Seminar – Fall 2023

Robot_Assisted CT_Guided percutaneous procedures to Improve in Accuracy of Navigation system

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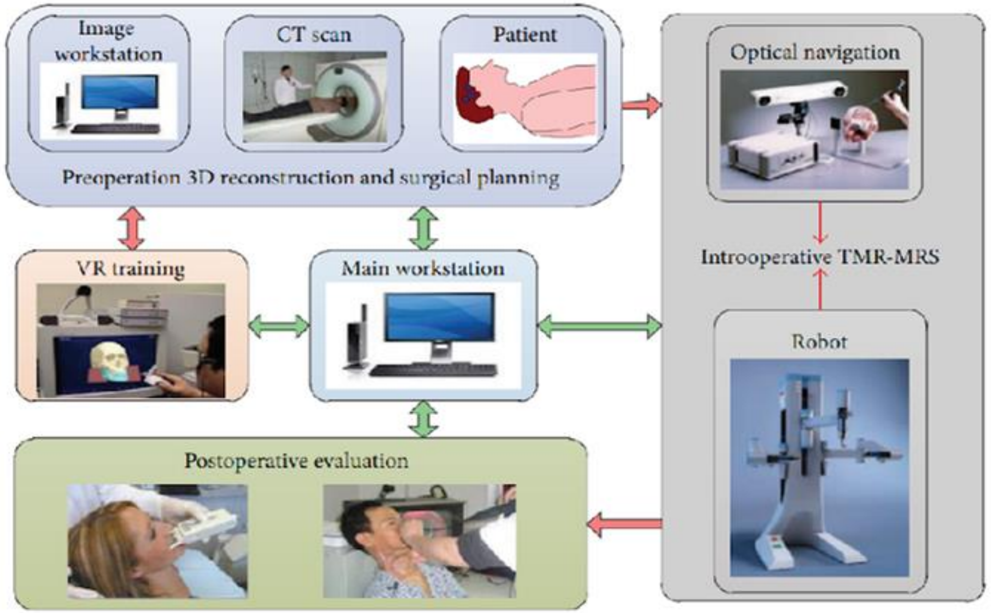
Recap

Robot-assisted Surgical Procedure



Computer assisted surgery can be divided into three basic steps:

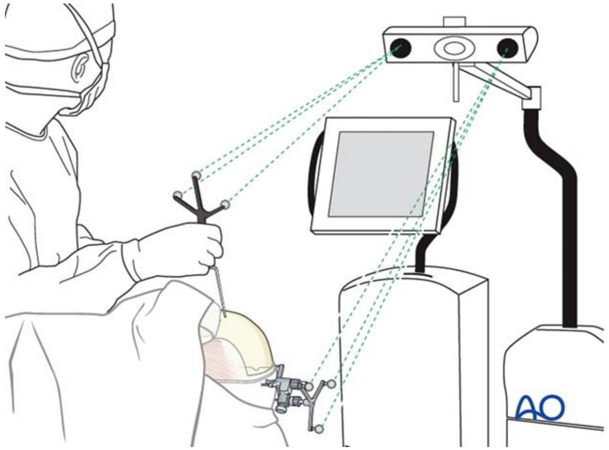
- Pre-operative presurgical planning
- Intraoperative
- Postoperative

Dual Sensor for Real-time Tool Tracking in Computer assisted Surgery

Introduction

- The computer aided surgery systems aim to empower surgeons with advanced visual guidance, precise control and real-time feedback

