Operating room quality assurance for spine surgery using known-component 3D-2D image registration

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Collaborators

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Pedicle screw placement

Clinical motivation
- 488K cases/year in US (Weiss et al. 2011)
- >30% malplacements (Gezbein and Robbins 1990)
- 1–2% undergo revision surgery (Gautschi et al. 2011)
- 18% revision using intra-op CT (Sembrano et al. 2012)

Intra-op guidance – radiography
- Limited to 2D
- Subject to qualitative interpretation

Post-op QA – CT, MRI
- Added cost and morbidity

Experiments

Phantom & Clinical

Phantom

Clinical

AP ~OBL LAT

Spine phantom (Sawbones, Seattle)

Cios Alpha (Siemens, Germany)
3D-2D registration
Patient pose determination

\[ \hat{T}_p^o = \arg \max_{\theta} \sum_{\theta} \text{GO} \left( R_\theta, \int_{\theta} P(\theta_H) d\theta \right), \quad \tilde{H} = H_0^o T \]


**3D-2D registration**

Patient pose determination

\[ T_P^o = \arg\max_T \sum_{\theta} \text{GO} \left( R_\theta, \int_{\mathcal{P}} (\bar{\mathcal{P}}_R) \, d\mathcal{P} \right), \quad \bar{H} = H_0^{T} T \]

- **Radiographs**
- **Patient CT**
- **Projection**
- **Metric**: GO
- **Optimizer**: \( \arg\max_{T} \text{GO} \)
- **GPU parallelization**
- **CMA-ES**
- **DDR**

**KC-Reg**

Known-components

\[ \hat{T}_C^o = \arg\max_T \sum_{\theta} \text{GC} \left( R_\theta, \int_{\mathcal{C}} (\bar{\mathcal{C}}_R) \, d\mathcal{C} \right), \quad \bar{H} = H_0^{T} \hat{T}_P^o T \]

- **Radiographs**
- **Patient CT**
- **Projection**
- **Metric**: GO, GC
- **Optimizer**: \( \arg\max_{T} \text{GO} \), \( \arg\max_{T} \text{GC} \)
- **Component**
- **3D component model**


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**KC-Reg**

\[ T_\ell^p = \arg \max_T \sum_\theta GC \left( R_\theta, \int C (\vec{f}_H) \, d\vec{r} \right), \quad \vec{H} = H_\theta T_\ell^0 T \]

This is an optical tracker!

- **C-arm** ≈ Tracker
- **Components** ≈ Tracked rigid-body markers
- **Patient** ≈ Reference marker

No "dedicated" equipment
No manual fiducial registration
No rigid-body markers
No line-of-sight requirement

**pKC-Reg**

**Parametric components**

\[ \hat{T}_C^p = \arg \max_T \sum_\theta GC \left( R_\theta, \int C (\vec{f}_H) \, d\vec{r} \right), \quad \vec{H} = H_\theta \hat{\hat{T}}_\ell^0 T \]


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\[ d\text{KC-Reg} \]
Deformable components

\[ \bar{u}_C = \arg \max_u \sum_{\theta} \text{GC} \left( R_\theta, \int_{\mathbb{R}^2} C(u, \tilde{r}_\mathbb{H}) \, \text{d}r \right), \quad \bar{H} = H_\theta T_P^0 \]

\[ \tilde{u}_C = \arg \max_u \sum_{\theta} \text{GC} \left( R_\theta, \int_{\mathbb{R}^2} C(u, \tilde{r}_\mathbb{H}) \, \text{d}r \right), \quad \tilde{H} = H_\theta \tilde{T}_P^0 \]
\[
\{\hat{T}_i^p\} = \arg\max_{\theta} \sum \text{GC} \left( R, \sum_i \int_{P} c_i (\vec{r}_H) d\vec{r} \right), \quad \vec{H} = H_{\theta} T_P^0 T_i
\]
Quality Assurance
Pedicle screw pose determination

Quality Assurance
Pedicle screw shape estimation

Goerres et al. (2016) Atlas-based pedicle trajectory prediction for automatic assessment and guidance of screw insertions. CARS. Heidelberg, Germany

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Quality Assurance
Initial clinical studies

Conclusion

Extend utility of mobile radiography to quantitative QA

Present:
- Patient pose determination from radiographs,
- Component pose and shape determination,
- Support for non-rigid components,
- Handling multiple components while respecting physical constraints.

Future:
Clinical studies with focus on workflow and safety
Application to broader procedures and diverse instruments
Integration with other navigational and robotic technologies