Evaluation of the Intel RealSense SR300 camera for image-guided interventions and application in vertebral level localization

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ABSTRACT

PURPOSE: Optical pose tracking of medical instruments is often used in image-guided interventions. Unfortunately, compared to commonly used computing devices, optical trackers tend to be large, heavy, and expensive devices. Compact 3D vision systems, such as Intel RealSense cameras can capture 3D pose information at several magnitudes lower cost, size, and weight. We propose to use Intel SR300 device for applications where it is not practical or feasible to use conventional trackers and limited range and tracking accuracy is acceptable. We also put forward a vertebral level localization application utilizing the SR300 to reduce risk of wrong-level surgery.

METHODS: The SR300 was utilized as an object tracker by extending the PLUS toolkit to support data collection from RealSense cameras. Accuracy of the camera was tested by comparing to a high-accuracy optical tracker. CT images of a lumbar spine phantom were obtained and used to create a 3D model in 3D Slicer. The SR300 was used to obtain a surface model of the phantom. Markers were attached to the phantom and a pointer and tracked using Intel RealSense SDK's built-in object tracking feature. 3D Slicer was used to align CT image with phantom using landmark registration and display the CT image overlaid on the optical image.

RESULTS: Accuracy of the camera yielded a median position error of 3.3mm (95th percentile 6.7mm) and orientation error of 1.6° (95th percentile 4.3°) in a 20x16x10cm workspace, constantly maintaining proper marker orientation. The model and surface correctly aligned demonstrating the vertebral level localization application.

CONCLUSION: The SR300 may be usable for pose tracking in medical procedures where limited accuracy is acceptable. Initial results suggest the SR300 is suitable for vertebral level localization.

Keywords: optical tracker, Intel RealSense, pose tracking accuracy evaluation, vertebral level localization

1. PURPOSE

Computer-assisted interventions, involving position tracking devices, are becoming an integral part of modern medicine. The most commonly used position tracking devices in patient care are optical trackers. Optical trackers are typically accurate and reliable, but they tend to be expensive (ranging typically from about $5,000 to $40,000, especially those with higher accuracy), and relatively large, taking up valuable room in an operating area. For example, the popular Polaris tracker (NDI, Waterloo, ON, Canada) camera size is 613x104x86 mm and weighs almost 2 kg. It is not always feasible or practical to use a conventional optical tracker for all procedures, for example, where high portability is needed.

In this paper, we investigated if the Intel RealSense SR300 camera (Intel, Santa Clara, CA, USA) could be a suitable alternative to conventional optical trackers in applications where a small device is preferable and lower accuracy is acceptable. The SR300 is 110x12.6x4.1 mm, cost $130, and the camera module weighs less than 10 grams. It is portable and can be mounted on a tablet and also available integrated into tablet computers. The camera's operating range (20-120cm) is optimal for close-up tracking of surgical interventions. The camera is compatible with modern Windows computers and tablets with a USB 3.0 connection and also available as built into tablet computers. Kinect (Microsoft, Redmond, WA, USA) is a similar device to the SR300, but Kinect is optimized for room-scale imaging. Alnowami *et al.* tested the depth accuracy of the Microsoft Kinect resulting in an error between 1-10 mm depending on the distance from the camera [1]. Noonan *et al.* also used the Kinect to test the accuracy of marker-less tracking which suggested the more the object moves the greater the error [2]. We have not found any publications about the accuracy of the SR300 used as an optical tracker.