- Enhances the precision and safety of surgical interventions

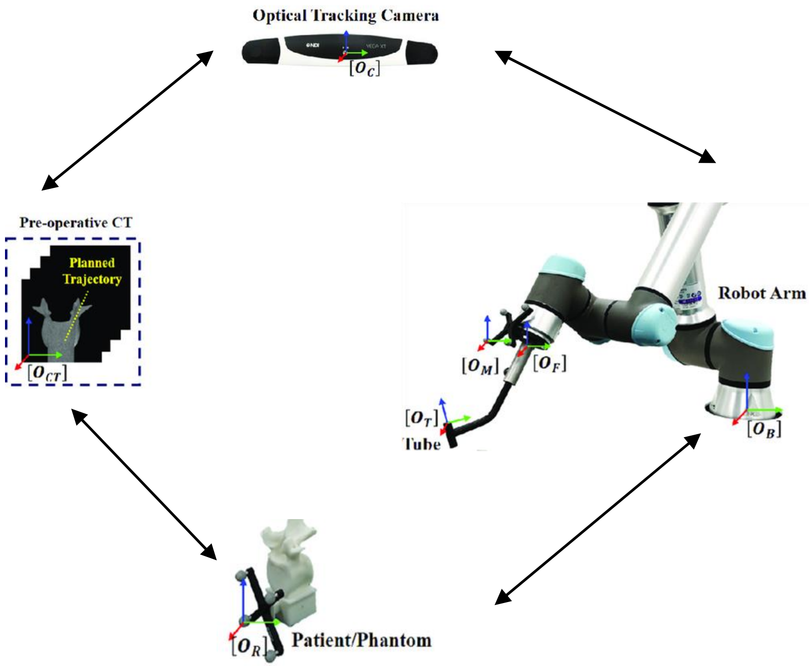


Introduction

- Precedent researchers create pre-operative surgical plans by utilizing medical imaging modalities (CT)

- Pre-operative surgical plans are spatially aligned with the coordinates of the intra-operative devices

- Benefit: Accurate localization of the predetermined surgical plan, precise manipulation of surgical instruments

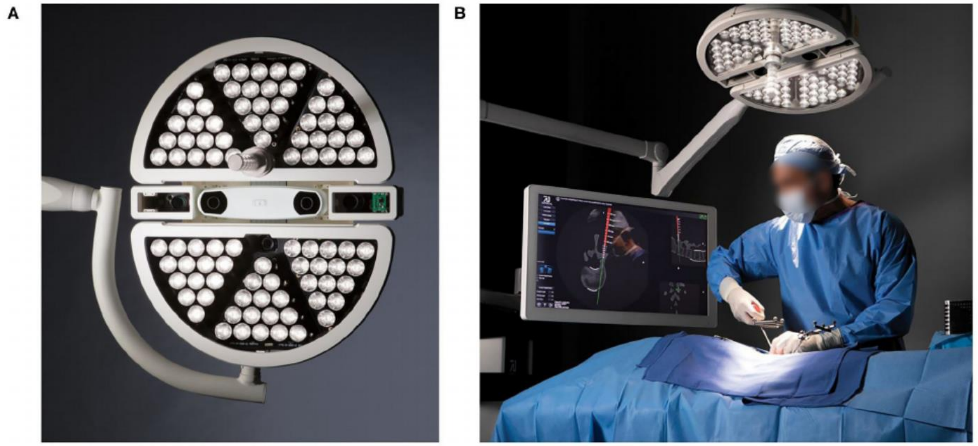


Related Work

<u>Navigation sensor for spine surgery (Jakubovic et al.)</u>

- Components: :Stereo vision-based optical localizer
  Binocular structured light cameras
  Conventional surgical light head

- Binocular structured light cameras
  - capture a 3D surface of the surgical field
    (Scanning time-5s)



- This 3D data is segmented and used to align with pre-operative images

- Commercial and clinical use (Toronto, Canada)

Related Work

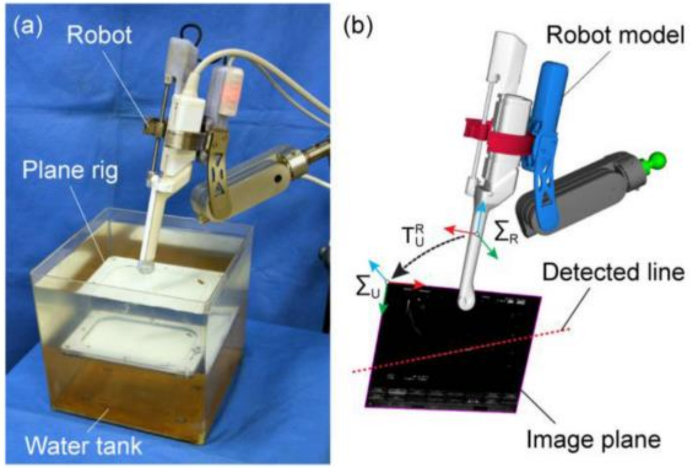
<u>Transrectal ultrasound-guided robot (Lim et al.)</u>

- Four degrees of freedom (DoF) robot ,guided by ultrasound probe for prostate biopsy

- Real time imaging capability (US + robot)

- Perform a 3D scanning even as it undergoes deformation due to the presence of surrounding tissues and US probe

- 3D scanning time is 30sec, which does not meet the criteria for real-time shape sensing.

