AUTOMATIC COARSE REGISTRATION OF 3D SURFACE DATA IN ORAL AND MAXILLOFACIAL SURGERY

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Our aim is to support the surgeon during the adjustment of a displaced eye ball after a fracture of the zygomatic bone. Therefore, the facial surface is repeatedly measured intraoperatively by an optical range sensor. These data have to be registered with preoperatively modeled target data in order to perform a reproducible nominal/actual data comparison based on well defined criteria. Since the spatial orientation and position of the sensor relatively to the patient's face can not be presumed, the registration process via the ICP-Algorithm requires a prior coarse registration. This paper presents a problem-oriented method for the fast automatic coarse registration of facial surfaces. The method exploits some characteristics of the Gaussian image that are invariant against the facial form changes caused by the surgical operation.

1. Introduction

The zygomatic fracture associated with a dislocation of the eye ball is one of the most frequent traumata to the facial skeleton. The success of adjusting the correct globe position depends on the experience of the surgeon. In the last two years we have developed a system based on an optical range sensor that supports the surgeon during the operation by comparing intraoperatively gained actual 3D data with preoperatively computed 3D nominal data of the face (as triangle meshes) and the eye globe position. During the operation the surgeon can easily acquire actual 3D data at any times with low time cost and without any radiation exposure. In order to give practical feedback to the surgeon some clinical characteristics are calculated indicating the relative globe position [1,2].

The data have to be rigidly registered for comparison. The registration process is done in two steps: Coarse registration and fine registration. The fine registration is done by default via the Iterative-Closest-Point-Algorithm (ICP) [3] whereas the necessary coarse registration is often accomplished by user interaction [4]. Despite of several approaches the reliable real time automation of geometry based coarse registration still remains a challenge. Moreover we need an algorithm that deals with data that are subject to form changes by the operation.

2. State of the art

One can find several methods for the geometry based coarse registration of three-dimensional free-form surfaces in the literature. The majority of the approaches are feature based and favor the calculation of local differential geometric [5] or statistical point features [6]. As a global method [7] might be mentioned, that is based on a Hough-Table.

As a general rule these algorithms hold a high degree of universality and are time-consuming in implementation and runtime.

Our approach is based on the *Gaussian image* of an object (see *methods*). The application of Gaussian images can primarily be found in the field of object or form recognition, for example [8]. It is often used in an extended and more complex form, for example for symmetry detection [9]. The application for matching has been limited so far to static objects (surfaces constant in time) that are closed or convex like in [10]. The application for the registration of three-dimensional facial surface data (non-convex and non-closed data) has been introduced for the first time by [11]. The paper in hand describes an improvement of this algorithm.

3. Methods

The hardware of the system is built up by an optical range sensor according to [12] that performs fast, highly accurate and non contact 3D surface data acquisition (Fig. 1). One measurement needs 640 ms and has an uncertainty of 200 µm. Two cameras are used simultaneously in order to gain a wider field of view.

The sensor is connected to a commercial PC and controlled by the software 3D-Cam®. The sensor calibration is accomplished according to [13]. Sensor hard- and software is produced by 3d-shape[*].

The measurements generate raster range data that are converted to triangle meshes after some data preprocessing. The data are smoothed by the normals

[*] http://www.3d-shape.com

filter according to [14]. The preprocessed data sets of faces consist of 20,000 to 30,000 vertices.

Figure 1. *Left*: Optical 3D-Sensor (phasemeasuring triangulation) built up by a light-source with a projector (active illumination) and two cameras bedded on an adjustable and moveable tripod. *Right*: A sinusoidal stripe pattern is projected onto the patient's face and measured by the cameras.

The nominal 3D data of the patient's face and eye position are computed preoperatively from the first data acquisition [15]. Fine registration is performed by an optimized ICP variant according to the fundamental results of [16]. The preceding coarse registration is automated by our approach that adopts the Gaussian image of a face. The Gaussian image of an object is built up by its surface normals that are anyway calculated for the visualization of the 3D data. A Gaussian image looks like a dotted unit sphere surface. A short repeat of the method in [11] is given below:

The algorithm discretises the Gaussian image by an overlaying cubic lattice. Only those cells of the cubic 3D lattice that intersect the sphere surface and contain normals are used for all further calculations (Fig. 2a).

