Optical Tracking Education Guide

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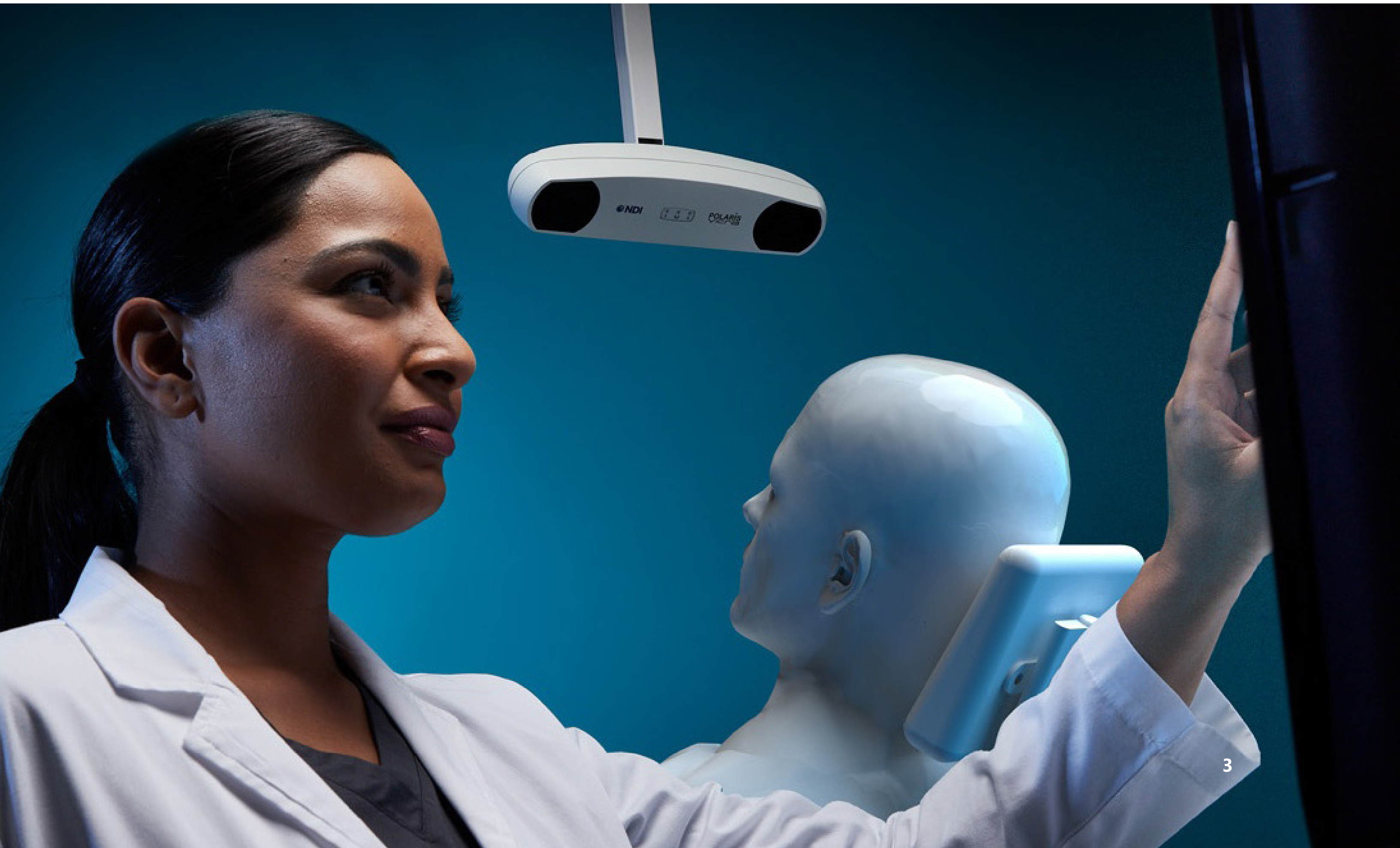
Introduction

