2010 IEEE International Conference on Robotics and Automation
Anchorage Convention District
May 3-8, 2010, Anchorage, Alaska, USA

An automatic and complete self-calibration method for robotic guided laser ablation

H. Mönnich[1], Daniel Stein[1], J. Raczkowsky[1] and H. Wörn[1]

[1] IPR Karlsruhe, University of Karlsruhe, Karlsruhe, Germany

***Abstract*— This paper describes the content of the video for ICRA 2010. The approach presented in the video is a complete automatic registration of all needed devices for robotic guided CO2 bone processing. The system consists of an optical tracking system, a lightweight robot and a scan head. While a standard point to point transformation for the transformation between optical tracking system and robot is inadequate, a special registration algorithm was developed and therefore is used. This allows an automatic registration by moving the robot to different positions and storing the position of a body attached to the robot TCP. The scan head is registered to the optical tracking system or to the robot using a camera that tracks the prototype laser. Only the patient must be registered manually. The result is that the robot moves to the target position on the bone defined inside the segmented 3D CT dataset. With the known registration between robot and tracking system the robot can also be controlled via visual servoing.**

Keywords— **Surgical robotics, self calibration, scan head, laser osteotomy**

I. INTRODUCTION

The AccuRobAs project proceeds with the current state of the art by combining a laser system with a robot and additional sensors. In the experimental setup developed inside the AccuRobAs project a demonstrator for laser ablation on bone using a lightweight robot is developed. Therefore an automatic calibration method was developed for all relevant parts for robotic laser osteotomy [1].

II. MATERIAL & METHODS

This chapter describes the current experimental system for robotic surgery at the IPR. The main part of the system is the KUKA LWR robot. The repeatability of the robot is up to 50µm. This value was proved with an FARO measurement arm. While this value is quite good the absolute accuracy is lower, up to 1mm. This value is even influenced by the fact that the LWR robot cannot measure the forces in all joints in all directions, e.g. bending cannot be measured. For this reason a body consisting of marker spheres is attached to the end-effector of the robot to measure the actual position. The end-effector consists of a colour camera, a scanhead, a flange for the laser mirror arm, a laser distance sensor and the already mentioned body. The scanhead can ablate the laser light into a plane. The size of the plane is mainly limited by the used optics. In this case 15cm x15cm square is reachable with our scanhead. The scanhead itself is controlled by a RAYLASE PCI controller card that allows real-time access to the scanhead to control the position in every update cycle of the scanhead.

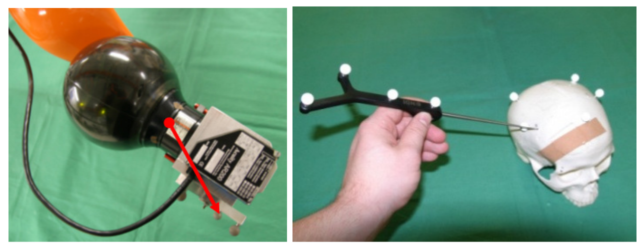

Figure 1: Translation vector $\vec{t}_c$, which defines the transition between the origin of the end effector to the origin of the rigid body and bone with marker spheres, titanium screws and pointer

The bone that should be processed is in our experimental system a skull, which is tracked with the navigation system. The position of the robot is defined inside a visualisation, where the robot pose is defined with respect to a model of the skull. The model is based on 3D segmented CT data.
A marker based standard registration method is used for the registration of the patient. Marker spheres are attached to the skull to track it. Additional titanium screws are drilled into the skull and a CT scan is performed, see figure 1. The titanium screws can be identified inside the segmented CT data. To localise the screws in the bone a standard pointer device is used that is tracked by the same tracking system. To acquire the position of the marker the points acquired by the tracking system have to be fitted to a sphere. The following method describes the estimation of the points via using a tracked pointing device. The tip pointer device is put to the screw and moved. The tracked position of this pointer is fitted to sphere and the middle point of this sphere is the position of the screw. Each titanium screw is localised using the pointer. The resulting point cloud is then registered to the point cloud from the CT data set to acquire the transformation between the two coordinate systems, see figure 4. The method used for the registration between the two point clouds, one from the CT Data and one from the tracking system, is the method of Horn et al [3].
To be able to use the robot together with the tracking device the robot must be registered to it. Marker spheres added to the

robotic tool allow recording the position of the robot in the robot coordinate system and the coordinates from the body at the tool in coordinates from the tracking device. A modified Gauss-Newton algorithm is then used to calculate the transformation matrix between the robot and the tracking system [2]. This method estimates the transformation matrix between the two coordinate systems.