Spinal surgery is an intervention where low-accuracy tracking may be utilized. During spinal surgery, the surgeon must correctly identify the vertebra they intend to operate on. In some cases, the vertebra is wrongly identified resulting in wrong-level exposure or wrong-level surgery. Although there are many factors that can lead to these outcomes, most are preventable. Such factors include anatomical variance, counting using a different technique in the operating room than in pre-operative planning, and low quality of images. Wrong-level surgery is often devastating to the patient and costly to the healthcare system; it was the second leading cause of malpractice litigation in 2012 [3]. To correctly identify the vertebral level, the accuracy threshold must be less than the length of a spinous process. To decrease the occurrence of wrong-level surgery, Nowitzke *et al.* created a method which utilized object tracking to correctly identify the vertebra using a registered probe and a reconstructed model of the patient's spine. This method has shown promising results. In all 17 cases reported, this method has produced the correct vertebral level but used the large, expensive surgical navigation system (StealthStation, Medtronic Navigation, Minneapolis, USA) [4].

In this study, we evaluated the accuracy and robustness of the SR300 used as an optical tracking system. We tested the feasibility of using the camera for a vertebral level localization application.

2. METHODS

2.1 Tracking accuracy assessment

We compared accuracy and robustness of the SR300 camera to the Polaris optical tracker, which is a high-quality pose tracker with approximately 0.1mm accuracy.

2.1.1 Marker creation

As suggested in RealSense SDK documentation, we first evaluated using markers provided in the Metaio toolbox (Metaio, Munich, Germany) for object tracking. We found that RealSense SDK's 3D tracking method could not reliably distinguish these markers from each other. We created new markers (referred to as the RealSense marker) consisting of a simple asymmetric black and white pattern. Different sizes of markers were tested and we found that markers of 80x80mm size produced the most accurate results. Figure 1 shows a complex Metaio and our new marker.

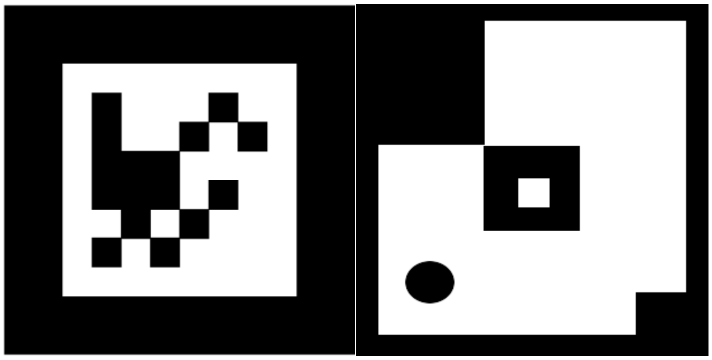

Figure 1. Metaio example alignment marker (left) and RealSense marker (right).

2.1.2 Software setup

The PLUS software toolkit ([5], www.plustoolkit.org) was extended so that the SR300 tracking data can be acquired and relayed to the 3D Slicer application (www.slicer.org) using OpenIGTLink protocol (Figure 2). SlicerIGT extension was used for calibrations and registrations (www.slicerigt.org) [6]. A PLUS configuration file was created to include a camera calibration file, marker files, and a temporal calibration. Camera calibration files (.xml) were created through Metaio toolbox. The Intel SDK supports two kinds of tracking: 2D tracking option allows the camera to track features on an image of a planar marker, while 3D tracking allows for a point cloud, generated from a 3D object, to be tracked. Typically, 2D tracking is steadier but its performance can be greatly degraded by variations in lighting conditions. PLUS supports both tracking methods.

