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Towards markerless 3D pose estimation for Computer Assisted Orthopaedic Surgery: a comparison study of depth cameras

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Abstract

This abstract addresses the problem of localizing surgical instruments during orthopaedic surgeries. Compared to usual approaches based on surgical navigation with markers, we propose here a novel method that estimates the 6-DoF pose of surgical instruments without specific markers using a depth camera. The goal of this paper is to compare, on real data, the registration precision of an algorithm called Point Pair Features (PPF) according to consumer depth cameras available on the market. Experimental validation using sawbones has been conducted and 8 cameras have been tested in realistic clinical environment. The Kinect Azure reports the best precision with a registration error of 1.13mm ± 1.00mm.

1 Introduction

Knee arthritis causes cartilage between the bone joints to wear away and often leads to patient's joint pain. Total Knee Arthroplasty (TKA) is a common response to this disease and [1] forecasts a growth by 673% up to 3.48 million TKA procedures in the USA by 2030. Yet, around 24% of TKA patients declares being unsatisfied with the postoperative results [2]. Besides, surgeons are traditionally guided by navigation systems during the operation. However, these solutions require both expensive sensors and additional time and complexity in the surgical workflow mainly due to the markers attached on patient bones. Therefore, we propose to evaluate the precision of an algorithm called Point Pair Features (PPF) [3] which could be used to estimate intraoperatively the 3D pose of orthopaedic cut guides. The goal is to compare the precision of different general public depth cameras according to this algorithm.

2 Methods

The PPF algorithm was tested on ex-vivo realistic data: we placed the surgical cut guide on a sawbone at 50cm from the depth sensor in an operating room with scialytic lighting conditions and measured this error for a dataset of 100 real scenes for each of the 8 evaluated depth camera. Thus we evaluated the 3D pose estimation PPF algorithm on around 800 real data captured by the cameras described in the table 1. The calculated registration error corresponds to the distance between points belonging to the cut guide in the scene and the registered model mesh computed by the PPF algorithm. This error defines a distance map between the registered model and the scene.

Camera	Technology	Range (m)	Depth Resolution +FPS	Field of View
Intel RealSense D415	Active Stereo (rolling shutter)	0.16-10	1280x720 @30FPS	63° Hor 40° Ver
Intel RealSense D435	Active Stereo (global shutter)	0.11-10	848x480 @30FPS	85° Hor 58° Ver
Orbbec Astra S	Structured Light	0.4-2	640x480 @30FPS	60° Hor 50° Ver
Orbbec Astra Embedded S	Structured Light	0.25-1.5	1280x800 @30FPS	68° Hor 45° Ver
Occipital Structure Sensor	Structured Light	0.4-3.5	640x480 @30FPS	58° Hor 45° Ver
Occipital Structure Core	Active Stereo (global shutter)	0.3-10	1280x960 @54FPS	59° Hor 46° Ver
Microsoft Kinect V2	Time of Flight	0.5-4.5	512x424 @30FPS	70° Hor 60° Ver
Microsoft Kinect Azure	Time of Flight	0.25-5.46	1024x1024 @15FPS	120° Hor 120° Ver

Table 1: List of evaluated depth cameras and hardware specifications

3 Results

To begin with, both D435 and D415 provide respectively a mean registration error of 2.83mm ± 1.80mm and 2.67mm ± 1.52mm and many false positives estimated pose of the cut guide mainly due to the poor raw depth accuracy in presence of scialytic illuminations. KinectV2 performs also poorly because of the sensor low resolution which generates too few points to localize the surgical instrument in the scene for PPF algorithm. Then Astra S, Embedded S as well as Structure Sensor and Core give decent similar results (median around 1.30mm). Finally, the Microsoft Kinect Azure shows the best results with a mean registration error of millimeter order (1.13mm ± 1.00mm). Results are provided in the Figure 1.

