Intraoperative visualization of surgical planning data using video projectors

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Abstract. The Institute for Process Control and Robotics has developed a new system using projector based augmented reality for the intraoperative visualization of preoperatively defined surgical planning data. Projector based augmented reality in medical applications represents a new field of research and gives an alternative solution to the commonly used Head Mounted Display technology. Moreover, the projector is not only used for visualization, but also for registration of the patient and the presented system renounces attaching invasive landmarks (screw markers, rigid bodies) or fixations to the patient. Recent results showed an achieved accuracy of ± 1.5 mm which roughly meets clinical demands.

1. Introduction

In recent years different methods for the intraoperative visualization of preoperatively defined surgical planning data have become a field of considerable interest [1]. Normally, preprocessed diagnostic image data from CT or MRI serve as basis for the planning task. The intraoperative appropriation of surgical planning data mostly traces back to one of the following methods:

- The surgeon manually transfers the planning data to the area of interest by surveying the monitor screen and memorizing unequivocal anatomical landmarks.
- The surgeon is guided and supported by a navigation system overlaying the current pointer position with corresponding data on the computer screen.
- A robot performs parts of the surgical intervention.

The latter two methods require the use of artificial markers which are fixed to the patient's bones before acquiring the diagnostic image data and remain there for intra-operative registration of the patient's position. Furthermore, the surgeon is constrained to persistently reorient his view from the patient to the monitor and vice versa, which influences the surgeon's general practice.

Great efforts are being made to directly visualize the surgical planning data in the operation area. Most commonly used devices are Head Mounted Displays (HMDs) which superimpose virtual objects to the real environment. But in consideration of precision, resolution, vision frequency, and sterility HMDs still show great disadvantages and often

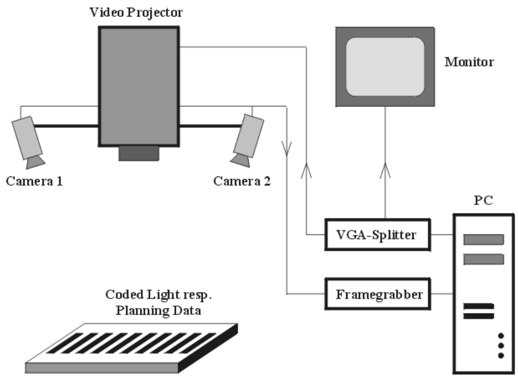

Fig. 1 Schematic system configuration

lead to queasiness of the porter. However, directly visualizing the results of a preparatory surgical planning in the area of interest entails significant advantages.

The Institute for Process Control and Robotics (IPR) has developed a new system which allows to directly visualize the surgical planning data on the patient's surfaces (skin, bone, tissue) by using a common video projector [2]. The latter is both used for visualization and registration of the patient which will be explained in the subsequent section.

2. System description

The presented system (see Fig. 1) consists of a common video projector, two CCD-cameras and a state-of-the-art PC (800 MHz CPU, 256 MByte RAM) and assumes the availability of an appropriate operation planning system to define trajectories, boreholes, osteotomy lines or other relevant symbols. It is assumed that regions of interest are preoperatively generated by analyzing and segmenting appropriate images from CT or MRI. In addition to defining the actual surgical plan it is necessary to generate a so-called distance tomogram, which stores the shortest distances of all voxels to the surface (skin) of the area of interest by assigning the corresponding value to the voxels (appropriate tools were developed at the IPR). The distance tomogram intraoperatively serves to registrate the patient which will be explained further below.

The essential part of the developed system is formed by a 3D surface scanner which is used to intraoperatively generate a 3D point cloud of the patient's surface. This is accomplished by projecting a sequence of stripe patterns (coded light) on top of the region of interest with the aid of the integrated video projector. The corresponding images are acquired by the cameras, analyzed in consideration of emerging Moiré-patterns and yield a 3D point cloud of the scanned area [3]. After removing inevitable outliers, the resulting point cloud can be matched to the preoperatively segmented surface of the diagnostic image data (CT, MRI) where the surgical plan has been defined on.