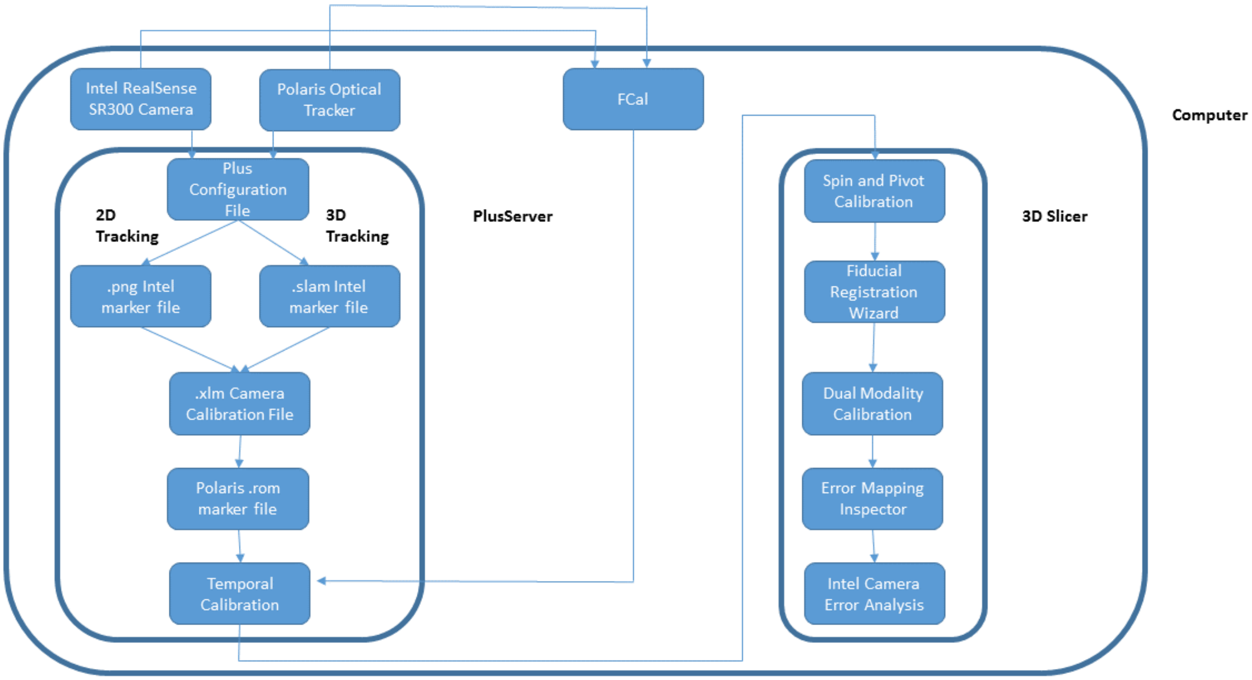

Figure 2. Configuration of equipment for error mapping analysis.

2.1.3 Experimental Setup

By adapting the method of Harish *et al.*, the tracking error of the SR300 was compared to a Polaris optical tracker in 3D Slicer [7]. The experimental setup is shown in Figure 3. We created a dual modality pointer which had markers for both SR300 and Polaris tracker. PLUS toolkit's temporal calibration method is used to compensate for latency difference between the two trackers. Position and orientation errors of the SR300 tracker relative to the Polaris were obtained. This was done by computing the ground truth transform of the Intel marker relative to the optical tracker using the Polaris (Figure 4) and comparing it to the transform obtained from the SR300.

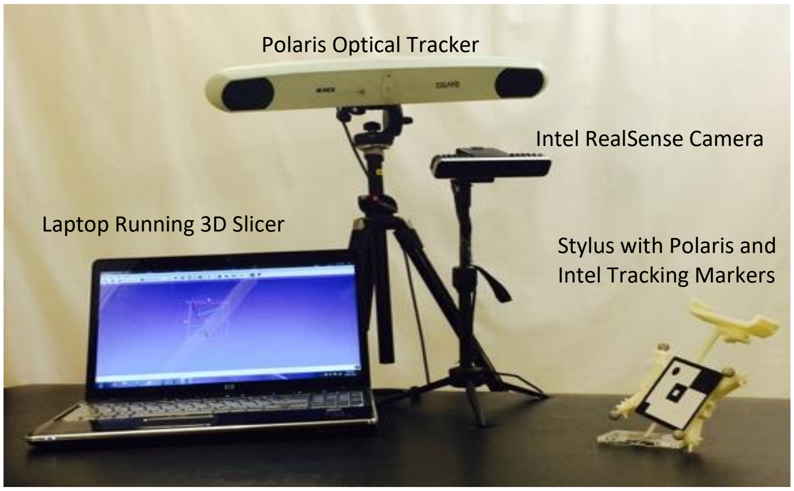

Figure 3. Setup of Polaris optical tracker and SR300 for error mapping.

