A marker free patient to digital image registration process

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Abstract. *Image guided surgery (IGS) is a routine practice in neurosurgery. The "real world coordinates" to digital image registration is the key for a precise navigation. In this work we developed a marker free patient real world to virtual digital image registration. By filtering just the surface points of the patient image we achieved a faster and more automatic registration process.*

1. Introduction

Digital image guided surgery (IGS) in cranio-maxillofacial plays an important role to increase the operation precision, reducing risks [Yu et al. 2013]. The IGS system derives its data from pre-operative digital image like computer tomography (CT) or magnetic resonance imaging (MRI) and optical tracking probe instruments in operation room, providing a mean to precisely locate targets in patient's brain.

The key factor for a accurate navigation is the registration of "real world patient's positions space" to "virtual digital image space" [Eggers et al. 2006]. In this paper we describe a ongoing project to make a precise and faster marker-free patient-image registration process.

The main contributions of this work is a technique to pre process the virtual image to registration process and a dataset of real world patients cloud of points to registration evaluation.

In Section 3 we describe a marker free method using only the optical tracking device. In Section4 we evaluate some early results of this method.

2. Patient to Image registration

The patient-image registration is the process to obtain a function that takes coordinates from the probe and gives coordinates in digital-image space. In case of a rigid-body registration the registration can be formalized as the process of finding an affine matrix M_f such that given a point p_r acquired by the optical tracker in the "patient real world coordinates" transform this point to correspondent virtual digital image coordinate p_v, $p_v = M_f p_r$.

Image registration for IGS can be categorized in marker-based registration and marker free registration. Marker-based methods use fiducial marker in pre-operative images to match points between patient and image. Fiducials can be, for instance, implants

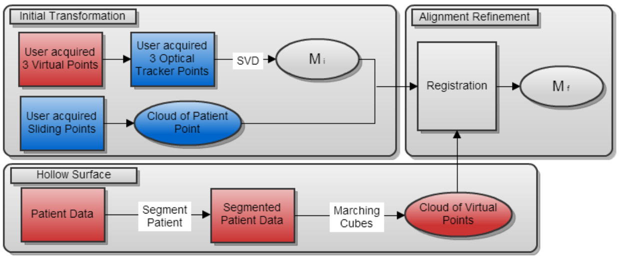
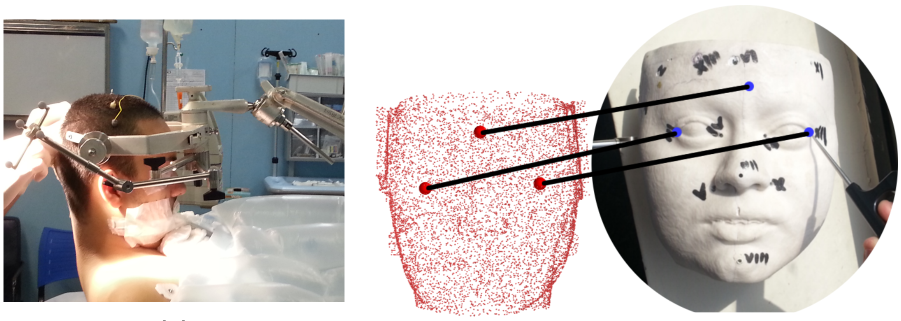


Figure 1. Steps for the registration.



(a) (b)

Figure 2. In (a) a patient in operation room with several occlusions and in (b) the acquisition of initial three points from a phantom model.

screwed to bones [Ammirati et al. 2002] or special markers glued to the patient's skin. Although a fiducials based method may result accurate registration [Ammirati et al. 2002] , it presents several drawbacks as the presence of markers in pre-operative imaging and the fact that invasive markers may impose stressful experience to the patient.

Marker free methods rely on correspondence of anatomical points in patient to digital image[Maintz and Viergever 1998]. There are also techniques using laser scan devices[Hoffmann et al. 2005, Marmulla et al. 2003] to obtain a dense set of points and calculate the registration transformation. Laser scans can suffer with occlusions and external devices not present in image acquisition. Figure 2a shows a common scene in operation room where a patient has several occlusions in the face area.

3. Marker free registration method

Our method for image-patient registration consists in three main steps: Initial Transformation, Hollow Surface and Alignment Refinement as shown in diagram is shown in Figure 1.

