BA Final:
Pose-aware rendering of live ultrasound data for mixed medical AR
Structure

• Motivation
• Goal
• State-of-the-Art
• Setup
• Framework
• Results
Motivation

• Teaching
• Find past poses
• Possibly as HMD
• Exchangeable display
Goal

- Augmenting tracked live ultrasound data on a tracked Android device (Tablet, Smartphone, Google Cardboard)
- Live-Guidance to find past measures
First live ultrasound with AR

- live ultrasound data (1-2 fps) augmented on a HMD in 1992
- Polhemus EM Tracker

Bajura et al. 1992 "Merging virtual objects with the real world: Seeing ultrasound imagery within the patient"
SIGGRAPH 1992
AR-driven Needle Application

- Modified Sony Glasstron LDI-D100 HMD
- Image-guided technologies FlashPoint™ 5000 optoelectronic tracker

Mobile 3D

- Teaching system for the use of ultrasound device
- Mobile live AR on iOS and Android
- Marker based tracking (Vuforia)
- Deforming heart

Palmer, C. L. et al. 2015 "Mobile 3D augmented-reality system for ultrasound applications" IUS 2015
Setup

Setup

- Android device (Smartphone, Tablet)
  - with Api-level >=21 (5.0 / Lollipop)

  - Android 6.0 (API Level 23 / Marshmallow)
  - 5.2” Display
  - Resolution 1280*720 (HD)
  - 2 GB RAM
  - CMOS 13.0MP (aperture F1.9)
  - Video recording with Resolution 1280*720 @30fps
  - 1.2GHz Quadcore

Setup

- Android Device
- Ultrasound Probe (calibrated to NDI-Marker)
Setup

- Android Device
- Ultrasound Probe
- Switch/Hub for local network (OpenIGTLink)
- NDI Polaris Vicra
AR application for live ultrasound
Felix Scheidhammer
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Framework

OTS

~20 photos

hand-eye calibration

undistort

https://docs.opencv.org/2.4/modules/calib3d/ 05/09/17

http://campar.in.tum.de/.. 05/09/17
Hand-Eye Calibration

• if Y is unknown
Hand-Eye Calibration

- Capture n (~20) pictures and poses at the same time ("stations")
- OpenCV: calibrate [Zhang 2000]
  - intrinsic parameters
  - n extrinsic transforms $B_i$

Zhang "A flexible new technique for camera calibration" TPAMI 2000
Hand-Eye Calibration

- [Tsai Lenz 1989] linear least-squares solution to find
  - first rotation
  - then translation of X


http://campar.in.tum.de/Chair/HandEyeCalibration

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Hand-Eye Calibration

• For better results
  – large rotations between stations
  – Large angle between rotation axes
• → Take stations in this order for [Tsai Lenz 1989]:

Hand-Eye Calibration

- Capture \( n \) (~20) pictures and poses at the same time (“stations”)
- OpenCV: calibrate pictures [Zhang 2000]
  - intrinsic parameters
  - \( n \) extrinsic transforms \( ET \rightarrow n \) same \( HT \rightarrow \text{average} \)

Zhang "A flexible new technique for camera calibration" TPAMI 2000
Transformation Averaging

- The i-th transformation $\frac{E}{H}T_i$ consists of
  - rotation $\frac{E}{H}R_i$ and translation vector $E_{P_{\text{HORG}}_i}$

$$\frac{E}{H}T_i \cdot H_P = \frac{E}{H}R_i \cdot H_P + E_{P_{\text{HORG}}_i}$$

- Average of Rotation
- Average Translation
Transformation Averaging

- Average over all $n$ rotations:
  \[ S = \arg\min_{R \in SO(3)} \sum_{i=1}^{n} d\left( \frac{E}{H} R_i, R \right) \]

- Using Weiszfeld algorithm [Hartley 2011]:
  - Initiate $S^0$ with any L2-mean, repeat:

\[ \log(S^T R) \]
Transformation Averaging

\[ E_T^H \cdot H P = E_R^H \cdot H P + E_{P_{HORG}}^i \]

• Average of translation:
  - Describe translations relative to coordinate system E’:
    \[ E'_{P_{HORG}}^i = S \cdot E_R^H \cdot E_{P_{HORG}}^i \]
  - Average with arithmetic mean:
    \[ E'_{P_{HORG}} = \sum_{i} \frac{E'_{P_{HORG}}^i}{n} \]

• Average transformation
  \[ E_T^H = \begin{pmatrix} S & E'_{P_{HORG}}^i \ 0 & 0 & 0 & 1 \end{pmatrix} \]

https://en.wikipedia.org/wiki/Centroid 21/01/18
Rendering

- Distortion correction of received images from Camera
  - Known undistortion [BouguetMCT MATLAB calibration tool] + [Zhang2000]:
    \[ r_u = r_d \times \left(1 + k_1 r_d^2 + k_2 r_d^4 + k_3 r_d^6\right) \]
  - Undistort once (bilinearly interpolated)
  - positions as color → lookup table

Image: docs.opencv.org/..../camera_calibration_and_3d_reconstruction.html 05/09/17
Framework

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undistort

hand-eye calibration

http://campar.in.tum.de/Chair/HandEyeCalibration
05/09/17

docs.opencv.org/..../camera_calibration_and_3d_reconstruction.html

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Rendering

- Transform Ultrasound Image to Camera view
- perspective projection
Textual Guidance:
Relative translation
X-Y-Z fixed-angles-rotation
Results
Results

- delay of 1.15s on average

Bar chart showing misalignment error in mm and standard deviation in mm for:
- Tsai Lenz 1989: 23.39 mm (error), 14.62 mm (std. dev.)
- Rosenthal 2001: 2.48 mm (error)
- Palmer 2015: 6.5 mm (error), 23.1 mm (std. dev.)

Legend:
- misalignment error in mm
- standard deviation in mm
Results

• Empirical Evaluation:
  - Standard: ~8.58s
  - AR: ~9.56s
  - Guided: ~9.4s
  - Overall positive feedback (except delay, screen size)
  - Task too easy
Questions?