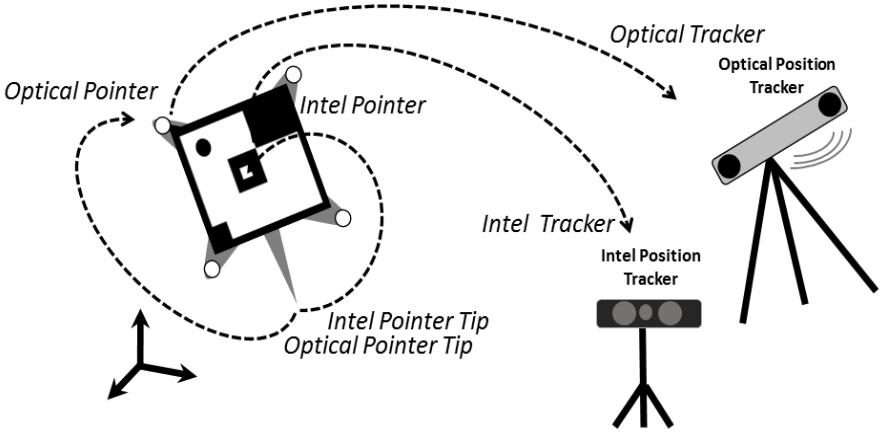

Figure 4. Coordinate systems and transforms used for accuracy evaluation.

2.2 Application for vertebral level localization

To test the feasibility of using the SR300 camera to aid in vertebral level localization we used the Spine Holder Set L1-Sacrum (Sawbones, Vashon Island, WA, USA). Circular markers were attached to the phantom's skin surface with 2.3 mm diameter metal balls in the center (Figure 5) so that the markers were visible in Cone Beam Computed Tomography (CBCT) image and to the optical camera of the SR300. A CBCT was taken of the spine within the holder and converted to a 3D surface model using 3D Slicer. The SR300 was used to acquire the surface of the phantom which was imported into 3D Slicer. Fiducial registration was used to register the model and surface using the circular markers. This aligned the acquired surface with the 3D model, which allowed for visualization of where on the skin the incision should be made to reach the correct vertebral level.

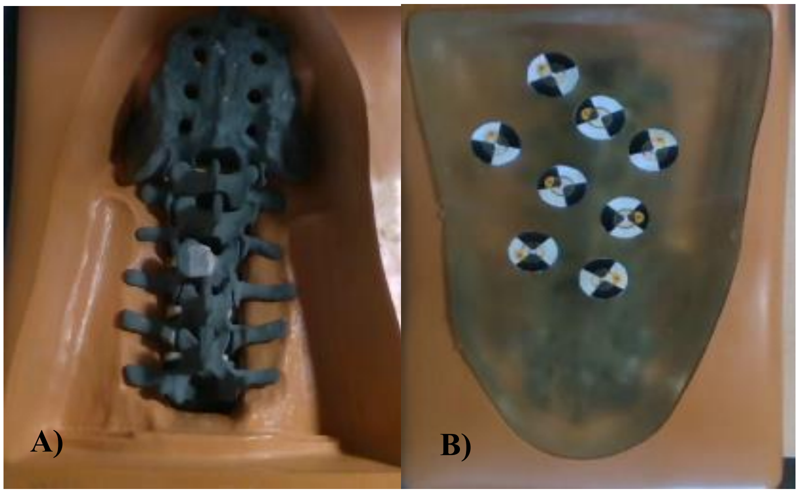

Figure 5. A) Spine phantom with exposed spine. **B)** Spine Phantom with Intel and CT markers attached to the skin.

