Potential, Limitations and Challenges of Markerless Registration with the DLR 3D-Modeller in Medical Applications

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Purpose

Registration is necessary whenever planning data (e.g. biopsy needle trajectories or bone cutting planes for knee surgery based on preoperative images) have to be transferred into the operation room (OR). A successful registration is crucial for the quality of the medical procedure in image guided surgery. Often standard approaches in clinical use are based either on artificial landmarks (e.g. a dental splint with markers or implanted markers[1]) or anatomical landmarks, e.g. the manubrium. These landmarks are segmented in the preoperative image data and localized in the OR with e.g. optically tracked pointing devices. Corresponding intra- and preoperative landmark positions are then determined, and the (rigid) transformation matrix is calculated using simple least square fitting algorithms.
This work analyses a markerless and contact free registration using the advanced DLR 3D-Modeller (3DMo) [1] as shown in Fig. 1. The 3D-Modeller allows for acquiring the patient surface intraoperatively using three different methods: a stereo camera system (SCS), a laser-range scan (LRS), and a light-stripe profiler (LSP).

[1] Referred to as the gold standard method in this work, see Fig. 2 right.

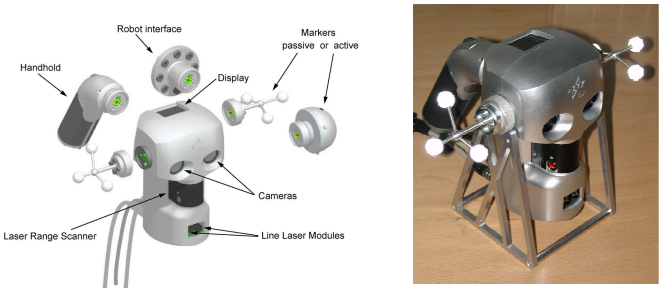


Figure 1: The DLR 3D-Modeller.

Methods & Results

Each scan of the plaster cast model takes only few seconds (ranging from 10 s to 20 s for LSP and 15 s to 30 s for LRS). Using the software *Visu3D* developed at DLR [2], online surface reconstruction is possible and allows for visualisation during the scanning procedure. For registration, an iterative closest point algorithm integrated in Visu3D is used. It takes 20 s to 2 min, depending if manual adjustment of the initial pose is necessary or not. With the used plaster cast models, none of the registrations completely failed (with complete failure defined as errors above 1 cm). Table 1 shows the mean deviations and worst values for all artificial landmarks, obtained during 10 different scans for each table row. Overall three different plaster cast models were considered. Mean deviations between gold standard and surface based methods are in the range of 1.6 mm to 2.2 mm.

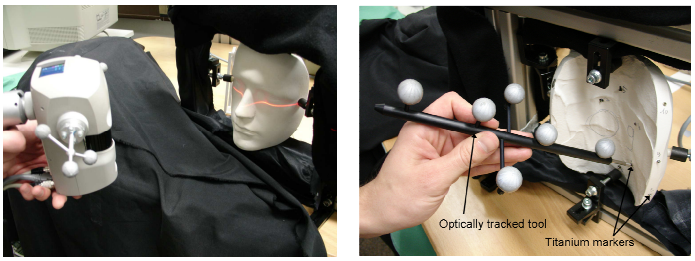


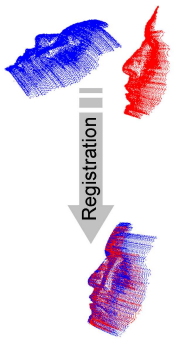
Figure 2: Surface based method (left) and gold standard method (right).

Conclusion

This work analyses two basic methods for surface based registration as implemented in the handheld DLR 3D-Modeller, namely the laser-range scan method and the light-stripe profiler method. Both methods show comparable results in worst-case accuracy of better than 3 mm. The main source of inaccuracy stems from the optical tracking system and in particular from its errors in measuring the correct orientation of the 3D-Modeller. Improvement of the tracking system accuracy is therefore a pressing demand.
The penetration depth of the laser light into the patient skin and soft tissue displacements require further investigations. Furthermore, especially the LSP needs verification for operational robustness in OR environments.
To conclude, the evaluation of the presented registration procedure shows a sufficiently good accuracy to be applied in a variety of medical applications, ranging from port placement in minimally invasive surgery to image guided bone segment navigation, and foreign body removal.
A future step will be to evaluate the accuracy of the presented approach using real data from test subjects.

Table 1: Accuracy in translation x (mean x_{mean} and worst x_{max}) of the surface based registration with respect to the gold standard method.

	Mask	x_{mean} [mm]	x_{max} [mm]
LRS	1	1.9	2.8
	1, with glasses	2.2	3.0
	1, scan time < 10 s	2.1	2.9
	2	1.6	2.7
	3	1.7	2.2
LSP	1	2.1	2.9
	1, with glasses	2.3	3.0
	1, scan time < 10 s	2.0	2.5
	2	2.2	2.8
	3	1.8	2.7



References

[1] M. Suppa, S. Kielhöfer, J. Langwald, F. Hacker, K. H. Strobl, and G. Hirzinger. The 3D-Modeller: A Multi-Purpose Vision Platform. In *Proceedings of ICRA*, Rome, Italy, pages 781 – 787, 2007.
[2] T. Bodenmüller and G. Hirzinger. Online Surface Reconstruction from Unorganized 3D-Points for the DLR Hand-Guided Scanner System. In *2nd Symposium on 3D Data Processing, Visualization and Transmission,*, Thessaloniki, Greece, pages 285 – 292, 2006.

Acknowledgement

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