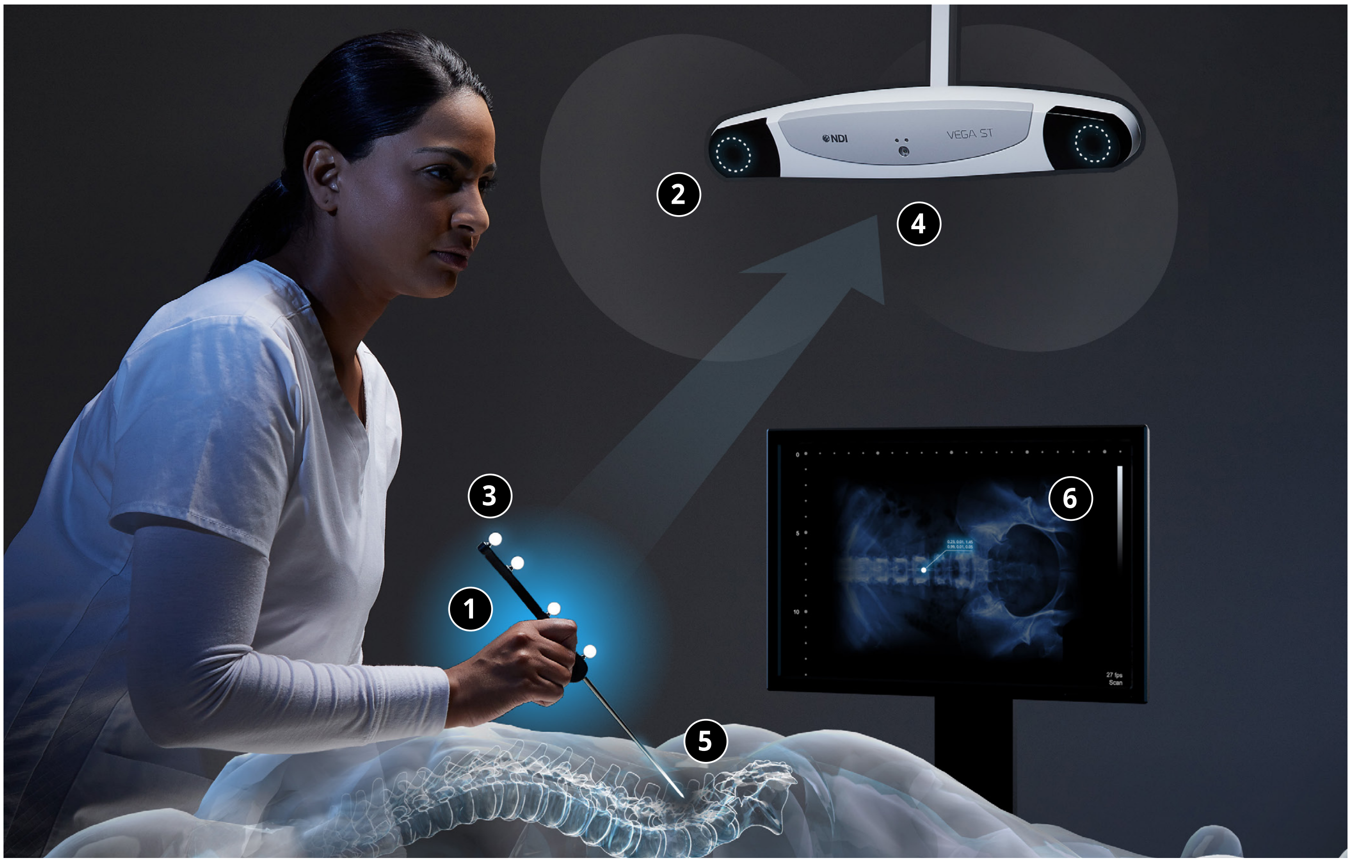
Today's most intricate procedures demand precision and reliability. Most image-guided surgery or therapy systems track the positions of instruments in the physical space occupied by the patient. This task is commonly performed using either an optical or electromagnetic tracking system. This guide focuses on **optical tracking technology** - the core concepts and functions, how it pertains to the NDI Polaris Vega® and Polaris Vicra®, and why optical tracking is the best choice for large volume tracking applications that require exceptional measurement accuracy.

Optical Tracking Explained

Optical measurement (tracking) has long been a mainstay of navigation systems. An optical measurement solution consists of two core components that work together: the optical tracker, sometimes referred to as a 'camera', and navigation markers, such as passive marker spheres, Radix™ Lenses, or retro-reflective discs. Using near-infrared (IR) light to detect and track markers attached to OEM instruments, the optical measurement system uses triangulation to determine the 3D position of each marker. When incorporated as components into the workflow of navigation systems, the navigation markers provide a visual reference for pinpointing instruments in 3D space, and for guiding the instruments in relation to patient image sets.



