Non-rigid Registration of Point Clouds Regularized by NURBS

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Abstract

Development of three dimensional (3D) modeling technologies has being widely used in medical application. Many different methodologies have been proposed in the past; however, low cost and easy-to-use equipment is highly desirable for the medical community. As a low-cost sensor, Microsoft Kinect has been adopted in many reconstruction methods; nevertheless, most of them fail to represent fully-aligned model due to non-rigidity between captured views. In this paper we propose a simple method to perform non-rigid registration, refining the result obtained from a rigid methodology. The implemented methodology was tested using breast cancer patients data.

1 Introduction

Within recent years, 3D modeling has enhanced medical scanning techniques to provide adequate information for specialists. Many methods have been recently proposed to use either 3D views or complete 3D models, in order to obtain relevant medical features; as in [5], to perform breast aesthetic evaluation after Breast Cancer Conservative Treatment (BCCT), authors extracted complimentary features from 3D frontal view of patients. Providing accurate 3D models to be used in medical applications, often requires expensive devices which are not available in every clinics. On the other hand, typically, scanning procedures are difficult to be performed by both technicians and patients, obtaining undesired non-rigid movement between views, which reinforces the importance to use low-cost and easy-to-perform devices.

Besides scanning issues, there are some difficulties affecting the 3D reconstruction of the different views. To cover that, a recent method was proposed to reconstruct patient model by using a 2-step rigid registration [1]; though reconstruction fails when scanned views have significant non-linear differences, due to non-rigid movements of human body. In this paper, we developed a methodology to improve the aforementioned rigid reconstruction [1], by fitting the views using a non-linear registration method, supported by a 3D structure using Non-Uniform Rational Basis Splines (NURBS).

2 Related work

2.1 Registration

3D models of human body has been studied widely in recent years [4], using low-cost devices, such as Microsoft Kinect, which provide a synchronized RGB and Depth information in each image pixel. Also colored point clouds can be obtained using Kinect output information. Although Kinect has been launched for video gaming applications, it was shown in [5] that the device is accurate enough to be used as a medical sensor to capture breast cancer patients' views, to be used for aesthetic quantification.

Since a single view does not have all necessary 3D information, registration methods are required to fuse different views into a complete 3D point cloud. Recently, applied on breast cancer patient images, a 2-step rigid registration method has been proposed [1, 2], based on an initial coarse registration followed by a fine registration stage. In the coarse registration step, views are approached to each other based on corresponding features. Such features can be either a point, a subset of points or shared characteristics between points of different views [2]. In this way, breast reconstruction reveals special difficulties because of featureless nature of human torso. Well-known coarse registration methods, using Principle Component Analysis (PCA) together with different Keypoint selection methods (i.e spin image, point curvature) fail or carry out poor reconstructed models since they cannot detect correct correspondences in different views [2]. In such manner Costa *et al*. [1] proposed to extract the global structure of the object in each view using Delaunay Triangulation method, as keypoint selection, and then align them using a rigid approach. The registration process is then applied by computing the rotation and translation, from the matched features between corresponding views. Finally, a fine registration step, using Iterative Closest Points (ICP) is used for fine adjustment of the views.

Although Costa's method [1] outperforms other coarse registration methodologies, namely in situations of high translation and rotation, when non-linear movements are present, the obtained reconstruction is not accurate, hence the method uses rigid transformation, and cannot deal with non-linear movements. In this manner, we propose a methodology to improve Costa *et al*. [1], using a non-linear transformation, supported by a 3D structure using NURBS.

2.2 NURBS

NURBS is widely employed in parametric fitting of curves and surfaces. Presenting stability, local modification and flexibility, it is supported in many modern 3D standards such as OpenGL and IGENS. Nevertheless, the quality of generated surface (or curve) is dependent to the structure of points which control the NURBS. Since almost all registration methods produce scattered and unorganized point clouds, in order to use NURBS structure in a registration stage, it is essential to organize them prior the surface generation [3].

Leal *et al*. [3] proposed to organize scattered points using a simple method. Initially, points are mapped into a plane found using PCA. Based on the projection of the points onto the regression plane of the cloud, the point cloud is regularized by inserting and removing points, respectively if in some regions there is lack of points, or if the cloud is too dense, creating an uniform grid. Such grid is used to create an order required to generate the NURBS. Refined points are then re-projected into point cloud while preserving their order. Finally, point cloud is optimized by modifying the weights of each point. The resulted organized point cloud will be fed to NURBS generator to draw the required surface.

3 Non-Rigid Registration

Although NURBS is not originally introduced to carry out registration, the idea behind this work is to use its structure in order to fit different point clouds. Previously discussed, rigid registration methods cannot handle non-rigid movements, since they are unable to manipulate individual points; however NURBS provides the necessary strategy to manipulate a point cloud by updating the location of a patch of points [6]. The registration pipeline discussed in [1] certifies that the views are well aligned; however some misalignment can be observed in the presence of non-linear movement. Proposed method refines points or patch of points, where this misalignment is detected.

