Creating a Digital Twin of Spinal Surgery: A Proof of Concept

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Video

1 Introduction

Surgical Digital Twins (SDTs)

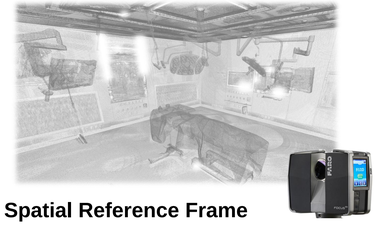
- SDTs are high-fidelity representations of relevant entities and their interactions during the surgery, e.g. patient, surgical instruments devices, staff.
- SDTs have significant potential for a wide range of applications: education and training, surgical planning, automation, training surgical robots in simulation, synthetic data generation
- Their creation requires the fusion of available information from sensors and prior knowledge into a common spatio-temporal representation.

Criteria for SDTs

1) **Faithful**: enables precise 3D measurements and highly immersive training and education for surgery
2) **Explicit**: provides interpretability and compatibility with standard rendering engines
3) **Modular**: enables object-level reasoning and manipulation, customization
4) **Complete**: provides broad context and applicability to various downstream tasks

Based on these criteria, we develop an approach to surgery digitization which digitizes relevant entities independently as a collection of textured 3D meshes.

2 Methods



Spatial Reference Frame

A fusion of 8 high-resolution point clouds obtained from a laser scanner serves as a spatial reference.

Modelling the Operating Room

The operating room is modelled by a graphics designer based on the fused laser scans and detailed photographs.

The Surgical Digital Twin

Reconstructing the Anatomy and Operating Tables

The operating tables and anatomy surface is reconstructed using photogrammetry.

Tracking Surgical Instruments

A marker-based tracking system captures all instrument trajectories.

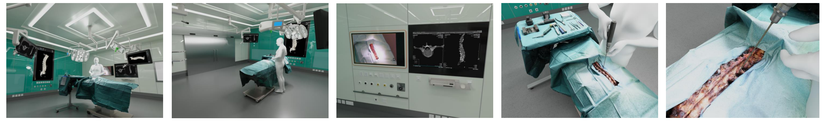
Tracking Medical Staff

Five RGB-D cameras capture motion and dynamics. We fit a SMPL-H model to the multi-view RGB input.

3 Results

We demonstrate our approach by digitizing the pedicle drilling step done within spinal surgery.

Qualitative Results



Quantitative Results

- Point-to-point registration of the laser scans

Laser Scan	1	2	3	4	5	6	7	Mean
# Markers	12	13	13	14	12	13	12	12.7
RMSE (mm)	7.81	6.42	6.72	5.79	6.95	8.16	6.03	6.84
CD (mm)	4.47	5.02	4.90	4.08	2.90	3.50	3.81	4.10

- Reprojection errors of the RGB-D cameras after spatio-temporal calibration

Camera	1	2	3	4	5	Mean
Mean error (px)	0.75	0.40	1.06	1.63	0.39	1.19
Std of errors (px)	0.36	0.29	0.89	1.12	0.38	0.92

4 Outlook

Our proof-of-concept is a step towards the **systematic capture of surgeries**. It can already be used to capture and re-render surgical steps or simple interventions, e.g. for educational purposes.

- Further sensors (e.g. medical imaging, patient vitals, microphones) should be integrated
- Sensor streams should be fused jointly to enforce consistency in the shared spatio-temporal representation
- Dynamics and deformations should be taken into account when reconstructing the anatomy
- Multiple manual registration steps still need to be automated