The 3D positions of the navigation markers are used to determine the overall position and orientation of the instrument to which they are attached. Similar in concept to vehicle GPS navigation, tracking data can be used to visualize the instrument's location relative to patient image sets, and to plan and navigate the instrument's path to the target/treatment site. Each instrument has a unique array of markers that distinguishes one instrument from another within the OEM navigation interface.



Polaris Vega ST

How Optical Measurement Works

1. Markers can be attached to OEM instruments.
2. The Polaris optical tracker floods the measurement volume with infrared light.
3. This light is reflected from the markers back to IR sensors on the Polaris optical tracker.
4. The points where extrapolated lines intersect are the markers' 3D coordinates within the measurement volume.
5. Coordinate data are mapped to the associated instrument and used to calculate the pose of that instrument.
6. Tracking data are communicated to the host application and can be used for real-time visualization and navigation of instruments, relative to patient image sets.

Benefits of Optical Tracking

Optical tracking continues to provide new opportunities for medical device OEMs to innovate within complex navigation systems and indications. The term image-guided surgery (IGS) refers to a surgical procedure that makes use of tracked surgical instruments with intraoperative images or preoperative images to navigate the procedure. With this technology, a surgeon links the operative field to the preoperative imaging data, reflecting the exact location of a surgical instrument to the adjacent anatomic structures. Tracking the surgical instrument relative to the patient image sets provides real-time feedback about its position, as well as its relationship to surrounding tissue, and helps surgeons perform safer and less invasive procedures. IGS has become a recognized standard of care in many procedures including cranial, otorhinolaryngology, spine, orthopedic, and cardiovascular.

Navigation systems are also being utilized in other medical procedures including radiation therapy and Transcranial Magnetic Stimulation (TMS), where navigation enables providers to have accurate, reliable, and repeatable placement of the TMS coil.

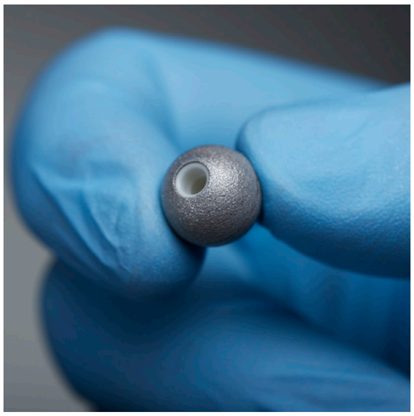
Equipment Calibration

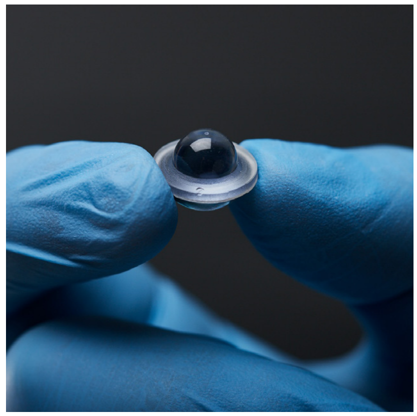
The performance of an optical tracking system is subject to the quality of its calibration. Calibration is the process of setting the camera's internal and external parameters. This 'characterization' process optimizes the camera performance and ensures that it is ready to use out of the box to use in the field, without additional calibration. Both the Polaris Vega® and Polaris Vicra® systems are factory calibrated to ensure accuracy and consistency in the field. The NDI calibration facility fully encompasses the entire Polaris Vega and Vicra measurement volume, and while system accuracy is validated using a coordinate measurement machine (CMM). NDI provides calibration certificates for all of its optical tracking systems, and the output can be traced back to standards set by the National Institute of Standards and Technology (i.e., NIST traceable).