Initial Transformation is calculated using 3 virtual points and its 3 correspondent points on patient space. The former virtual points are collected by user in the software interface and the following are acquired by the optical tracking camera using the probe over patient skin as shown in Figure 2b. The two sets of three points are submitted to a singular value decomposition (SVD) [Golub and Kahan 1965] algorithm, finding a transformation matrix M_i that is used as a initial approximation for the registration.

For the *Hollow Surface* we developed a algorithm filtering points from the image obtaining mostly skin surface points for the next step. First we segment the image in pa-

(a) (b) (c)

Figure 3. Hollow surface steps: In (a) an original slice of the image. In (b) the segmented image. In (c) the resulting cloud of points with the external surface of patient region of image.

tient and non-patient regions. Our method does the patient and non-patient segmentation working similarly to a flood and fill starting from the edges of the image flooding the non-patient points where the threshold to stop the filling advance is proportional to the current pixel. After the segmentation we use marching cubes algorithm in order to obtain a polygon with a cloud of edges points. This set of virtual points, say V, are used as input for the next step. In Figure 3b we show the process of segmentation to the cloud of points in Figure 3c This step can be executed beforehand the registration process and stored for further processing.

In the *Alignment Refinement* step a set of real points, say R is acquired by sliding the probe over the patient's skin. A cloud of points resulting of this sliding process example can be seen in Figure 4a. We use this set R and the set V from the Hollow Surface step as input for the ICP algorithm[Zhang 1994]. The algorithm produces a rigid body matrix transformation M_f that transforms points from R to V minimizing the mean squared error. We use M_{ini} calculated in the Initial Alignment step as a first approximation for the algorithm. Therefore, M_f is such that: $M_f \cdot (M_{ini} \cdot p_r) \approx p_v \mid p_v \in V, \quad p_r \in R$

In Figure 4a we show an example of real points sets R, acquired by sliding the probe over the same phantom model of Figure 2b. Figure 4b shows the resulting registration of the three steps of our process.

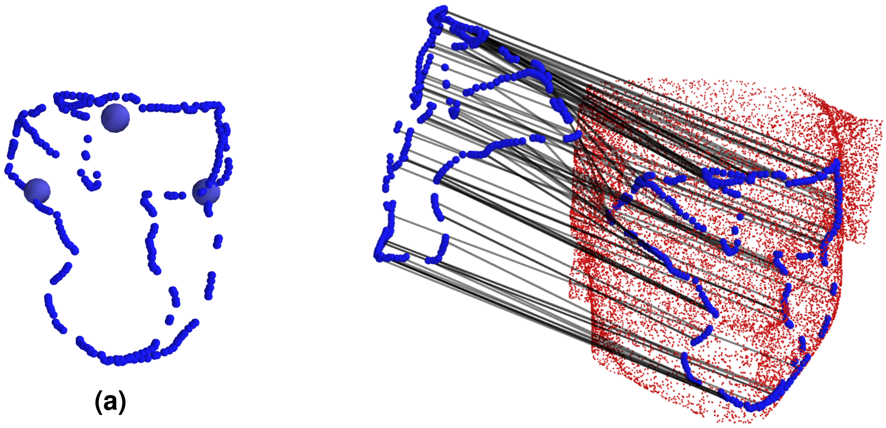
4. Results

We evaluated our process using a phantom model from with 13 fiducial marks. The dataset used in this work can be used for cloud-point registration evaluation[1].

We captured 3 samples of real points as shown in Figure 4a. To measure the impact of the hollow surface segmentation we compare the registration with a virtual set of points from the hollow to the surfaces created by simple thresholding the image. The threshold is the same value used to print the phantom model and therefore optimal. The time and error presented in Table 1 are the mean of the test with the 3 samples.

The results shows that with the additional step of removing invalid virtual points

[1]Data will be available at *http://artis.com.br/publications/*



(a)

(b)

Figure 4. Alignment Refinement step: Figure (a) shows an example of points acquired by sliding the probe over phantom model surface. Figure (b) shows the matching positions of the later points given by the resulting registration.

Table 1. Results of registration

	Number of points	Time	Eerror
Manual threshold	477,969	2.8s	0.49 mm
Hollow surface	152,188	0.8s	0.43 mm

the time consumption and accuracy of registration process are improved. Further investigations include testing non-rigid body registration methods and compare the results with other method for removing non-relevant points of virtual image.

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