Refinement of a view takes place by organizing its point cloud in a grid proposed by Leal *et al*. [3]. By preserving a control point of each grid (or cp), the organizing method simplifies and arranges the point cloud to be drawn as a NURBS. Next step is followed by NURBS generator which interpolates points between control points to generate a smooth surface. All the points are then grouped in different patches regarding the nearest control point. Considering point cloud P_i to be refined and point cloud P_j as reference, control point of each patch from P_i is updated as follows:

$$cp_k^i = average(p_{(x,y,z)}, q_{(x,y,z)}); \forall p \in P_i, q \in P_j : \|p-q\| > \delta$$

where p and q are corresponding patches from two point clouds, cp_i^k is control point of patch k on refining point cloud and δ represents the maximum allowed distance between patches, to be considered that a specific

patch is well registered with the reference. The method updates the control point of patch k to the average of the points of both patches on two point cloud, if the distance between patch k and the corresponding patch on the reference point cloud is greater than δ.

4 Experimental Results

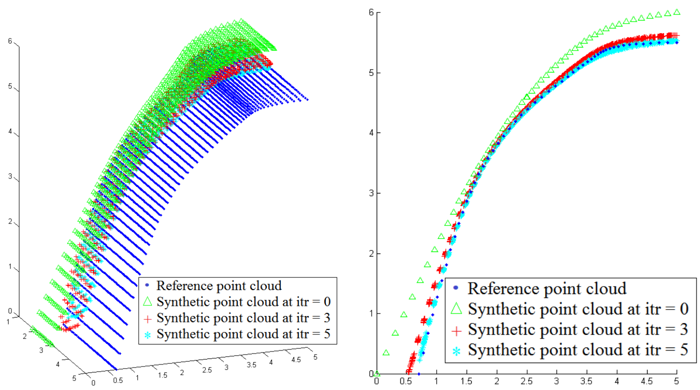
The proposed methodology was implemented in Mathworks MATLAB R2014a and executed on a machine with 8 GB of memory which was powered by Intel Corei7 vPro.

4.1 Dataset

Two experiments were conducted using synthetic data and scanned patient model. Synthetic data contained two views belonging to a surface that has some intersected areas. To test the ability of method to register them non-rigidly, point clouds of each view are not completely aligned. The other dataset contained two point clouds of the arm of a patient which were scanned using Kinect and rigidly registered by [1].

4.2 Results and Discussion

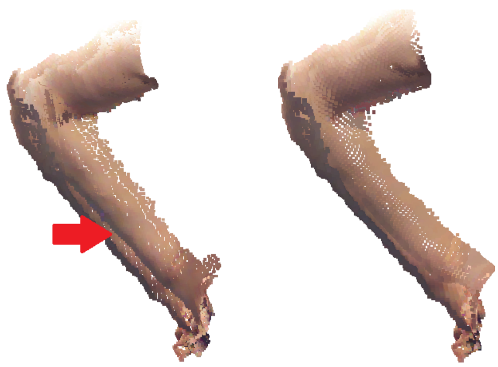
Synthetic data was used in order to demonstrate how the implemented methodology deal with non-linear misalignments. In Figure 1 we can see that the original point cloud is, iteratively, well registered with the reference in 5 iterations. Within each iteration, patches on synthetic point cloud are being approached to the corresponding patches on the reference point cloud, since control points of the patches are pushed to the reference during each iteration.



(a) (b)

Figure 1: Non-rigid registration of point cloud (△) onto the reference (.).

Additional experiment was conducted using data from breast cancer patient, containing the arm, in the presence of non-linear movement between views. In Figure 2(a) the alignment using only rigid transformations and respectively in Figure 2(b) the result after applying the methodology presented in this paper can be seen. Unfortunately we can only demonstrate the output of our method visually, because required ground truth model was not obtained in the same conditions as the patient was scanned.



(a) (b)

Figure 2: Non-rigid registration of patient arm, red arrow shows the gap between two rigid registered point clouds; a) rigid registration; b) registration with proposed method.

5 Conclusion and Future Work

Although rigid registration methodologies are not capable to present an accurate registration in the presence of non-linear differences, by utilizing NURBS technique it is possible to assure the alignment of point clouds. In this paper we proposed a simple method to manipulate point clouds individually in order to align them, even in the presence of non-linear misalignments. Experimental results indicate that proposed method aligns the views, in term of decreasing residual distance between registered point clouds; however, quantitative evaluation using ground truth data is necessary to properly validate the implemented methodology.

Additionally, and using only the regularization step of the method, the proposed method can be used to fill missing areas of point cloud, since NURBS generates uniform surfaces. In Figure 3 we can visualize the result after applying the proposed approach, to point cloud breast data acquired with Kinect device.

Future work will be focused on two aspects: conducting more accurate non-rigid registration, and improving the performance of hole filling. Non-rigid registration can be enhanced by using color information of the points in order to select correct corresponding patches. Besides, value used to define maximum allowed distance between patches can be obtained using point cloud density, rather than using predefined values. On the other hand, inserting control points in correct positions guarantee the accurate filling of missing points in order to preserve deformation of reconstructed model.

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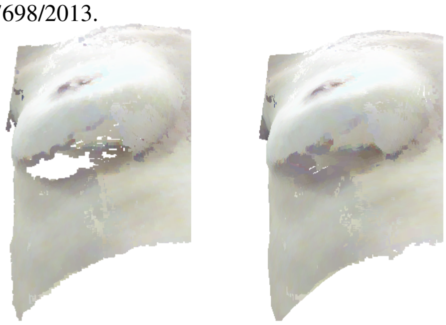

(a) (b)

Figure 3: Filling holes using interpolation of the NURBS generator; a) point cloud wit holes in the bottom of breast; b) point cloud after applying proposed method. Note that breast beneath is reconstructed with darker color because it was shadowed by breast during scanning procedure.

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