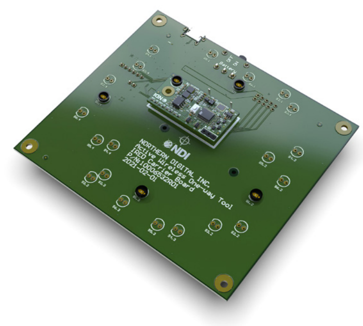
Passive and Active Markers

An optical tracker detects both passive and active markers and does so using different methods. Passive marker spheres have a unique retro-reflective surface that consists of tens of thousands of microbeads which reflect infrared light which allows the tracker to 'see' them during tracking. NDI's optical sensors also work with the NDI Radix Lens. Similar to the passive marker sphere, the Radix Lens is a retro-reflective marker that features a smooth plastic surface which makes it highly impervious to liquid and particulate contamination. If the lens does become contaminated during the procedure, it does not need to be replaced – just wipe it clean to resume tracking. These properties make the Radix Lens a good alternative to passive marker spheres. The Radix Lens alleviates possible marker-to-marker interference on OEM instruments by way of its low marker profile. Radix Lenses and passive marker spheres can be used on separate tools during the same procedure, within the same measurement volume.

Markers on active wireless tools emit infrared light in response to pulses of infrared light from the optical tracker's illuminators. An infrared receiver on the active wireless tool detects the pulses and activates the markers for the duration of the exposure time.


Passive Marker Spheres

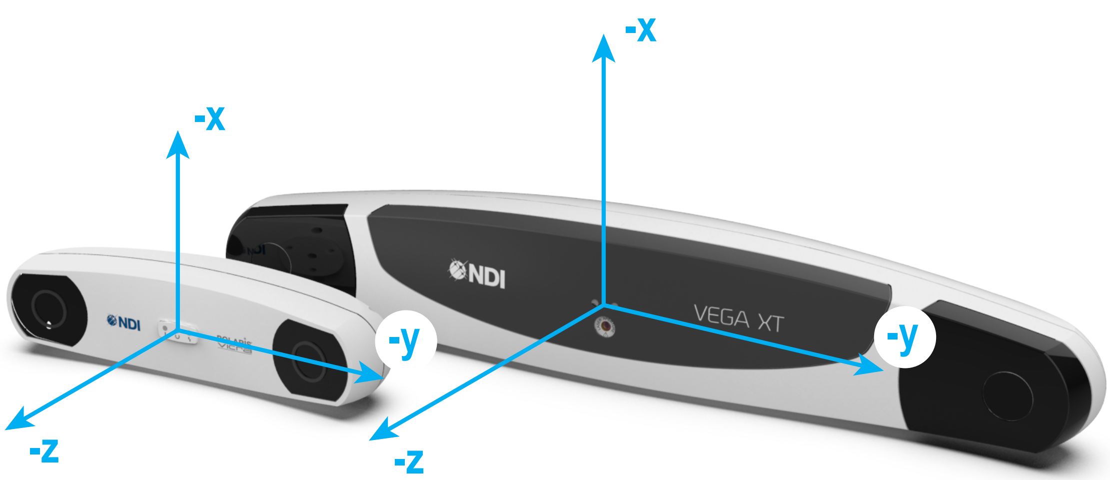

Radix Lens



Active Wireless Tool

Global Coordinate System and Measurement Volume

NDI's Vega and Vicra cameras use a coordinate system with an origin located at the camera, and three axes aligned as shown below. To maintain accuracy and reliability in the field, this global coordinate system is defined at the factory and cannot be adjusted.