3. RESULTS AND DISCUSSION

3.1 Results of tracking accuracy assessment

We quantified the tracking quality of the SR300. We found that small central regions of interest within the camera field of view provided the best results (Table 1). Figure 6-A shows a histogram of the position error for a region of interest of size 10x10x5 cm. The dual modality calibration method calculates the ground truth transform between the Intel marker and

Polaris tracker using an initial fiducial registration. When used to calibrate the dual-modality stylus for the results in Table 1, it resulted in a residual error of 3mm [7]. Figure 6-B shows the position and orientation error across the field of view.

Table 1. Position and orientation error calculated using the error mapping module in 3D slicer for the SR300.

Region of Interest	Position Error Percentile		Orientation Error Percentile	
	50th	95th	50th	95th
5x5x5 cm	2.24 mm	4.77 mm	1.21°	2.10°
10x10x5 cm	3.04 mm	5.85 mm	1.29°	2.28°
10x10x10 cm	3.45 mm	5.90 mm	1.57°	2.55°
20x16x10 cm	3.32 mm	6.67 mm	1.59°	4.29°

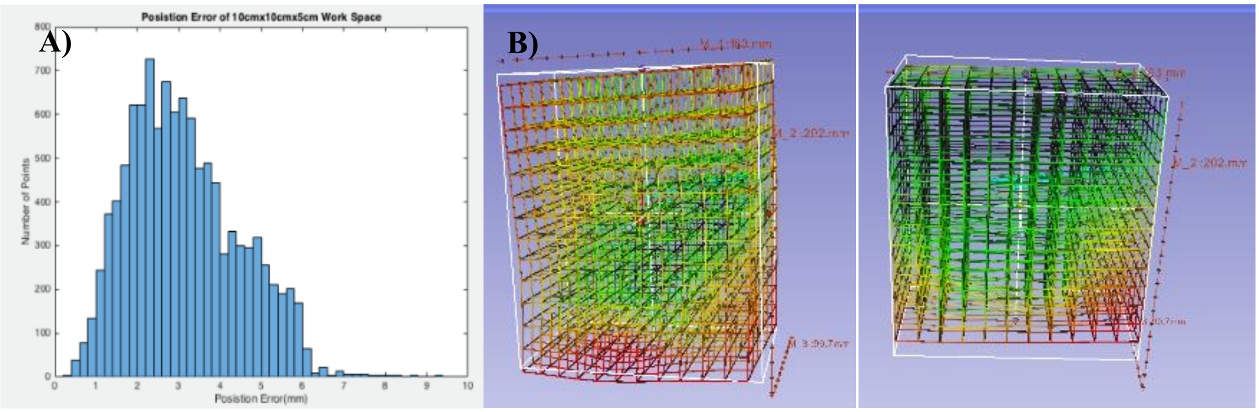

Figure 6. A) Position error in a 10x10x5 cm region of interest. **B)** Grid representation of position error (left) and orientation error (right) in a 20x10x16 cm region of interest; black = 0 mm, green = 1 mm, yellow = 3 mm, red >=5mm.

3.2 Discussion

The study revealed that tracking accuracy was improved when the marker and camera were closer together. To obtain acceptable results for this application a marker should be no more than 450 mm away from the camera although the camera specification states operation range up to 1200 mm. The z axis of the SR300 represents depth (Figure7). The z axis fluctuates the most in its tracking values whiles the x and y axis remain relatively stable.

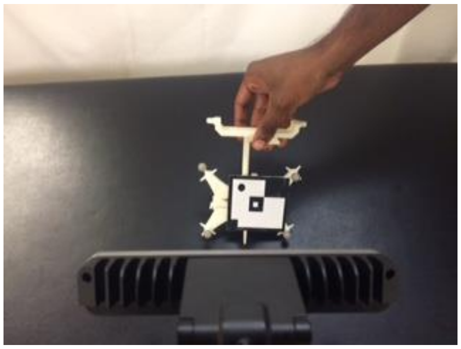

Figure 7. Dual-modality pointer shown from the SR300’s camera point of view (Z axis).

