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Medical Technology | Science | Systems

Simultaneous localization and mapping for camera-based EEG electrode digitalization

Agenda

- Motivation
- Robotic Data Acquisition System Setup
- Problems and Solutions
- Results & Discussions
- Conclusion and Future Work

Motivation

- Electrode position is important during EEG process.
- Several RGBD camera based electrode detection methods exists [1][2].
  - Fixed head position.
  - Time consuming.
- A convolutional neural network (CNNs) based method has been proposed [3].
  - Accounts for head movement.
  - Fast detection.
- CNNs require a large amount of ground truth data (electrode position).
- A robotic data acquisition system is developed for this purpose.

Objectives

- Setup new Microsoft Kinect camera.
- Integrate the deveoped system to existing framework.
- Achieve the bench mark for hand-eye calibration.
  - Translational error < 3 mm
  - Rotational error < 1.5 degrees
- Data generation atleast for 3 caps.

Robotic Data Acquisition System Setup

Figure 1: Setup consists of Microsoft kinect, Atracsys fusionTrac 500, UR3 robot, EEG caps by eemagine Medical Imaging Solutions GmbH, Berlin, and Markers.

Camera calibration

Parameters	calibrated values
α_x	968.7
α_y	968.9
S	0.0
C_x	1026
C_y	774.0
K_1	0.075 88
K_2	0.042 85
P_1	−0.000 64
P_2	0.001 32
K_3	−0.257 94

Table 1: Microsoft Azure Kinect calibration result

Implementation

Camera calibration is implemented in OpenCV

Hand-eye calibration

- Chessboard pose estimation with new Kinect is integrated to existing hand-eye calibration framework
- Results,

Camera	Translation error (m)	Rotational error (deg)
Kinect	$0.001 \pm 1.40 \times 10^{-7}$	0.258 ± 0.000
fusionTrac	$0.001 \pm 2.8 \times 10^{-7}$	0.205 ± 0.000

Table 2: Hand-eye calibration results

Exceeded the benchmark

Translational error < 1.1 mm and rotational error < 0.3 degrees.

Head coordinate system

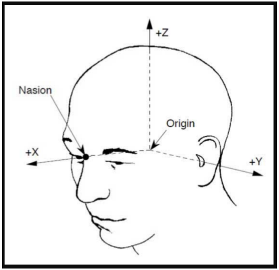

Figure 2: The BTi/4D coordinate system convention.

- The origin is between LPA & RPA
- The x axis goes through nasion.
- The y goes through LPA, orthogonal to x
- The z axis is orthogonal to both x & y

Head coordinate system

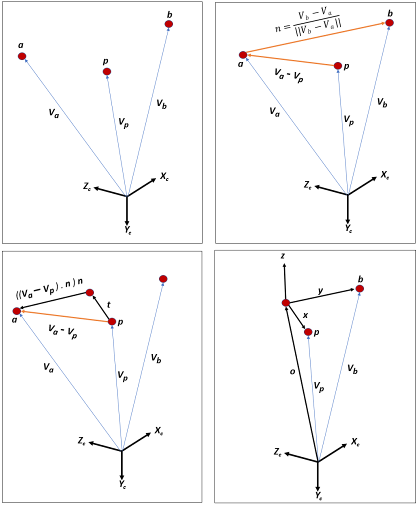

Figure 3: Vector algebra in head coordinate system creation.

Head coordinate system

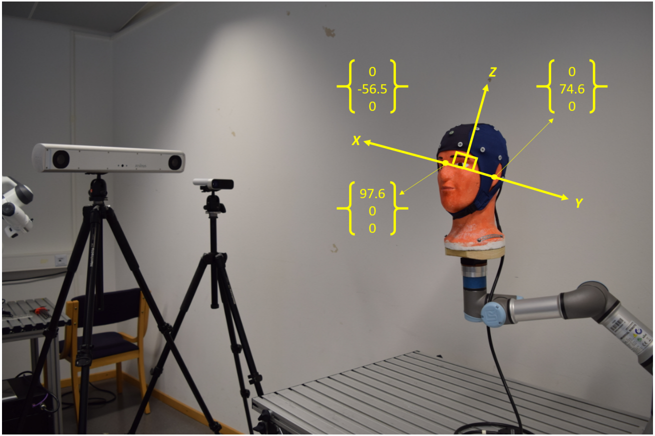

Figure 4: Head coordinate system using RPA, nose and LPA

Electrode mapping problem

We cannot map all the electrodes in the cap without disturbing the head position

Figure 5: Difficult to capture electrodes at the back of the phantom head.