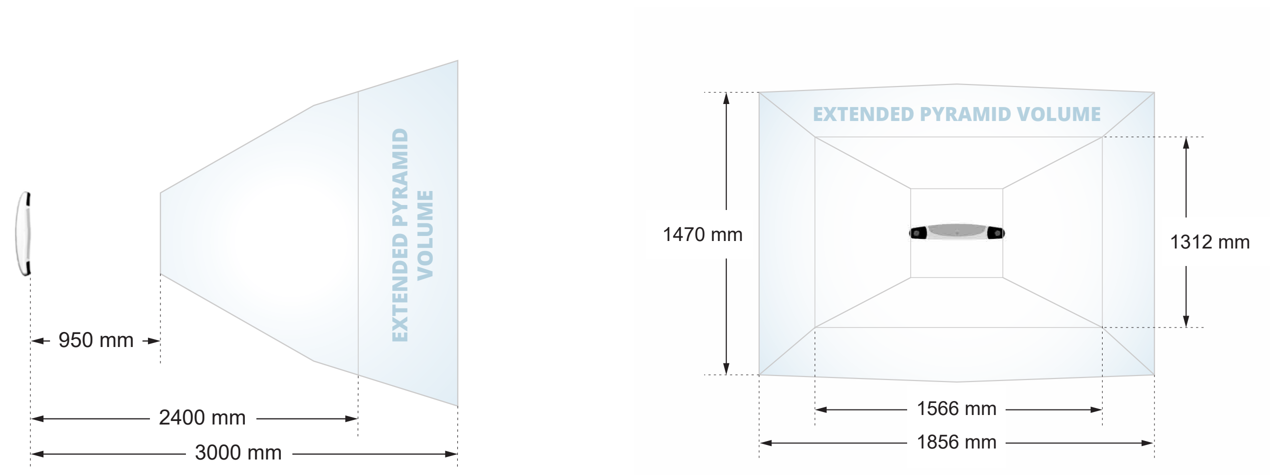
Polaris Vicra, Polaris Vega XT

The Polaris Vega and Vicra systems will report the positions of OEM instruments in the global coordinate system. However, if using a reference tool, software can calculate, and report poses relative to the local coordinate system of the reference tool.

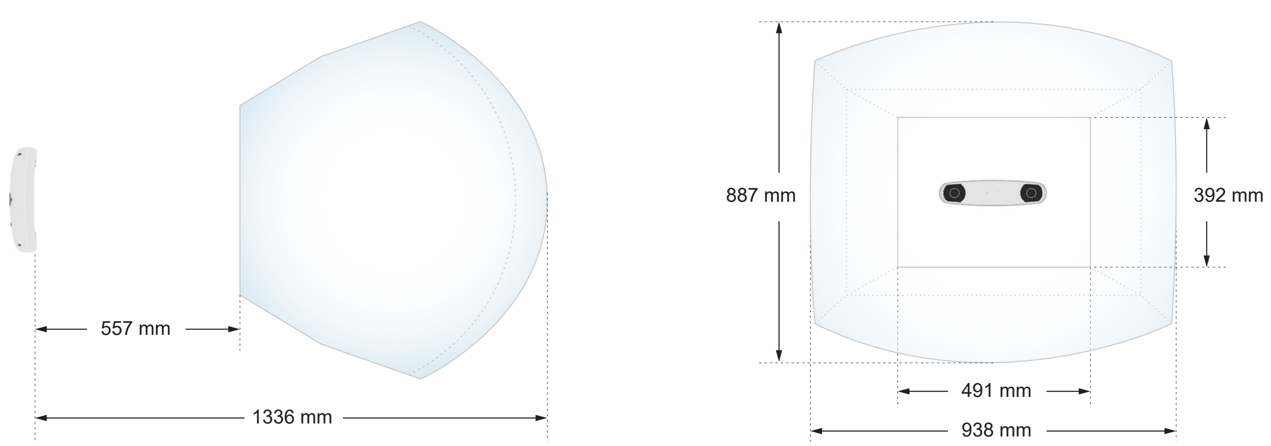
The field of view is the total volume in which the camera can detect markers regardless of accuracy. The characterized measurement volume is a subset of the field of view. It is the volume in which data were collected and used to characterize the camera.

There are two characterized measurement volumes available for the Polaris Vega System - the Pyramid Volume and the Extended Pyramid Volume. The Polaris Vicra has a single characterized measurement volume. All are illustrated in the diagrams below.

Measurement accuracy and reliability are the foundations of the NDI optical measurement and tracking solutions. However, accuracy represents more than measurement values hitting a theoretical 'bullseye' – although that's important too. For clinicians, high tracking accuracy provides confidence that when they navigate the instrument's path to the treatment site (the target), they will reach it exactly as expected every time. As a result, using an accurate image-guided surgery system can help shorten procedure times and minimize surgical invasiveness, which supports improved patient outcomes.



Polaris Vega

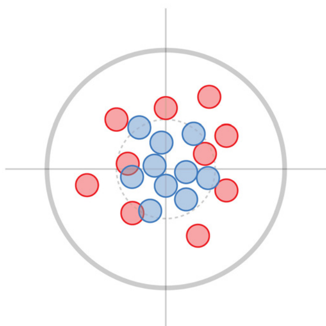


Polaris Vicra

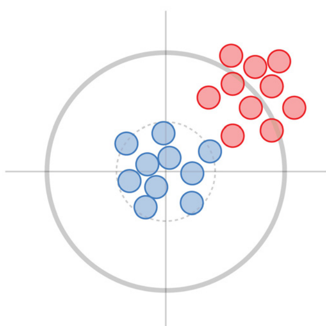
How Is Accuracy Determined?

