig. 2).

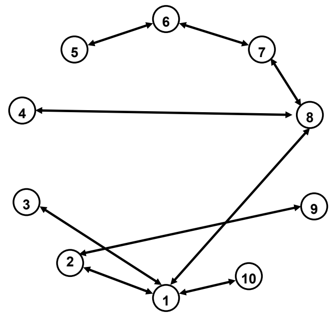

Figure 2: Example of final graph obtained with Dijkstra. View 1 is the reference frame, and all views can be represented with respect to it.

The final transformation between each view and the reference frame is the product of all transformation matrix in the optimal path, the global registration error (see Eq. 2) related to the same view is the sum of the partial registration errors involved in the path.

$$GloRegError_i = \sum_{j=2}^{i} err_i^{i-1} \quad (2)$$

where err_i^j is the error of the Pair-wise registration between views i and j.

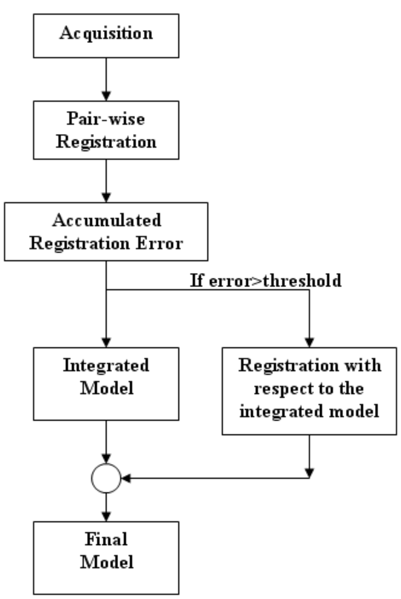

Figure 3: Steps of the implemented method

When all global errors are obtained, all views whose global error are smaller than 2σ are fused, creating an integrated model, where σ is the variance of the global errors. A threshold is added to avoid introducing bad registered views to the model.

However, the removal of incorrectly transformed views might produce holes in the registration model (increasing the number of images, the area of holes may be minimized). Generally, bad alignments in the registration process are caused by a little overlapping region. To solve this problem, all not included views are registered with respect to the integrated model. As these views are registered with respects to a bigger surface than in the initial Pair-wise, better results are generally obtained due to bigger region of overlapping (results are shown in Fig. 7). The transformation matrix obtained in this situation is directly the matrix that transforms all points to the reference frame. An scheme of all steps is presented in Fig. 3.

4 Experimental Results

Several views of a synthetic model are acquired (see Fig. 4). The motion between all views are the identity matrix, because surfaces are extracted from the global model. All views are registered using the method of Zimβer [5] obtaining the transformation matrices and the registration errors (the mean of the distance between point correspondences). The results using only the Pair-wise registration are shown in Fig. 5, considering connections only between consecutive images.

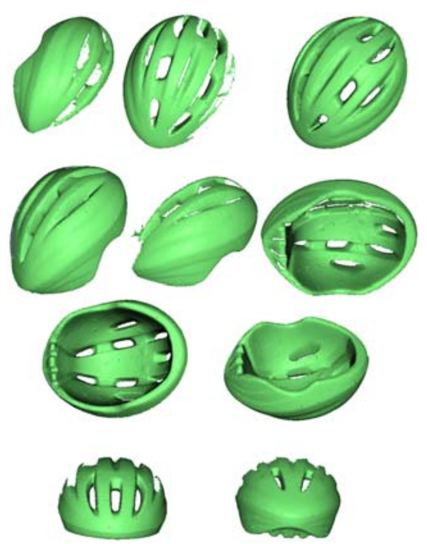

Figure 4: Set of initials views used in the registration

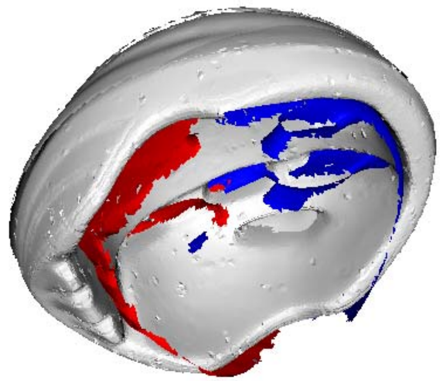

Figure 5: Final model using the traditional Pair-wise registration

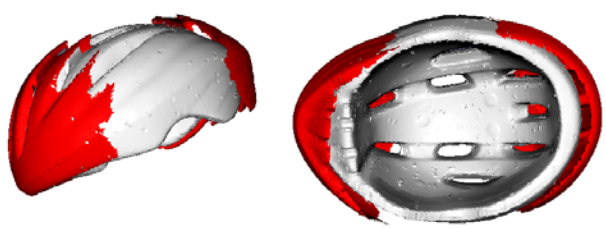

Figure 6: Final model using our proposal without the elimination of bad registered views

Minimizing the sum of the errors, the results shown in Fig. 6 are obtained, where all views are transformed to the reference frame through the optimal path. However, due to the fact that two of the registration matrices were incorrect (views 9 and 10 in this example), there are two views bad integrated in the model.