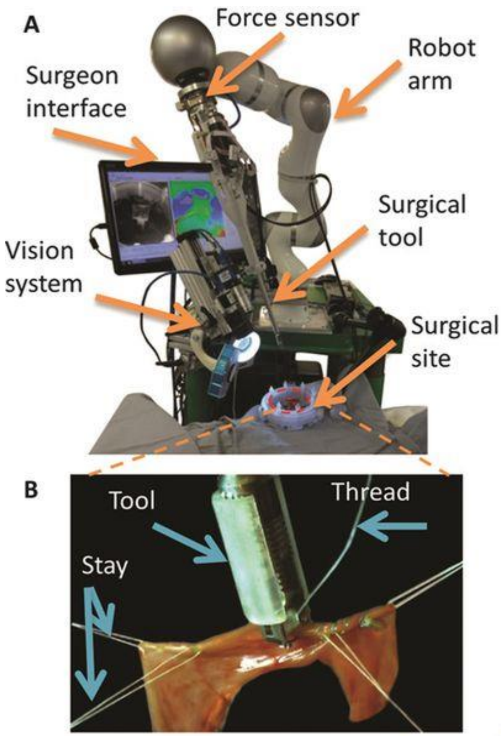


Related Work

Smart tissue autonomous robot (STAR) (Shademan et al)

- A robot arm that holds a laparoscopic suturing tool, an optic camera for 3D surface measurement and 3D visual tracking system using near-infrared fluorescent imaging

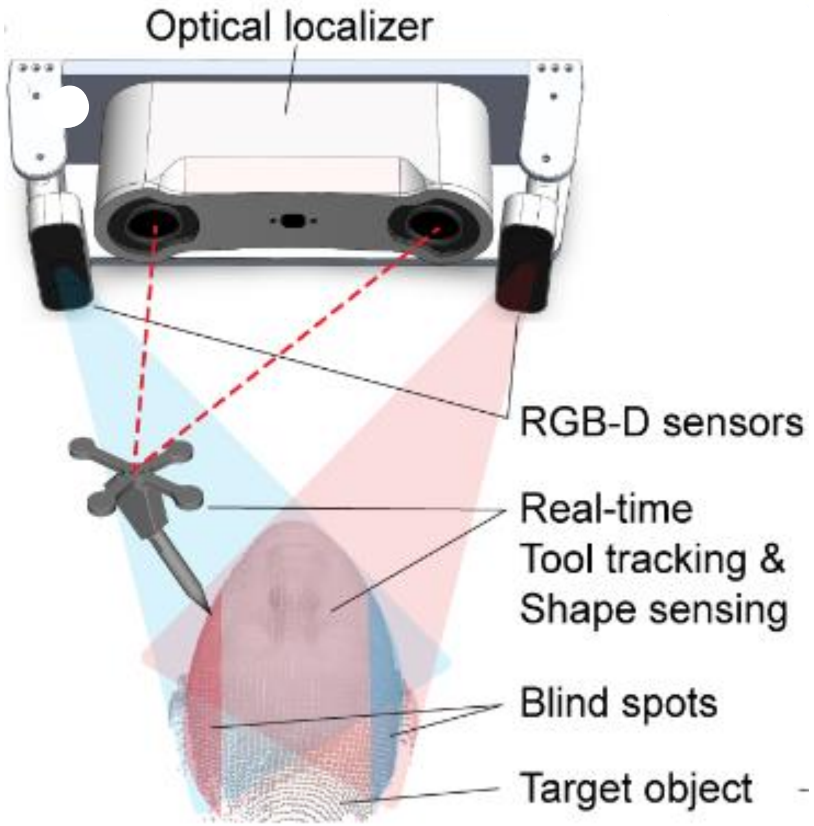
- Significance of research involves demonstrating the potential of autonomous robots in soft tissue surgeries



Objectives and Contributions

- Dual sensor integrates two RGB-D sensors with an optical localizer
- Unique capability of conducting real-time sensing of 3D surface shapes and 6-DoF tool poses concurrently
- Apply in CISs requiring real-time monitoring of deforming human organs, breast, face, and incised skin
- Real-time scans of intraoperatively de-forming surgical targets with accurate tracking of surgical tools