Although often used interchangeably, the terms 'accuracy' and 'precision' have separate scientific meanings. The term accuracy encompasses the concepts of trueness and precision. Trueness refers to the closeness of agreement between the mean of test results and the true (accepted) reference value. It denotes systematic errors. Precision refers to the closeness of agreement between test results. It denotes noise and random errors.

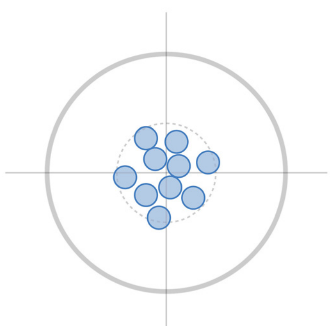
The concepts of trueness and precision can be visually depicted as a target, where:



Trueness represents how close measurements are to the bullseye (the true reference value). In this example, the red and blue targets are both true, but the red measurements are less precise because they are far apart.



Precision represents how close repeated measurements are to each other (test results). In this example, the red and blue measurements are both precise, but the red measurements are less true because they are off target.



Accuracy represents measurements that are close to the bullseye and close to each other. In this example, as with all NDI optical measurement solutions, the measurements are both true and precise.

NDI's optical measurement solutions adhere to the ISO 5725-4:2020 standard for trueness, accuracy, and precision.

Application Software Tools

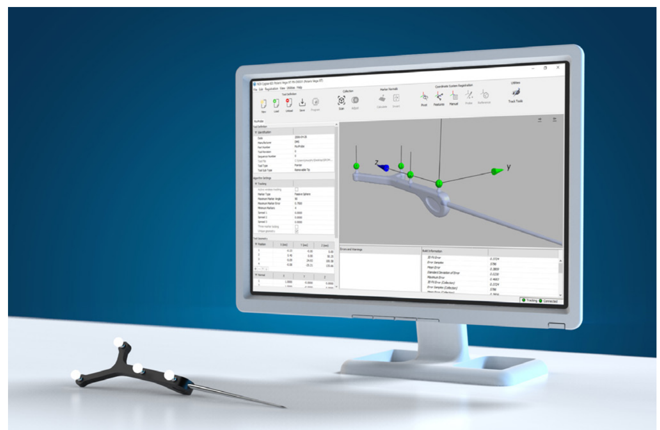
Additional software is available from NDI to assist OEM customers to configure, characterize, and track tools:

NDI ToolBox™

This collection of software utilities allows OEM developers to configure, upgrade, troubleshoot and test the Polaris solutions. It also supports tool tracking and the collection and saving of tool tracking data. For the Polaris Vega VT, the NDI ToolBox software also provides a video client application for streaming video.

NDI Cygna-6D™

This software program for the Polaris systems is an essential component of the tool characterization process and is necessary for the creation of tool definition files. Cygna-6D features an efficient user interface that has been streamlined to a single window, reducing the number of steps (and dialogue boxes) needed to complete tasks. Cygna-6D continues to let users measure relative marker positions; set important parameters; assign markers to faces; test marker geometries; and define local coordinate systems.



NDI Cygna-6D

Application Program Interface (API)

The Polaris APIs make it easy for OEM developers to integrate different Polaris operating commands and parameters into their host application software. The API is built directly into the Polaris system; it is not a separate software package that needs to run on the host computer. The API encompasses a wide range of functions, from data streaming and measurement rates to tool transformations and user alerts.
For example, the Polaris Vega contains over 49 standard commands—and over 100 user parameters—for configuring and controlling the Polaris Vega from the host application software. Specific commands for the Polaris Vega VT video camera are also included.

