Introduction to Digitization Techniques for Surgical Guidance

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Outline

• Overview of Tracking Technology
• Instrument Design & Calibration
• NDI Data Acquisition Software
  – 6D Architect – Tracked Body Calibration
  – NDI Track – Tool Tracking Utility
• NDI API Overview
• Tracking Data Acquisition via Slicer
Intraoperative Tracking is Critical in Surgical Navigation

- Tracking coordinate system defines “patient space” in OR
- Facilitates digitization for computation of “physical-to-image space” registration
- Allows for tracking of multiple surgical instruments for overlay in guidance system
Tracking Modalities used in Surgical Navigation

• Two primary tracking modalities used in commercial navigation systems:
  – Optical (Active & Passive)
    • Neurosurgery (StealthStation & BrainLab) and Abdominal Surgery Applications (Pathfinder & CAScination)
  – Electromagnetic
    • Interventional Radiology (Traxtal), Bronchoscopy (superDimension) and Orbital Surgery

• Northern Digital Inc. (Waterloo, Ontario, Canada) the dominant manufacturer
  – Supplier for major surgical navigation companies (BrainLab and Medtronic)
  – Offers products for other applications:
    • Optical CMM and metrology for industrial applications
Optical Tracking

Overview – First Principles

• Optical tracking utilizes the principle of triangulation to locate trackable markers in space
  – Given known tracker geometry, the system can compute the translation and rotation parameters for each tracked instrument

• Optical tracking can be either “active” or “passive” in nature
  – “Active” tracking uses markers (IREDs) that emit IR in known sequence
  – “Passive” tracking uses markers that reflect IR light emitted by position sensor

• Benefits & Costs
  – Wireless tracked instrument tracking with high degree of accuracy
  – Line of sight constraints
Optical Tracking Systems
NDI Polaris – Spectra / Vicra

- Major line offered for neurosurgical navigation applications.
  - Supports active and passive tracking
- Primary components:
  - Position Sensor
    - Illuminator rings provide IR source for passive tracking
  - Tool Interface Unit
    - Controls firing of IRED markers for active tracking
  - Active / Passive Markers
NDI Polaris System
Spectra Specifications

- Large, extended pyramid working volume
- Supports hybrid (active & passive) and passive only tracking
  - Up to 15 wireless tools (maximum 6 active wireless) with maximum 32 passive and 32 active markers in FOV
- Accuracy Performance:
  - Volumetric: 0.25mm RMS (Pyramid); 0.30mm RMS (Extended)
  - 95% CI: 0.5mm (Pyramid); 0.6mm (Extended)
NDI Polaris System

Vicra Specifications

• Compact form factor and working volume
• Supports passive and active wireless tracking
  – Up to 6 tools (maximum 1 active) with 32 maximum markers in FOV
• Accuracy Performance:
  – Volumetric: 0.25mm RMS
  – 95% CI: 0.5mm
NDI Polaris System

**Tracked Tools**

- NDI offers a series of active and passive tracked tools
  - Probes for point digitization
  - Rigid bodies to serve as coordinate reference or attach to other instruments
- Facilitate measurement acquisition without need for custom instrument design and fabrication
Electromagnetic Tracking

Overview – First Principles

• EM tracking works via the generation of spatially varying magnetic fields which creates a known measurement volume of varying magnetic flux

• Tracked instruments contain sensor coils which generate unique signal based on location in magnetic field
  – Induced voltage depends on sensor position and orientation in measurement volume as well as strength and phase of magnetic fields

• Benefits & Costs
  – No line of sight constraints on tracking
  – Potential for compromised tracking accuracy via eddy currents from presence of conductive materials
  – Requires wired tracked instruments
Electromagnetic Tracking System

NDI Aurora System

• Primary Components:
  – Field Generator
  – Tracked Instruments (sensors)
  – Sensor Interface Unit (SIU)
    • Converts voltages induced in sensor coils into digital data
  – System Control Unit (SCU)
    • Powers field generator and processes digital signals for position/orientation computation

• Two sensor types:
  – 5 and 6 degrees of freedom (DOF)
  – 6DOF incorporates two sensors in fixed relative position
Planar field generator has compact form factor and working volume

Accuracy Performance:
- 5DOF Position: 0.70mm RMS (Cube); 1.10mm RMS (Dome)
- 5DOF Position 95% CI: 1.40mm (Cube); 2.00mm (Dome)
- 6DOF Position: 0.48mm RMS (Cube); 0.70mm RMS (Dome)
- 6DOF Position 95% CI: 0.88mm (Cube); 1.40mm (Dome)

Sensors:
- Eight 5DOF or Four 6DOF
NDI Aurora System
Planar Generator Technical Specifications

Distance defined as the length of the position vector between the origin of the Field Generator coordinate system and the center of the sensor. The plots are shown to indicate qualitative trends in performance.
NDI Aurora System
Tabletop Generator Technical Specifications

• Large form factor and working volume
  – Shielded to minimize distortions from patient table

• Accuracy Performance:
  – 5DOF Position: 1.2mm RMS
  – 5DOF Position 95% CI: 1.8mm
  – 6DOF Position: 0.8mm RMS
  – 6DOF Position 95% CI: 1.2mm

