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Medical optical localizer based on Apple iPhone smartphone

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Abstract

Medical navigation providing intraoperative localization of medical instruments plays a crucial role in computer assisted surgery (CAS). Several different multiple-camera standalone optical localizers are available on the market nowadays. Our aim was to develop, easy-to-use, low-cost and portable medical localizer based on iPhone 6S camera. We decided to develop a specialized smartphone app which is able to detect two rigid bodies (RB) on the camera screen and estimate their position both in devices and global coordinate system using sensor fusion with smartphones accelerometer and gyroscope. In the procedure one RB serve as reference and the other is attached to the tool. The prototype was preliminary calibrated using 2D and 3D VDI/VDE 2634 standard. Validation procedure involved measurements of the position and distance of two RBs placed 500 mm from each other in a distance of 1 meter to the smartphones camera. The measurements were taken from three different angles: -30°, 0°, 30° regarding RBs plane. The standard deviation of the measured distance was 0.62 mm with average measured distance of 498.0 mm. The other tests were made in a test-setup where the virtual offset of ultrasound probe was added to one of the RBs so the distance between probe and reference was 195 mm. The tests showed that the position of ultrasound probe is estimated with standard deviation of 0.70 mm and the average measured distance is 195.18 mm. Due to the promising results of those evaluations, we plan to perform more specific tests in clinical setup in near future.

1 Introduction

Medical navigation providing intraoperative localization of medical instruments plays a crucial role in computer assisted surgery (CAS) improving implant alignment among other things (Mielke 2001). There are several different optical localizers available on the market nowadays. Most of them are multiple-camera standalone specialized systems, which are usually expensive and difficult to use for the user (Lavernia 2007). Mobile devices such as tablets and smartphones becomes popular nowadays in clinical practice (Mobasheri 2015). There is also more and more trials to provide a handheld navigation device for CAS (Nam 2016), mostly using gyroscopes and accelerometers (Thiengwittayaporn 2016). Our aim was to develop single-camera, easy-to-use, portable, and low-cost medical localizer based on a mobile device. The whole idea of mobile localizer is presented on fig. 1. As it is shown, two rigid bodies (RBs) reflects light to the smartphone camera so they are visible on the devices screen. Each rigid body is built from four round reflective markers arranged in a specific way. The localizer application is able to detect those rigid bodies and estimate their position in 3D coordinate system. The localizer was developed as standalone mobile application. It can be used on every supported smartphone. We decided to use iPhone 6s and iPhone 6s Plus smartphones because of their high performance, reliability and good optical parameters of their cameras (Apple iSight cameras). Moreover, iOS operating system which is used in both devices is the only one on the mobile market providing data security both in hardware and software, which is essential for the medical applications.

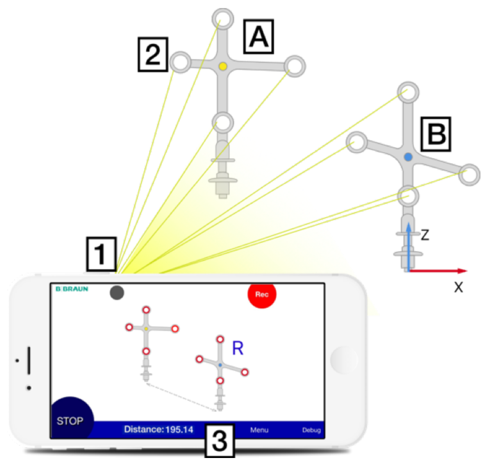

Figure 1: The idea of mobile localizer application on smartphone. Two rigid bodies (A and B) reflects the light from their markers (2) to the smartphone camera (1). The position and distance between both RBs is then computed on smartphone screen (3).