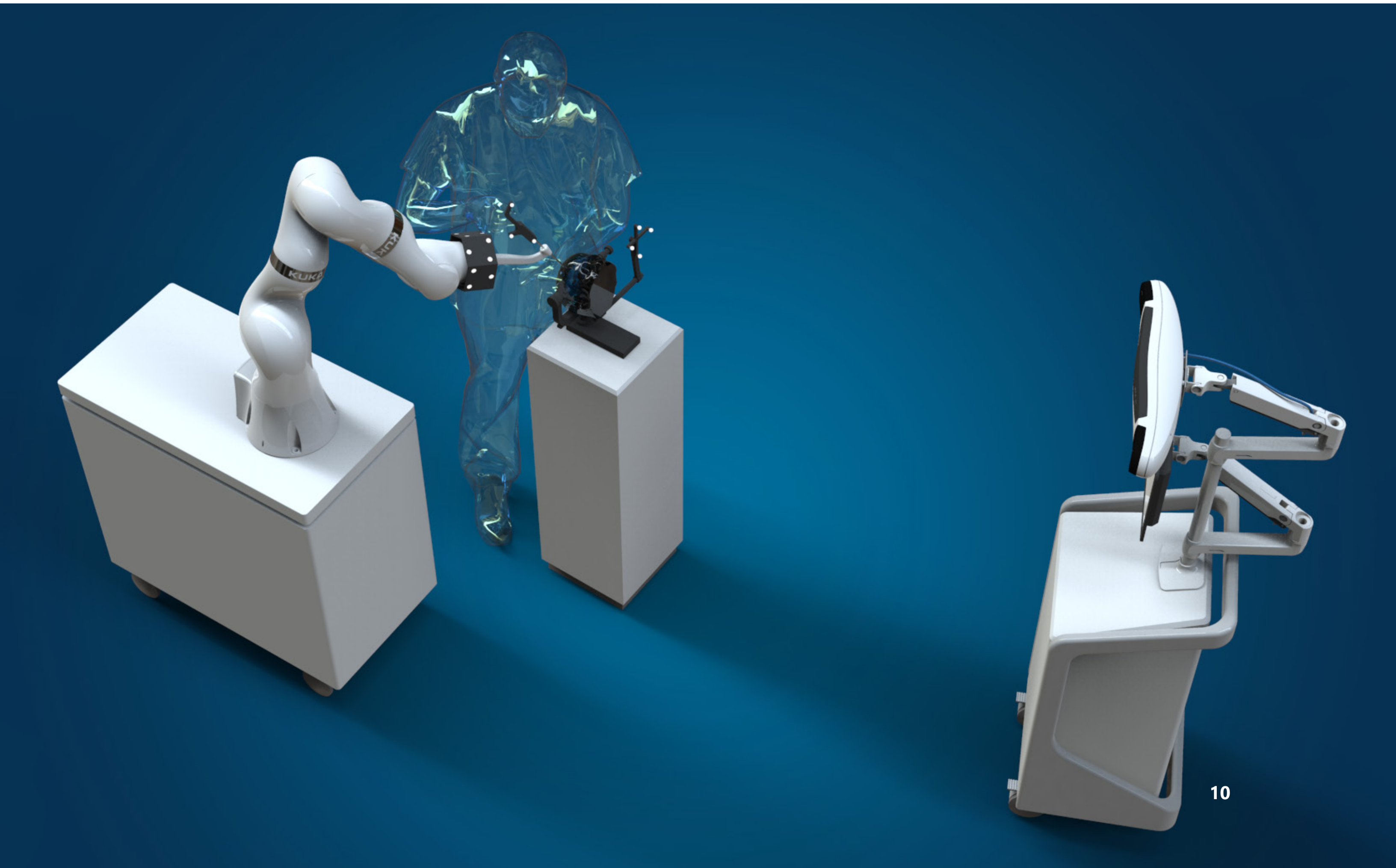
Application Program Interface (API) Sample

This sample source code helps developers to better understand how to communicate with the Polaris system through its API, and provides guidance for integrating the system with custom software applications.

Integration with Robotic-Assisted Systems

The trend towards minimally invasive surgical services continues to grow and the use of robotics is becoming an important component of these services. Research indicates that the inclusion of navigation technology can improve robot path planning, implant/device placement, and real-time tool positioning, during robotic-assisted procedures. Today, image-guided systems are integrating robotics into workflows for a variety of procedures including spinal and laparoscopic surgery, where they can be used in applications such as pedicle screw placements and bone milling. Another application includes Transcranial Magnetic Stimulation (TMS), where robotics contributes to improved reliability, accuracy, and repeatability of coil positioning, coil contact, and reduced human bias.[1]

The use of image-guided, robot-assisted tools in these procedures demands high-accuracy that cannot be achieved without the use optical tracking systems to correctly calibrate and monitor the robotic system and attached tools. The Polaris Vega® XT combines unrivalled measurement accuracy, high-speed tracking, and low latency, facilitating easy integration of 3D tracking within surgeon-controlled workflows, autonomous OEM robotic surgery systems, and applications. When used as a component of an OEM robotic-assisted surgical system, the Polaris Vega XT can track the positions of the robot base and end-effector in 3D space via attached navigation markers. The Polaris Vega XT can track the robot, surgical instruments, and patients in real time relative to each other, within the same coordinate system, during the same procedure.