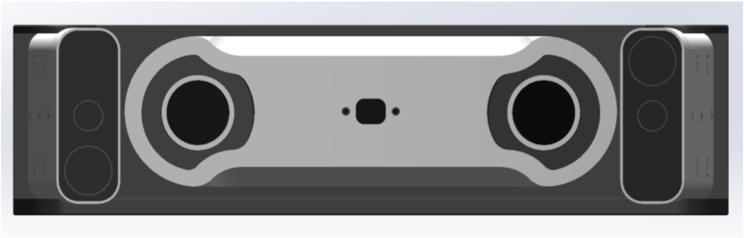
Design Concepts of Dual Sensor



The dual sensor is designed with:

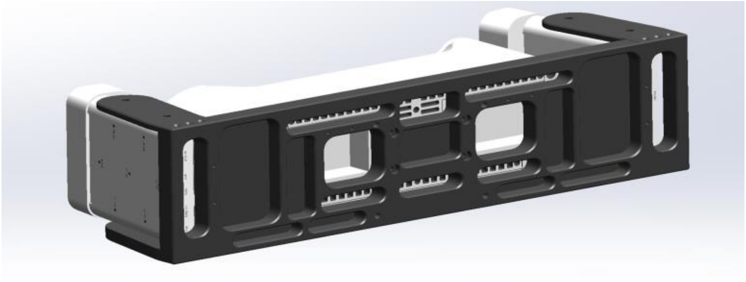
- Optical localizer
  - detects and tracks 6-DoF poses of medical instruments
- Two RGB-D sensors
  - equipped with a Tof depth sensor and a visible light camera that provides both 3D surface data and the corresponding RGB color information

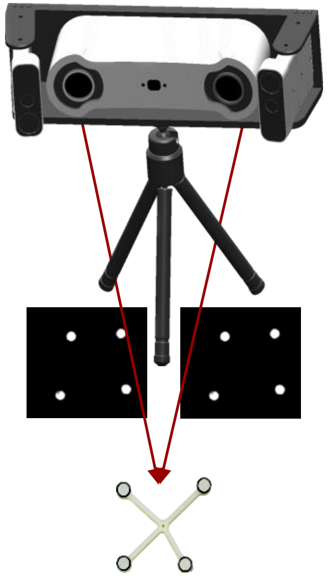
Design of Dual Sensor



Front View

Back View

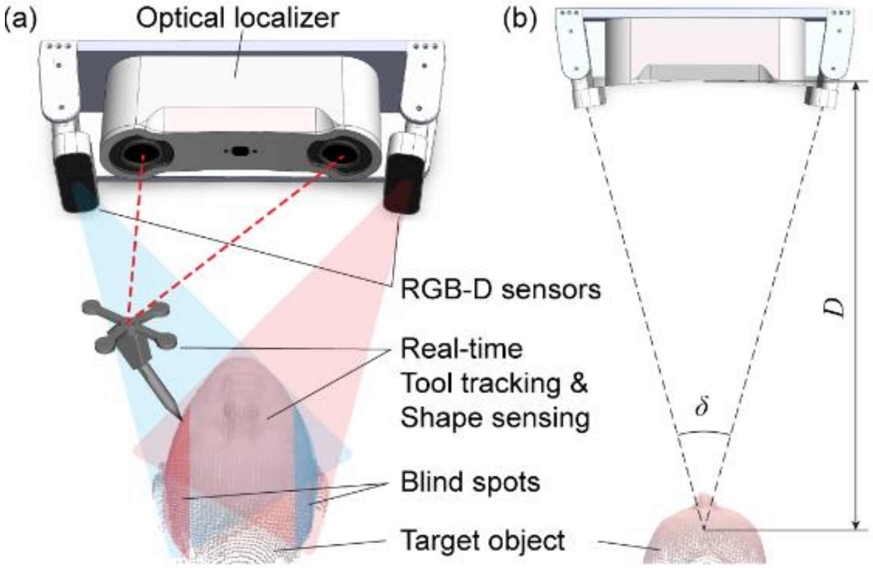




Images acquired with OT

Components : Fusion Track 250 , Azure Kinect Sensors
Size : 430mm x 100mm x 110mm
Weight : 4.56kg

Design of Dual Sensor



- Two-fold purpose: Broadens FOV and reduces potential blind spots inherent when relying on a single RGB-D sensor