2 Materials and methods

In our approach we used iOS localizer application, presented on Fig.2 which performs a set of algorithms to detect and estimate the position of two rigid bodies in a real world coordinate system. The localizing procedure consists of two stages. In the first stage, the markers of each rigid body are detected on the camera screen. Firstly, the image from the camera is transformed to grayscale to reduce the redundant data, then thresholding is performed. After that, the contours on a black and white image are being found and validated to distinguish marker contours from other distortions. To validate the markers we used and isoperimetric quotient Q. Isoperimetric quotient equals 1.0 for perfect circle. In our implementation every contour with $Q > 0.85$ is classified as a rigid body's marker. This method was chosen because of low complexity which was a key factor in real time vision application. The second stage of the algorithm is to make a 3D reconstruction of the position of rigid bodies markers based on their 2D coordinates. This is performed by using iterative method with

Levenberg-Marquardt optimization to find 2D-3D point correspondences (Moré 1977). Each found position is then validated by computing reprojection error. To estimate the position of the rigid bodies regarding earth, we used gyroscope, accelerometer and magnetometer sensors data in a form of rotation matrix. This matrix is computed each time when the camera frame is acquired. To make the whole 3D reconstruction possible, each camera needs to be calibrated. We decided to use both 2D camera calibration procedure with chessboard pattern (Zhang 2000) as well as 3D pattern camera calibration according to VDI/VDE 2634 standard (VDI/VDE 2012).

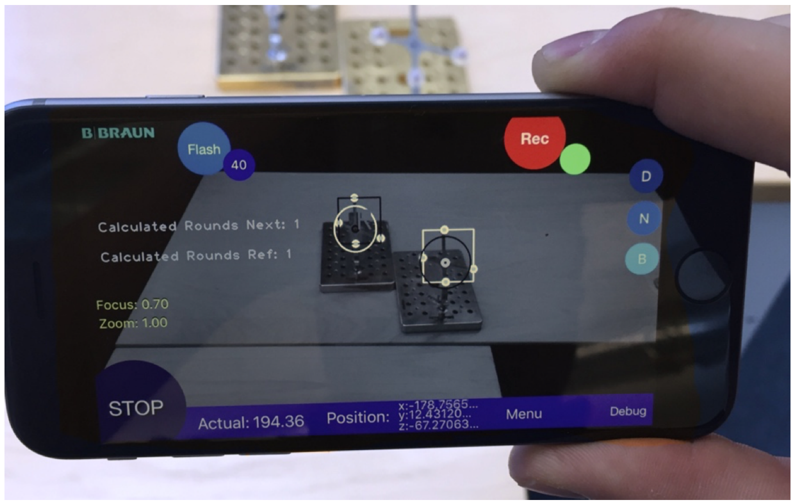

Figure 2: Overview of the localizer prototype

3 Results

To validate the localizer we have measured the position and distance of two rigid bodies placed 500 mm from each other from the distance of 1 meter to the smartphones camera. The measurements were taken in three different angles: -30°, 0°, 30° regarding RBs plane. The standard deviation of the measured distance in first validation trials was 0.64 mm with average distance of 498.0 mm. The other tests were made in a test-setup where the distance between rigid bodies was 200 mm, however, one rigid body had virtual 3D offset of standard ultrasound probe and was shifted 70 mm in camera's Z axis. The virtual distance between probe and the reference rigid body was 195.0 mm. The tests showed that the position of ultrasound probe is estimated with standard deviation of 0.70 mm and the average measured distance is 195.18 mm.

4 Discussion

We found out that the results of the first test trials are very promising for further development and clinical usage. The great advantage of our system is that it is easily scalable and embeddable in other applications like pelvic tilt measurements (Martin 2016) or in percutaneous pedicle screw surgery (Alk 2016). Moreover, Bluetooth and WiFi connectivity makes the integration with other devices possible, for example with Microsoft Surface or other tablets, smartphones and PCs which are widely used among modern orthopedic surgery (Pastides 2016). WiFi connectivity allows us to think about cloud integration or integration with Hospital Information Systems to provide better access to medical navigation results.

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