Decouple

decoupling the head coordinate system generation and electrode mapping

Electrode mapping solution

- First tranfer the head coordiante system to the end effector frame

$$^{\mathrm{EE}}\boldsymbol{T}_{\mathrm{H_{CS}}} = \left(^{\mathbf{Base}}\boldsymbol{T}_{\mathbf{EE}}\right)^{-1} {}^{\mathrm{Base}}\boldsymbol{T}_{\mathrm{fCam}} {}^{\mathrm{fCam}}\boldsymbol{T}_{\mathrm{H_{CS}}}$$

- Record all the electrodes in the end effector frame

$$^{\mathrm{EE}}\boldsymbol{T}_{\mathrm{electrodes}} = \left(^{\mathbf{Base}}\boldsymbol{T}_{\mathbf{EE}}\right)^{-1} {}^{\mathrm{Base}}\boldsymbol{T}_{\mathrm{fCam}} {}^{\mathrm{fCam}}\boldsymbol{T}_{\mathrm{electrodes}}$$

- hhh

$$^{\mathrm{kCam}}\boldsymbol{T}^{j}_{\mathrm{electrodes}} = \left(^{\mathbf{Base}}\boldsymbol{T}_{\mathbf{kCam}}\right)^{-1} {}^{\mathrm{Base}}\boldsymbol{T}^{j}_{\mathrm{EE}} {}^{\mathrm{EE}}\boldsymbol{T}_{\mathrm{electrodes}}$$

- where, j $\in$ N [1,2,.......N]

solution

decoupling allowed head movement during electcode mapping

Head movement during electrode mapping

Figure 6: Phantom head rotation along single and multiple axes.

- Transfer all the electrode position to head coordinate system

$$^{\mathrm{HCS}}\boldsymbol{T}_{\mathrm{electrodes}} = \left(^{\mathbf{EE}}\boldsymbol{T}_{\mathbf{H_{CS}}}\right)^{-1} {}^{\mathrm{EE}}\boldsymbol{T}_{\mathrm{electrodes}}$$

Error

Head movement while mapping introduced an error!

Effect of single axis rotation

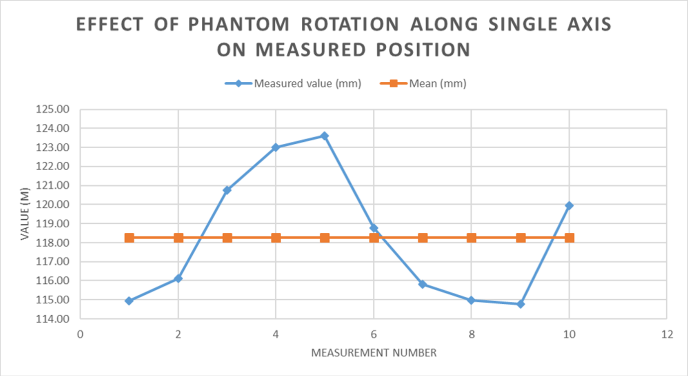

Figure 7: Measurement of single electrode when phantom head roatated to ten different angles along an axis.

measurement error

mean value with tolerance 118.26±4.5mm (SD)

Effect of multiple axis rotation

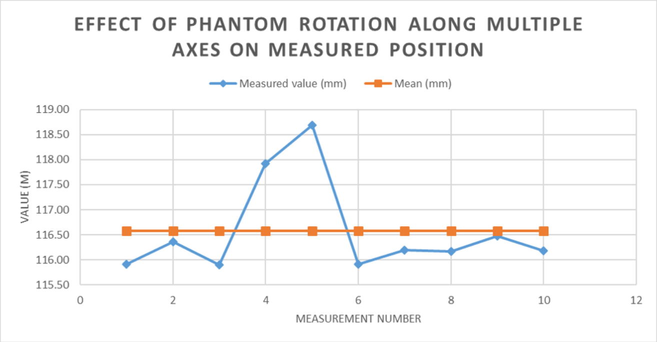

Figure 8: Measurement of single electrode when phantom head roatated to ten different angles along multiple axes.

measurement error

mean value with tolerance 116.5$\pm$ 1.5mm.

Effect of marker orientation

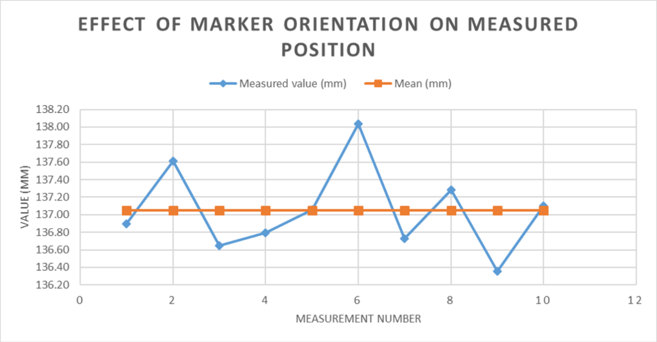

Figure 9: Measurement of single electrode with ten different marker orientation

measurement error

mean value with tolerance 137.05 $\pm$ 1 mm.