Camera	Mean error (mm)	Standard deviation (mm)	Median (mm)	Minimum (mm)	Maximum (mm)
Intel RealSense D435	2.83	3.08	1.80	0.000864	21.4
Intel RealSense D415	2.67	3.79	1.52	0.000580	30.4
Microsoft Kinect V2	3.73	4.50	2.13	0.000825	42.3
Orbbec Astra S	1.26	0.791	1.29	0.00000724	5.48
Occipital Structure Sensor	1.30	0.75	1.35	0.000882	5.11
Occipital Structure Core	1.76	2.05	1.36	0.00000603	40.3
Microsoft Kinect Azure	**1.13**	**1.00**	**0.85**	**0.000155**	**8.31**
Orbbec Astra Embedded S	1.29	0.76	1.39	0.000500	31.7

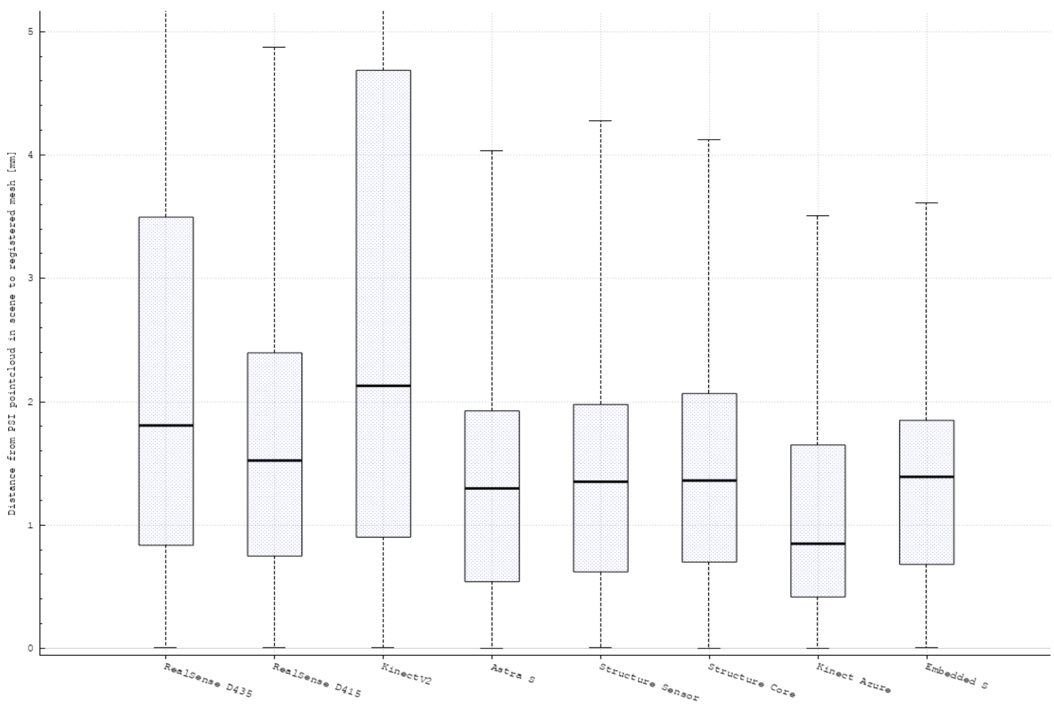

Figure 1: Statistical precision of compared depth cameras for 3D pose estimation

4 Conclusion

This study intended to compare low cost depth cameras precision for the markerless 3D localization task in the computer assisted orthopaedic surgery context. Not only such approach could reduce both intervention complexity and time associated to existing surgical navigation systems but also proved to be relevant in terms of precision. Indeed, the Kinect Azure shows a distance map mean registration error of 1.13mm, which could be suitable for TKA. Moreover, the results are very encouraging compared to the state of the art: [4] is similar to our work and intends to register intraoperatively bone surface with depth camera with a precision of 6.18mm. [5] also reports an higher average registration error of 11.46mm on real data for similar task. However, the 3D pose estimation algorithm precision could be further compared to traditional orthopaedic navigation with translation and angular error metrics and this proof of concept could also be pushed to even more realistic environment with cadaver soft tissues.

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