The tracking robustness was found to be dependent on lighting especially when 2D tracking method was used. If the lighting is changed in a room, the camera may stop tracking. In the initial position of a marker, it had to be fully visible to the camera and facing towards the camera. This orientation had to be approximately preserved to avoid losing tracking. Large rotation of a marker from its initial position sometime caused large position and orientation error, or even complete loss of tracking. To correct for this, the marker had to be moved back to the initial position.

We found that the current SDK only uses depth information for initial the marker characterization and not during the tracking process. The results above highlight the effect of this limitation: the depth and orientation of the marker cannot be accurately obtained using only the optical camera image. We believe that tracking accuracy could be greatly improved by a future SDK update, which would make the tracking method utilize the acquired depth information.

3.3 Results of vertebral level localization

This application of the camera shows it is feasible to visualize vertebral levels using inexpensive equipment and eliminates the need for intraoperative fluoroscopy or CT. Figure 8 shows results visualized in 3D Slicer: view of the model spine (blue) overlaid with the spine surface and the CT view of the spine model and surface (pink) intersecting. Future experiments would need to be conducted to assess if this method could also be used to validate the vertebral level once bone is exposed, as in obese patients the skin may move considerably after the skin is cut.

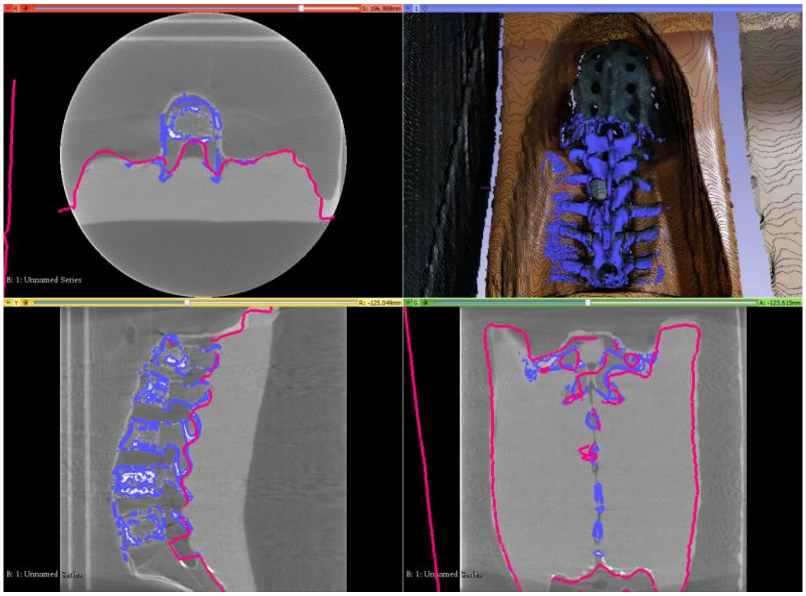

Figure 8. Registered CBCT and camera image visualization in 3D Slicer. Spine model constructed from CBCT image (blue) and spine surface provided by the camera (pink) intersecting with CT of the spine phantom and 3D view of model surface and model overlaid.

4. NEW OR BREAK THROUGH WORK

We evaluated accuracy and robustness by comparing the RealSense camera to a gold standard NDI Polaris optical tracker. The feasibility of using the SR300 to aid in vertebral level localization was demonstrated.

5. CONCLUSION

We evaluated the Intel RealSense SR300 to be used in medical interventions where it is not feasible or desirable to use a traditional optical tracker. The SR300 was tested in various ways to determine if it could provide accurate object tracking to be used in a clinical setting. The PLUS toolkit was extended to include for 2D and 3D tracking for Intel RealSense cameras. We explored potential sources of error that may decrease the accuracy of the SR300. We found that in optimal conditions that SR300 could reliably produce tracking results with less than 5 mm of position error. The feasibility of using this camera to aid in vertebral level localization was demonstrated using 3D Slicer and tested on a phantom.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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