- The convergence angle δ is determined by the separation distance D

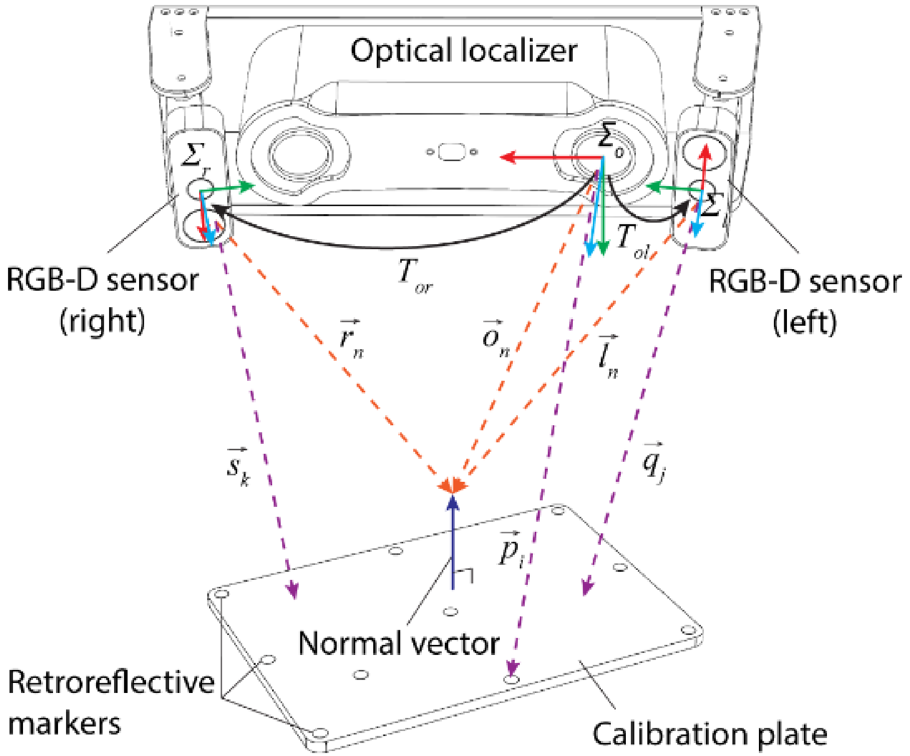
- Accuracy of sensors is inversely proportional to D

- D =1.2m angle set at 17.1 degree.

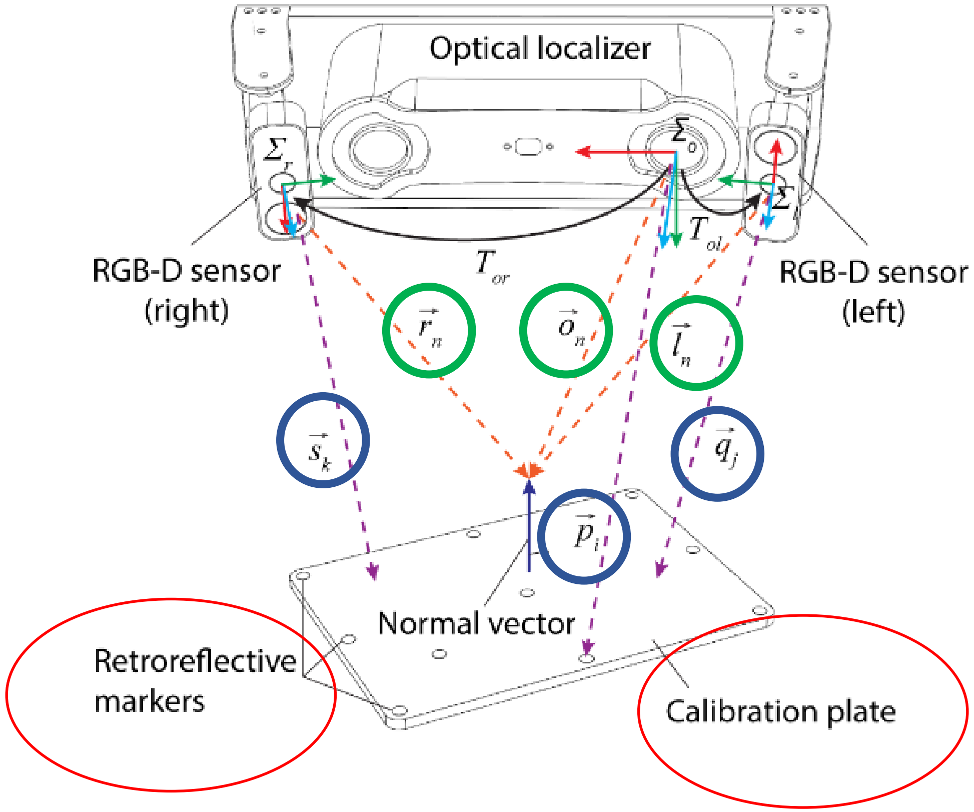
Sensor Calibration

The proposed one-time calibration method are introduced in the following sub-sections