Finally, after the removal of bad integrated views and the re-registration of them, a better final model is obtained (see Fig. 7).

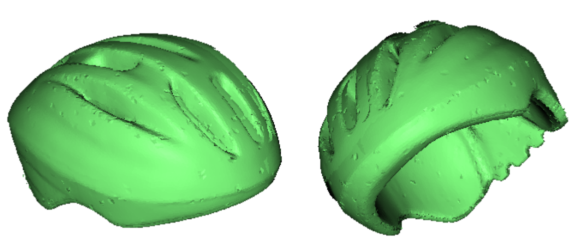

Figure 7: Final model obtained by adding incorrect registered views to the integrated model registering them with respect to the integrated model.

Table 2: Registration errors in Rotation with synthetic data

	Rotation angle error		
View	Pair-Wise	Without Correction	Our Proposal
2	0.32°	0.32°	0.32°
3	0.71°	1.90°	1.90°
4	6.40°	3.49°	3.49°
5	8.23°	1.29°	1.29°
6	8.34°	1.20°	1.20°
7	9.11°	0.57°	0.57°
8	9.75°	0.49°	0.49°
9	13.87°	11.15°	0.31°
10	17.1°	16.42°	0.32°

In order to quantify the errors of our proposal, and to compare with Pair-wise traditional registration, the error of registration is computed for each view. Theoretically, the identity matrix is the solution for each transformation matrix. The difference between the real matrix and the identity one is the error of the registration. In order to quantify this error, the rotation matrix is expressed in *axis-angle* representation. The value of this angle is a measure of the quality of the registration. Null angle is the ideal value for a correct registration. Three algorithms are compared, the first one is the traditional Pair-wise registration, where only consecutive views are registered. The second one is our proposal without the elimination of bad registered views. The final algorithm is our proposal with the correction of bad aligned views (see table 2). The results show that the first algorithm is very sensitive to error propagation. The second one minimizes the errors in the registration path and implies a minimization in the registration errors, however when two views are bad registered the error is considerable. The final algorithm presents good results for all views.

Furthermore, real range images are also used to validate the method. For this example 8 views of a frog are acquired in a Vivid Minolta 3D scanner. As the object is placed on a rotating table in order to determine the motion between views, only connectivity between consecutive views is obtained, and worse results than synthetic case are obtained. The final registration is shown in Fig. 8 and the error related to each view is shown in table 3. It can be observed than the error in view 4 (135°) is not propagated to the consecutive ones. However, the improvements in this view are not considerable.

Table 3: Registration results of the frog using real data

	Rotation angle error			
Real	Pair-wise (ICP)		Our proposal	
angle	Computed angle	Error	Computed angle	Error
45°	44.11°	0.89°	44.11°	0.89°
90°	88.41°	1.59°	88.41°	1.59°
135°	132.92°	11.08°	124.20°	10.80°
180°	168.60°	11.40°	183.86°	3.86°
225°	213.00°	12.00°	228.27°	3.27°
270°	256.39°	13.61°	271.67°	1.67°
315°	300.75°	14.25°	316.03°	1.03°

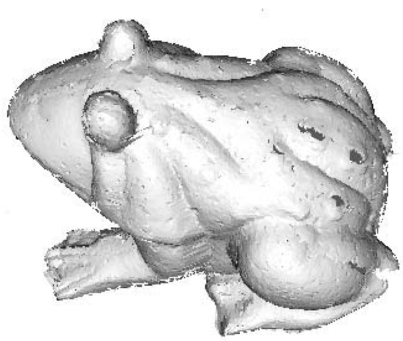

Figure 8: Final model obtained with real data. In this case, refinement step is not applied

5 Conclusions

This paper is focused in the drawbacks of Pair-wise registration techniques. The main drawback is the propagated error that can be avoided using a Multi-view registration. However, Multi-view can only be applied when all views are captured off-line. Moreover, Multi-view requires a high computing time, especially when there is a large number of range images to register.

In this paper, a proposal to fusion several range images is presented obtaining good results without the use of Multi-view registration techniques. The proposed algorithm minimizes the error of the global model when the Euclidean motion between range images is previously known. Our proposal detects automatically the adjacent views using the registration error. Additionally, a threshold is added in order to detect the bad registered views. To find the correct Euclidean motion of these views, they are registered with respect to the integrated model. Finally, experimental results are presented using a robust variant of the traditional ICP and testing our algorithm using synthetic and real data. Good results are obtained in both situations with respects to the traditional Pair-wise registration.

Acknowledgment

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