A single feature – the so called cell density – is calculated for each cell by counting the enclosed normals and normalizing this number by the area of intersection. The area of intersection is fastly approximated by the inscribed triangle planes that result from the intersection points between the sphere surface and the cell borders as outlined in Figure 2b.

The idea is to search for a compact region in the Gaussian image where a lot of normals are close together. Every normal is assigned to a single vertex of the 3D surface data. Because of the human face being roughly convex, such a dense region should nearly represent a contiguous shallow region in the face like a cheek for example. Searching the densest cell indeed leads to a corresponding subset of vertices of the facial data that basically represents a part of the patient's cheek (Fig. 3).

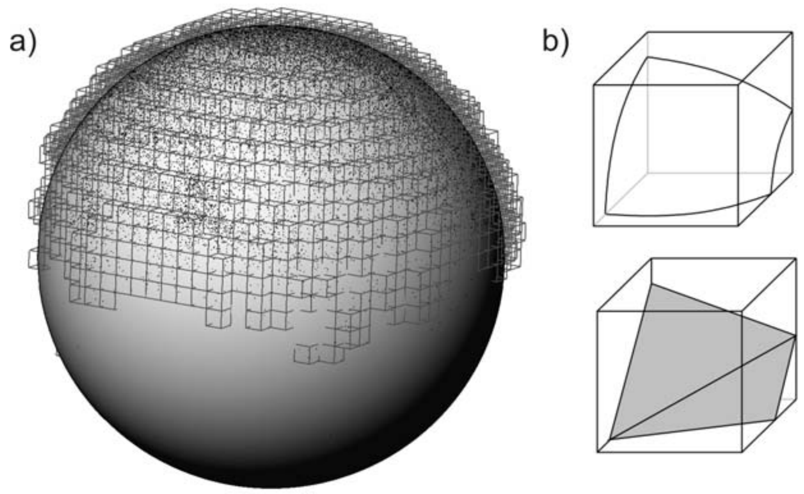

Figure 2. a) Gaussian image discretised by a cubic lattice. Discretising scheme here is 30^3 cells. b) Principle of the fast approximation of the area of intersection between a sphere surface and a cubus.

This region remains unaffected by surgery in cases of a zygomatic fracture. The subsets from different data but from the same person have similar patchy shapes. These shapes are suited for registration by principal axes transformation.

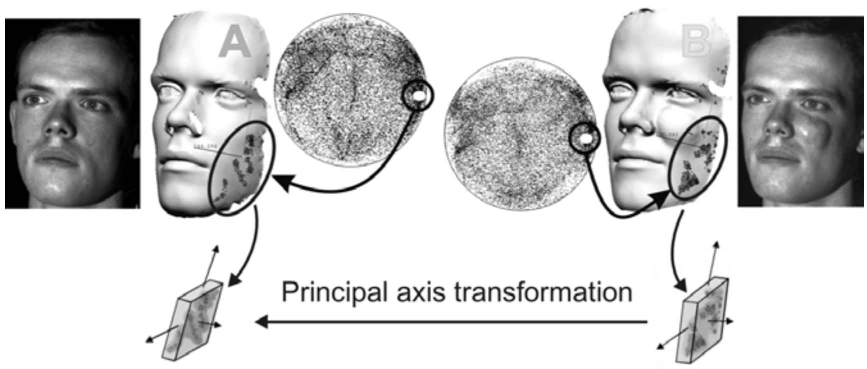

Figure 3. Video images, Gaussian images with the simple densest cell feature of [11] and the 3D surface data with marked corresponding subsets of vertices. The principal axes of the subsets are denoted underneath. The sphere discretization scheme was 15^3 cells. *Left*: Healthy person. *Right*: The same person with 6 ml saline solution injected into the malar region.

The algorithm has been tested by applying it to model cases created by a number of healthy persons: In order to simulate form changes in the face we injected 6 ml saline solution in the malar region and registered the 3D data without and with injection.

It has to be pointed out, that the principal axis transformation of the whole data is out of the question. Though always containing the region of interest, the data generally do not show the same display detail of the face because of changing camera positions during the operation (the system is designed to be flexible). Moreover principal axis transformation of the whole data set, including parts that are changing their forms, is not suited for registration.