1. Calibration Plate
2. Estimation of Normal Vector
3. Estimation of Rotation Matrix
4. Estimation of Translation Vector

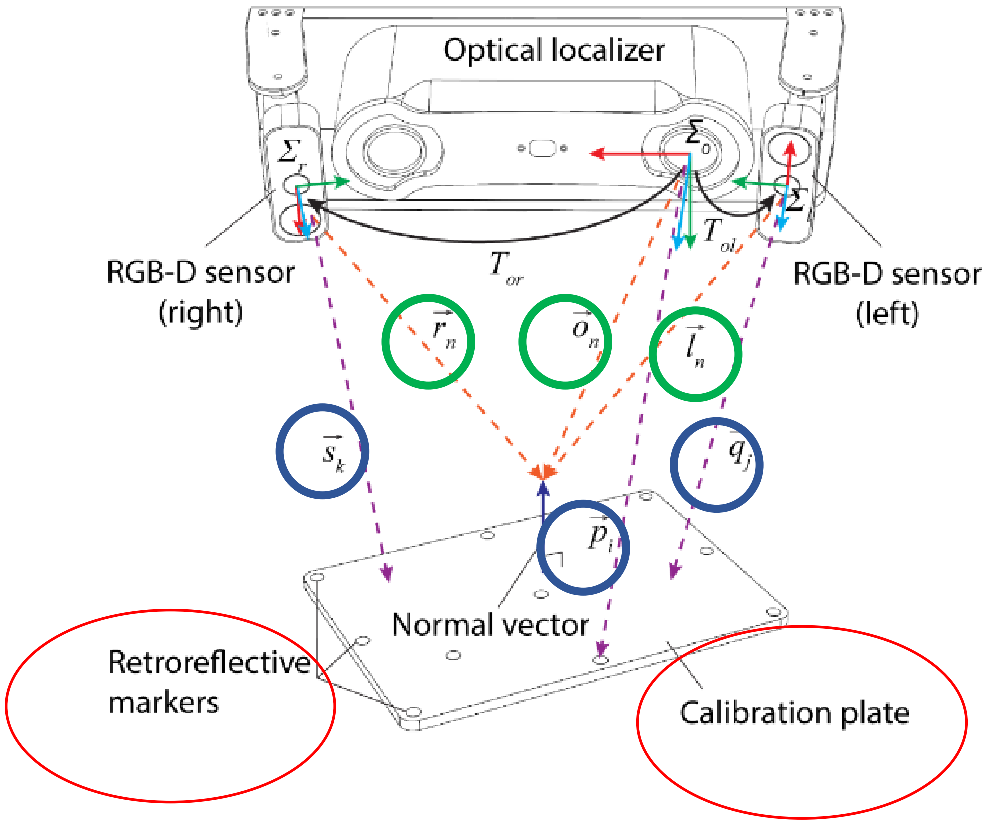


Sensor Calibration: Calibration Plate



Calibration plate to estimate a rigid transformation between an optical tracker and RGB-D sensor

Sensor Calibration: Estimation of Normal Vector



The normal vector of plate is measured by OT, by fitting a plane, ax+by+c=z

Center points of markers p= [x,y,z]T

Least Square equation is given by:

$$\begin{bmatrix} \vdots & \vdots & \vdots \\ x_i & y_i & 1 \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \vdots \\ z_i \\ \vdots \end{bmatrix}$$