• Sensors:
  – Eight 5DOF or Four 6DOF
NDI Aurora System

Tabletop Generator Technical Specifications

Distance defined as the length of the position vector between the origin of the Field Generator coordinate system and the center of the sensor. The plots are shown to indicate qualitative trends in performance.
• Off the shelf tools from NDI facilitates rapid data collection
  – Standard Probe (6DOF)
  – Standard Reference (6DOF)
  – Shape Tool (5/6DOF)
  – Needles (5DOF – 18G x 150mm & 21G x 150mm)
Overview

- Custom tools for tacking within the Spectra/Vicra system primarily via Radix Lenses
  - Accurate tracking in harsh environments and resistant to partial occlusions
  - Generate characterization file to describe geometry
- Sensor coils installed in custom tool for Aurora tracking
  - Perform tip offset calculation and write to tool’s SROM device
- Several constraints on instrument design:
  - Unique geometry (passive)
  - Tracking accuracy facilitated by selected geometry and sensor coil type/location
Design of Custom Tracked Devices

Guidance for Optimal Design

• Passively tracked bodies have geometry constraints
  – Unique geometry required for tracking of multiple instruments
  – Possible to use multi-faced tools
    • At least 3 markers per face, maximum of 20 markers, and maximum of 8 faces
• Geometry and position of rigid body relative to instrument tip has significant impact on tracking accuracy

Calibration of Custom Tracked Devices

Overview – 6D Architect

• Prior to using Polaris or Aurora tracking modalities, tracked instruments must be characterized

• 6D Architect is an NDI application that facilitates tracked instrument calibration
  – ROM File Generation (optical tracking)
  – Pivot Procedure Data Acquisition
Calibration of Custom Tracked Devices

ROM File Generation [1/2]

- Tracking active and passive tools requires generation of “.ROM” file
- After tool description entered (e.g. name, tool type, etc.), an initial snapshot of tracked body is acquired
  - All markers must be in view
- A series of data acquisitions performed with tracked body in different poses
  - Tracked body must remain motionless during acquisition
  - Typically use 10 to 15 different orientations
Calibration of Custom Tracked Devices

ROM File Generation [2/2]

• After poses are acquired, the coordinate system for the tracked body may be aligned
  – Tracked body local coordinate system required for Polaris to compute position and rotation of tool
  – Typically define z-axis along shaft of probe tools

• Finally, marker locations can be edited in coordinate space and face normals can be defined
  – Allows Polaris to determine tracking face angles that do not provide accurate data
Calibration of Custom Tracked Devices

**Pivot Procedure**

- Pivot procedure used to compute tool tip offset for tracked probes
  - Used for both Aurora and Polaris tracked tools
- Perform data collection where tool tip is fixed in a divot and rotated
  - Generally record data for 60 to 90 seconds
  - Important to rotate instrument in a slow and smooth motion
- Result is a translation that places origin of tool coordinate system at tip of instrument
  - Should result in sub-millimetric RMS error
Examples of Custom Tracked Tool Designs & Applications

Kingham et al. HPB. 14, 2012
Examples of Custom Tracked Tool Designs & Applications

Breast Surface Digitization
Custom Tracked Tool Application

Tracked US Calibration

Calibration

Custom Tracked Tool Application

Tracked US Overlay

Digitized Domain for Breast Surgery
Data Collection with NDI Software

Overview – NDI Track

- NDI Track software included within NDI ToolBox software suite
  - Facilitates diagnostics, maintenance, and testing of tracking hardware
- NDI Track facilitates recording tracking information in ASCII format
  - Output rotation matrix in quaternion format
- Allows for measurements to be performed “out of the box”
Data Collection with Custom Software

Overview - NDI API

- Custom data acquisition software (C++) can be created using the application programming interface (API) for Spectra, Vicra, and Aurora
  - Slight differences in API between Spectra/Vicra and Aurora
  - Example codes provided for guidance
- Previous student in BML wrapped the NDI API (Optotrak) in custom VTK classes
  - Created data collection panel using Python
- From an application perspective, tracking system is a serial device listening for commands
  - Upon receiving command, system performs action and returns status
  - System only initiates communication with application except on power up or reset
Data Collection with Open Source Applications

- 3D Slicer
  - Free, open source software for visualization and image analysis

- SlicerIGT
  - A 3D Slicer extension for image guided procedures

- PLUS
  - Open-source toolkit that communicates with SlicerIGT and navigation hardware for data acquisition, pre-processing, and calibration
• Several Extensions
  – i.e. Resection Planner, SlicerIGT, Mesh Generation, DiceComputation, Segmentation (several different extensions), Shape Analysis, etc
Configuring SlicerIGT and PLUS

• List of PLUS supported devices
  – Several ultrasound systems
  – NDI Polaris, Aurora, Optotrack Certus
  – Medtronic Stealth Station
  – Ascension EM tracking devices
  – Claron Micron Tracker
  – Many More (inertial measurements, simulators, ThorLabs compact spectrometer)

• Each device has its own configuration file
Configuring SlicerIGT and PLUS

- Once your tracking device is configured, PLUS streams live tracking data to 3D Slicer
Slicer IGT Capabilities

- Breach Warning
- Collect Fiducials
- CreateModels
- Fiducial Registration Wizard
- Fiducials-Model Registration
- Model Registration
- OpenIGTLink Remote
- OpenIGTLinkIF
- PathExplorer
- Pivot Calibration
- Plus Remote
- Transform Fusion
- UltrasoundSnapshots
- Volume Reslice Driver
- Watchdog
Conclusions

• Suite of products from NDI allow for “off the shelf” data collection very quickly
  – NDI API can be used for custom application development

• Significant open source software exists for data collection

Questions / Demo