At this stage, most known matching algorithms require user interaction in order to find an adequate starting position for the matching process. Since matching algorithms commonly work by optimizing an appropriate failure function, this step ensures that the global (and not only the nearest local) optimum is found. In order to realize a system that needs no helping hands from outside, we developed a new matching algorithm which imitates the human strategy for the matching process of two corresponding surfaces. The global optimum of the failure function which is computed with the aid of the described distance tomogram is found by reducing the dimensionality of the search space from commonly six parameters (rotation and translation) to three. Only those transformations are considered which move around the point cloud on top of the CT or MRI surface. After an adequate starting position is found, the fine tuning is realized by using an arbitrary matching algorithm (e. g. [4], [5]).

The matching process provides an initial transformation T_{ini} from the coordinate system of the diagnostic image data to the initial position of the patient. Since intraoperative conditions impede continuos scanning and in order to avoid attaching rigid fixations to the patient, succeeding registrations are performed by tracking markers pasted to the area of interest. These are tracked and registrated by analyzing corresponding images from the integrated cameras using Hough-transformations [6]. This step yields a second transformation $T_{cur}(t)$ mapping the patient's initial to his current position.

The global transformation $T_{global}(t) = T_{cur}(t)T_{ini}$ now allows to continuously transfer the surgical planning data to the patient's coordinate system resp. his position. The corresponding two-dimensional projector-bitmap which is projected onto the three-dimensional patient's surface is edited in order to avoid or minimize distortion in areas of steep and bended surfaces. Maintaining lengths and angles, however, requires a triangulated surface (Delaunay-Triangulation) in order to yield predications about normal vectors or other features.

3. Results and discussion

The described method enables the surgeon to visualize planning data on top of any preoperatively segmented and triangulated surface (skin, bone, etc.) uncovered during the operation. Furthermore, the tracking system allows dynamic adjustment of the data to the patient's current position and therefore renounces rigid fixation with stereotactic frames or similar devices. Particularly with regard to the fact that both the video projector (registration and visualization) and the cameras (registration and tracking) are multiply used, the system shows its attractiveness. While systems using HMDs generally require expensive navigation systems, the cost of the presented system are much lower than those of a corresponding system based on HMDs. Furthermore, it is currently superior to any HMD with regard to accuracy and resolution. Assuming the area of interest to be 200 x 250 mm, the planning data can be visualized using a resolution of 0.33 mm or less (SVGA or higher). Thereby, the currently achieved accuracy of the projected surgical planning data is about 1.5 mm (which nearly meets clinical demands) and will be further improved.

Moreover, neither the surgeon is obliged to wear encumbering devices on his head, nor the patient is affected by unpleasant screw markers or similar devices additionally burdening.

References

[1] S. Tang, C. Kwoh, M. Teo, N. W. Sing, and K. Ling, "Augmented Reality Systems for Medical Applications", IEEE Engineering in Medicine and Biology (May/June 1998), pp. 49-58, 1998.

[2] C. Loullingen, "Lagebestimmung mit Hilfe eines 3D-Oberflächenscanners", Diploma Thesis IPR, University of Karlsruhe, 1998.

[3] H. Gärtner, "Quantitative 3D-Vermessung mit codierter Beleuchtung", Institut für Technische Optik, Universität Stuttgart, 1998.

[4] K. S. Arun, T. S. Huang, and S. D. Blostein, "Least-Squares Fitting of Two 3-D Point Sets", IEEE Transactions on PAMI, vol. 9, no. 5, pp. 698-700, 1987.

[5] J. M. Fitzpatrick, J. B. West, and C. R. Maurer, "Predicting Error in Rigid-Body Point.-Based Registration", IEEE Transactions On MI, vol. 17, no. 5, pp. 694-702, 1998.

[6] C. F. Olson, "Constrained Hough Transforms for Curve Detection", Computer Vision and Image Understanding, vol. 73, no. 3, pp. 329-345, 1999.