The normal vector of plate is estimated as

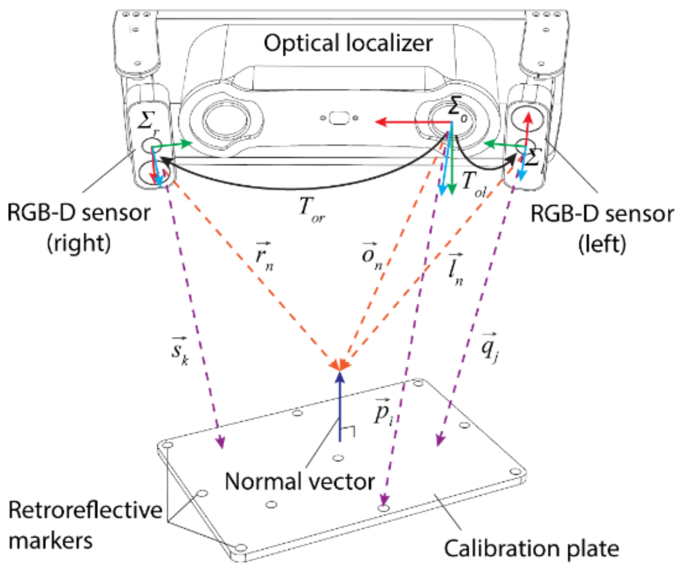
$\vec{o}_n = \vec{x}/\|\vec{x}\|$ where $\vec{x} = [a, b, c]^T$.

Sensor Calibration: Estimation of Rotation Matrix

- Normal Vectors $\vec{o}_n, \vec{l}_n, \vec{r}_n,$
- Rotation matrices of two Rigid Transformations

$$T_{ol} = [R_{ol}, \vec{t}_{ol}]$$

$$T_{or} = [R_{or}, \vec{t}_{or}] \quad \longrightarrow \quad H = \sum_{n=1}^{N} \vec{l}_n \vec{o}_n^T$$



By applying SVD to the Matrix $H = U\Sigma V^T$.

Rotation matrix is calculated as

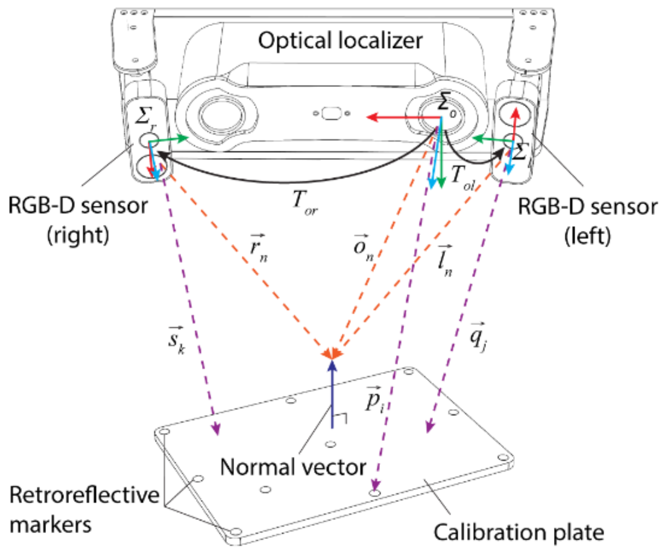
$$R_{ol} = V \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & det(VU^T) \end{bmatrix} U^T$$

Sensor Calibration: Estimation of Translation Vector

Constraint: Vectors defined between points measured by the tracer $\vec{p}_i$ and points transformed by the transformation $\vec{q'}_j = R_{ol}\vec{q}_j + \vec{t}_{ol}$ eq(1) are perpendicular to the normal vector measured by the tracker. $\vec{o'}_n$

The constraint is given by $\vec{o}_n^T(\vec{p}_i - \vec{q'}_j) = 0$ ---- eq(2)

By substituting (1) into (2) $\vec{o}_n^T\vec{t}_{ol} = \vec{o}_n^T(\vec{p}_i - R_{ol}\vec{q}_j)$ ---- eq(3)



Eq (3) can be expressed into least square formula:

$$A\vec{t}_{ol} = \vec{b}, \text{ where } A \in \mathbb{R}^{IJN\times 3}, \vec{b} \in \mathbb{R}^{IJN}$$

I=Retroreflective markers
J =Points measured by the left RGB-D sensor
N=Measurements

Software Implementation

Dual Sensor(llb)

- Fusion Tracker SDK (ftk500)
- Azure Kinect SDK

Open-Source Libraries

- C++, Qt
- Visualization Toolkit (Vtk)
- Grass roots DICOM (GDCM)
- Open Computer Vision (OpenCV)
- Point Cloud Library (PCL)

Ongoing Studies

- Calibration Accuracy
- Tracking Accuracy

Thank You