Data acquisition

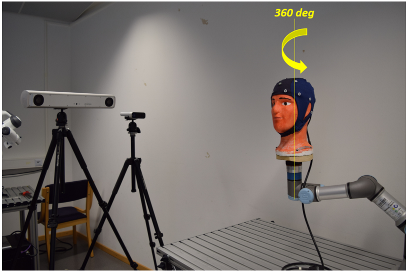

Figure 10: 360 degrees movement of the phantom head.

ROS bag record 30-45 seconds video at 30fps.

1. $/k4a/depth\_to\_rgb/camera\_info$.
2. $/k4a/depth\_to\_rgb/image\_rect$.
3. $/k4a/rgb/camera\_info$.
4. $/k4a/rgb/image\_rect\_color$.
5. $/k4a/points2$.
6. $joints\_states$.

Electrode position variation

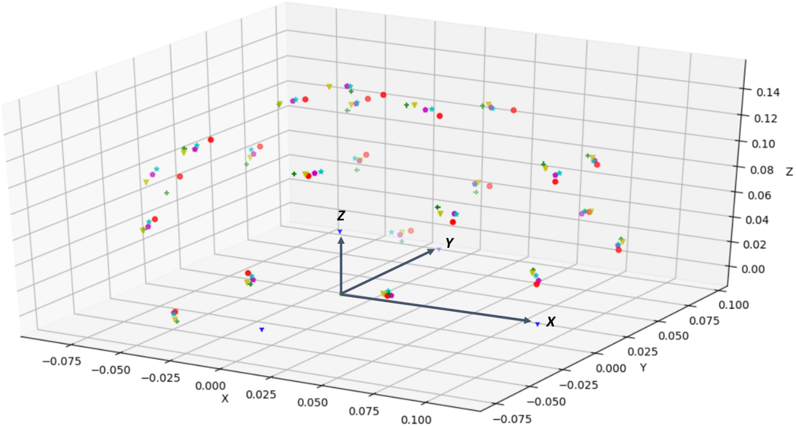

Figure 11: 3D view of electrodes at 5 different EEG cap wearing instances

Electrode position variation

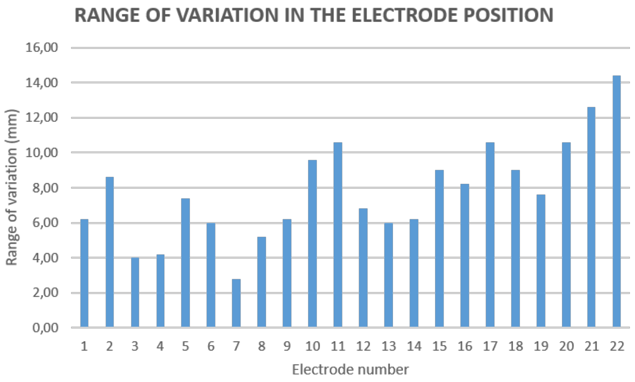

Figure 12: Range of electrode position variation at 5 different EEG cap wearing instances

Range of variation

mean value with tolerance 7.8 ± 5.8 mm.

Conclusion

- New Kinect is integrated successfully
- High degree of accuracy is achieved in hand-eye calibration.
- Electrode location can be recorded with accuracy of $< \pm$ 5mm
- A large amount of ground turth data generated for 3 EEG caps
- These data can used for
  - Training and evaluation of CNNs
  - Evaluation of camera based electrode detection algorithm in general
- Range of electrode position variation for 5 wearing instaces has been exlpored

Future scope

- Redesigning the reflective marker that can reach all the electrodes without having to move the phantom head.
  - Head movement while mapping introduced measurement error of $< \pm$ 5mm.
  - Current algorithms works any reflective marker.
- Filtering system
  - Not all the electrodes can be seen in a single image.
  - The position of all the electrode is recorded in the Kinect frame even the ones that are not visible.

The End

Thanks for your attension!

Camera calibration

${}^{\mathrm{Base}}\boldsymbol{T}_{\mathrm{EE}}$	M
${}^{\mathrm{EE}}\boldsymbol{T}_{\mathrm{CB}}$	X
${}^{\mathrm{Base}}\boldsymbol{T}_{\mathrm{Cam}}$	Y
${}^{\mathrm{Cam}}\boldsymbol{T}_{\mathrm{CB}}$	N

$$\boldsymbol{M}_i\boldsymbol{X} - \boldsymbol{Y}\boldsymbol{N}_i = 0 \tag{1}$$

$$\boldsymbol{A}\boldsymbol{w} = \boldsymbol{b} \tag{2}$$

$$\sum_{i=1}^{n} \|\boldsymbol{M}_i\boldsymbol{X} - \boldsymbol{Y}\boldsymbol{N}_i\|_F \tag{3}$$

Agenda