The scanhead is registered to the robot using a hand-eye method. The principal scheme is the following: The scanhead projects the laser beam to different points on the calibration pattern. The structure of the chessboard is known (edge length of 10 mm). In the first step the laser spot on the chessboard must be transformed from the camera coordinate system into the chessboard coordinate system. This is solved with the homography matrix. A canny filter is used to generate a black & white image with the contours of the image. The contours are identified and every identified contour is fitted to an ellipse. This ellipse with the best quality is selected. The position of the chessboard on the calibration pattern was determined previously. With this the points from the chessboard coordinate system can be transformed to the local coordinate system of the calibration pattern. The calibration pattern and the scanhead are tracked with marker spheres, at least 4 that form a body, with the optical tracking system. Hence the data can be transformed from the local coordinate system of the calibration sheet to the OTS coordinate system and then to the scanhead coordinate system. The points acquired at different distances to the chessboard compose lines and all lines should meet in a single point. This point is the "optical centre" for the scan head and is needed to calculate the vector between body and optical centre or the robotic TCP and the optical centre.

Due the noise and inaccuracy in the measurement procedure the points must be fitted to lines and then the point is searched with the minimal distance to all lines, see figure 2.

After the complete registration process the position of the bone structure can be translated into the coordinate system from the robot and into the local coordinate system of the visualization. Hence it is possible to assign a point relative to the segmented CT data and to move the robot to this point and thus it is possible to calculate the position of the robot inside the segmented CT data, see figure 3.

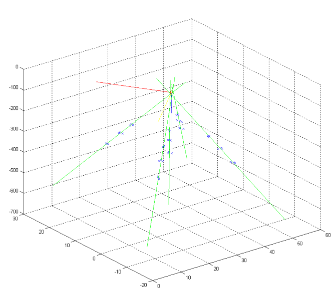

Figure 2: Combination of the 3 different registration results and the table with the registered result

V. Conclusion

The video shows a working demonstrator that can automatically register all relevant components automatically. This allows even a user to build up the system fast and the system can supervise its current error and if necessary re-register the components automatically. This is very important for the medical staff, because they should concentrate on the medical intervention and not be disturbed by technical issues.

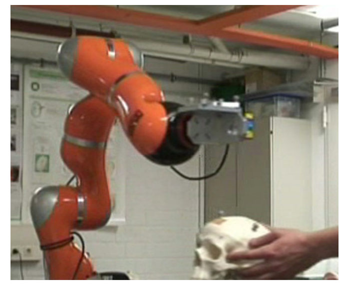

Figure 3: To precisely position a robot end effector of the robot to a tracked bone the transformation between the coordinate systems has to be determined correctly

VI. Future work

In some part the registration error could be improved. This involves the optical tracking system. The data from the system could be improved by filter techniques. Another disadvantage is the registration method for the patient using the pointer device. Firstly this is manual at the moment and could be replaced by laser scans for specific bones to perform surface matching.

Acknowledgment

This work has been funded by the European Commission's Sixth Framework Programme within the project Accurate Robot Assistant - ACCUROBAS under grant no. 045201. (http://www.accurobas.org/)

References

[1] Holger Mönnich, Daniel Stein, Jörg Raczkowsky, Heinz Wörn, SYSTEM FOR LASER OSTEOTOMY IN SURGERY WITH THE KUKA LIGHTWEIGHT ROBOT – FIRST EXPERIMENTAL RESULTS, IADIS eHealth 2009

[2] Daniel Stein, Holger Mönnich, Jörg Raczkowsky, Heinz Wörn, Automatic and hand guided self-registration between a robot and an optical tracking system, ICAR 2009

[3] B. K. P. Horn, "Closed-form solution of absolute orientation using unit quaternions",JOSA A, vol. 4, pp. 629–642, 1987

Authors: Holger Mönnich,
Daniel Stein
Institute: IPR - Institute for Process Control and Robotics
Street: Engler Bunte Ring 8
City: Karlsruhe
Country: Germany
Email: moennich@ira.uka.de,
dstein@ira.uka.de