Although sufficient in many cases, there is much room for improvement: In this paper we achieve a higher robustness of the algorithm by modifying the feature search strategy: First, the cubic cell size has been chosen lower to make the discretization finer. We changed the scheme from 20^3 to 30^3 lattice cells. Secondly, the search for the densest cell has been extended from single cells (Fig. 3) to the combination of one cell and its neighboring cells on the unit sphere (Fig. 4).

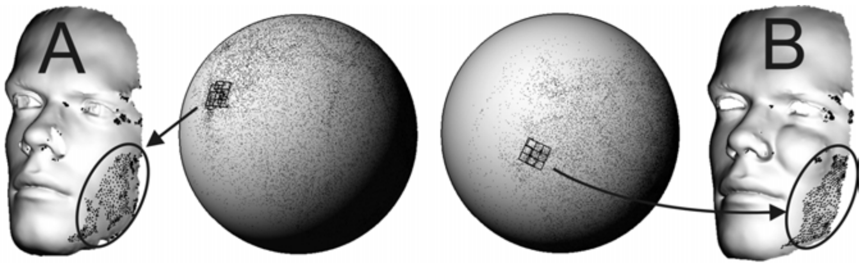

Figure 4. The same measurements as in Figure 3, but the densest cell feature is now given by the extended definition of cell and neighbor cells. The discretization scheme is now 30^3 cells. Obviously the shapes of the subsets are very similar.

On the one hand this procedure increases the time cost. On the other hand it allows a more uniform feature sampling and thus the patchy shapes are more similar.

4. Results and Discussion

The results showed both that the computing time is still in the range of our requirements. Finding the densest region in a Gaussian image by the above described method needs less than two seconds on a 1,3 MHz machine (512 MB RAM). The similarity of the subset shapes is generally higher than before, where only the single discretisation cells were considered. This improvement leads to better coarse registration results. Better coarse registration means faster convergence of the subsequent optimisation by the ICP-Algorithm.

As a consequence of the more uniform sphere sampling the densest region in the Gaussian image and the shape of the corresponding subset of vertices is more robust against arbitrary rotation.

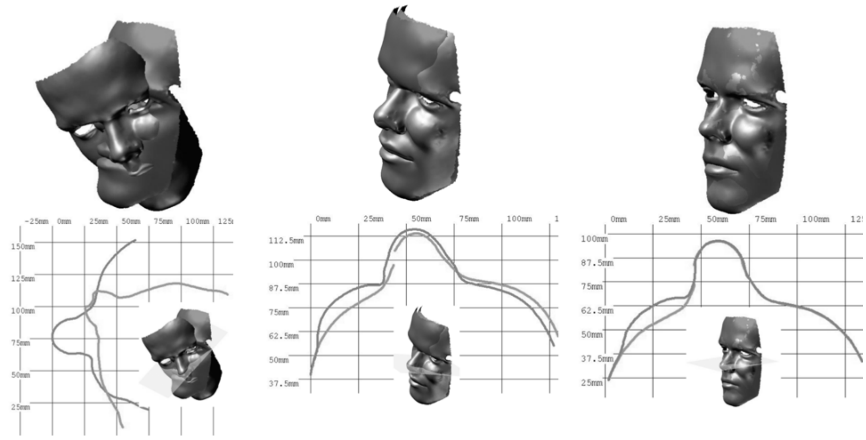

Figure 5. 3D data and cutting profiles of the test person in Fig. 4. *Left*: Unregistered data. *Middle*: after automatic coarse registration. *Right*: After fine registration (ICP).

5. Conclusion and Future Work

This paper is a contribution to the field of 3D image registration. The described approach deals with free form surfaces (not volume data) that are partially changing in time. In this context it might be called a 4D registration. The offered solution is problem-oriented because of it's limitation to oral and maxillofacial surgery. It works in real time and is hence suited for the intraoperative use. The methodical advantage of our approach compared to existing ones are the limitation of the search space to two dimension (surface of the unit-sphere) and the simplicity of the feature definition (one-dimensional feature space).

Future work will cover the coarse registration problem in the context of further applications of the system in oral and maxillofacial surgery, for example in cases of jaw-bone relocation.

Acknowledgements

This research project is funded by the DFG (Deutsche Forschungsgemeinschaft) within the subproject C4 in the framework of the SFB603: http://sfb-603.uni-erlangen.de/HTML/sfb603_g.html

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