Support for Augmented Reality Applications

Our specialized optical tracker, the Polaris Vega® VT, combines accurate optical measurement and live video streaming, which supports the development of augmented reality and machine vision in OEM system workflows. As with all Polaris optical trackers, the Polaris Vega VT can track OEM instruments via navigation markers. The HD video camera provides a live view of the instruments (and procedure occurring within the measurement volume) using a third-party streaming client.
IR tracking data and video data are aligned to a common coordinate system – the IR sensors and HD video camera see the same thing at the same time. Medical device OEMs can use this technology to enhance existing approaches, or introduce augmented reality and machine vision capabilities to their systems, for example:

- Adding AR visualization of internal structures via image fusion.
- Studying joint range of motion before/after implant surgery.
- Registering tools automatically by scanning barcodes.
- Augmenting patient case files with procedural recordings.
- Consulting with remote staff via streamed video feed.
- Recording pre-op rehearsals to enhance surgical planning.

Common Applications of Optical Tracking Technology

The performance and versatility of optical measurement tracking solutions have enabled real-time 3D tracking technology to be integrated into increasingly sophisticated applications and markets, including academic research, medical trainers, and medical device manufacturers. Here are some examples of how our OEM medical device customers have incorporated our tracking technologies as a component of their system workflow.

Neurosurgery

Establish the patient coordinate system using rigid bodies, which act as fiducial markers during patient-to-image registration. Point-based mapping enables tool planning through cranial anatomy.

Spinal Surgery

Fuse tracking data with preoperative images, which helps enable instrument visualization and navigation during planning and placement of pedicle screws or during microdiscectomies.

Radiation Therapy

Maintain accurate positioning and delivery of radiation to the target site by monitoring movement of the patient couch, and movement of the marker block used for respiratory gating.

Robotic-Assisted Surgery

Track the position of the robot base, surgical tools attached to the end-effector, and the patient, at update rates required for closed-loop, robotic-guided orthopaedic procedures such as spinal fusion and joint replacements.

ENT or FES Surgery

Track the positions of endoscopes, shavers, and suction devices in real time to avoid contacting the optic nerve, as well as other critical cranial anatomy near the sinuses.

Orthopaedic – Arthroplasty

Register and track bony anatomy for positioning and alignment of implant fit, measurement of joint rotations, and offsets. Visualize and guide the angle and depth of tool cuts.

Conclusion

Optical tracking systems, such as the Polaris Vega, provide the best measurement accuracy over the largest measurement volume of any comparable tracking technology. In order to meet the stringent standards of OEM image-guided applications, the tracking system should:

- Provide tracking over a large measurement volume.
- Be factory calibrated.
- Deliver sub-millimetre accuracy.
- Provide consistent and reliable measurement results.
- Offer customization and tool integration options.

Although the other factors described in this guide are just as important in differentiating between tracking systems intended for medical applications, these are the core unchanging attributes. The measurement environment, equipment setup, even integration with third-party hardware and software can be modified by the user to improve system performance.

About NDI

NDI is the world's pioneer and leading manufacturer of optical measurement and electromagnetic tracking solutions for OEM image guided surgical systems. We are grateful to have the opportunity to partner with the world's foremost OEMs in markets including but not limited to medical device, simulation, and medical research. Founded in 1981, NDI is headquartered in Waterloo, Ontario, Canada with manufacturing facilities in Waterloo, Germany, and the U.S., and a sales office in Hong Kong.

Endnotes

1 Rossi, Simone (2020). Safety and recommendations for TMS use in healthy subjects and patient populations, with updates on training, ethical and regulatory issues: Expert Guidelines - ScienceDirect. Retrieved from https://www.sciencedirect.com/science/article/pii/S1388245720305149?via%3Dihub.

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