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Original Research Article

Recognizing the surgical situs in minimally invasive hip arthroplasty: A comparison of different filtering techniques

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ABSTRACT

Purpose: Detecting the soft tissue envelope and determining the work space available of the surgical situs during surgery is important for advanced instrument navigation techniques, wound care treatment, augmented reality, and instrument design. Different filtering techniques were evaluated to increase detectability of the soft tissue envelope.
Methods: An algorithm was built for a time of flight (TOF) camera which recognizes the boarders of the soft tissue envelope. Different filtering techniques were tested on a dataset of eight surgical siti.
Results: By using a median filter, a temporal filter and combining different input information provided by the time of flight camera by a logic operation the proposed algorithm was able to recognize the surgical situs in 73% of the images on average.
Conclusions: The use of a TOF camera can introduce a new tool for recognizing the soft tissue envelope of a surgical approach.

1. Introduction

Time of flight (TOF) cameras are used in different applications for three dimensional (3D) mapping in robotic navigation [1–3], computer graphics [4], as well for gesture recognition [5–7]. In the medical field they are used for endoscopy [8], respiratory motion detection [9], enhancement of intra-operative images in augmented reality applications [10], and gait analysis [11].

Photonic mixing device (PMD) cameras combine fast imaging, and high lateral resolution with depth information of the captured scene. TOF-PMD 3D scanners are by far the preferred choice for accurate measurements of large structure

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at long range, because range accuracy is relatively constant for the whole volume of measurements [12].

Computer assisted navigation and augmented reality are currently evolving fields in surgery. With the advent of new surgical techniques in hip arthroplasty, such as robotic assisted surgery, it is important to recognize the available working space for surgical instruments in order to limit the movements inside established borders.

Dimensional assessment of large and complex objects requires the use of accurate 3D registration techniques. 3D simultaneous localization and mapping is becoming a very important research area for robot navigation and object recognition, as the robot can reconstruct the specific environment in which it is moving [2,13]. This additional object recognition information can also be used for guiding the surgeon and for developing so called ''smart tools''.

In this study we describe a first attempt to use a TOF-PMD camera in an orthopaedic application, where the camera is used for recognizing the soft tissue envelope in a minimally invasive (MIS) approach to the hip. The MIS direct anterior approach (DAA) to the hip is characterized by a reduced working space for the surgeon. Due to the reduced working space, special instrumentation was developed for this procedure [14]. Measuring the space inside the surgical situs during different operation steps has never been described in literature and may lead to better instrument design for minimally invasive hip surgery.

The aim of this study was to analyze different image processing methods in order to develop an algorithm that identifies the soft tissue envelope in real-time during minimally invasive hip arthroplasty with a TOF-PMD camera.

2. Materials and methods

A TOF-PMD camera (CamCube2, PMD Technologies GmbH, Siegen, Germany) was used for the experiments. The PMD camera provides 200×200 grayscale images as well as distance (depth) and amplitude values for each pixel at a frame rate of 40 fps. The TOF-PMD camera technology is based on the principle of modulation interferometry [15]. The camera consists of an optical transmitter and an optical receiver [6,12,16]. Objects in the scene are illuminated with near-infrared light which is reflected. The difference between both signals, emitted and reflected, causes a phase delay that is detected for each pixel and used to estimate the distance. Thus, the TOF-PMD camera provides 2D depth information of dynamic or static scenes irrespective of the object's features. Given the speed of light, c, the frequency modulation, ω, the correlation between signals for four internal phase delays $r_1(0)$, $r_2(90)$, $r_3(180)$, $r_4(270)$, the camera computes the phase delay, φ, the amplitude, a, and the distance, d, as follows:

$$\varphi = \arctan\left(\frac{r_2 - r_4}{r_1 - r_3}\right) \quad (1)$$

$$a = \frac{\sqrt{(r_2 - r_4)^2 + (r_1 - r_3)^2}}{2} \quad (2)$$

$$d = \frac{c\varphi}{4\pi\omega} \quad (3)$$

The PMD camera has two adjustable parameters: the modulation frequency and the integration time. The modulation frequency was set to ω =20 MHz, as recommended by the manufacturer.

The stability of the obtained measurements, such as intensity and distance of the range images, depends on the integration time. The integration time, t, was set to 50 μs previously adjusted in relation to the distance of the objects which appear in the environment (10–1000 mm) [15]. Using the application programming interface of the PMD Camera (PMDSK2 V.2.2.1, PMD Technologies GmbH, Siegen, Germany) the output data, distance, intensity and amplitude values of each frame, were calculated using the signal processing package of MATLAB® (MATLAB® R2011b, MathWorks®, Natick, MA, USA). Using these three input datasets, a 3D point cloud can be calculated. An algorithm was developed in MATLAB® to test different filters and the set up of the algorithm. The simplified working principle of the algorithm is shown in Fig 1.

The algorithm consists of several steps, which will be explained in detail in the following section. First, an image correction is applied to the input data and unnecessary background information is removed. The images are filtered to reduce noise, and an edge detection filter is applied. A logic operation combines the different inputs and, after a border dilatation, the resulting region is filled by a fill operation. The corresponding area of the surgical situs is selected from the other recognized areas using its elliptical shape. The selected area is then used as a mask to select 3D coordinates of the surgical situs. In order to improve the algorithm a temporal filter is introduced, which takes the average of two or multiple masks and combines the 3D coordinates in successive time steps. To compensate the movement of the camera each mask with its 3D coordinates has to be rotated and translated to the previous time step. The area is calculated using the Delaunay triangulation [17].

2.1. Input data

The raw data from the distance, intensity and amplitude images, obtained with the TOF-PMD camera and imported to MATLAB® with the application programming interface, were scaled to a gray scale image with a range from 0 to 1 (Fig. 2).

2.2. Image correction

The amplitude image given by a TOF-PMD camera has the drawback that objects located farther away appear darker than those located near the camera. Since the power of a light wave decreases with the square of the distance it covers. In order to compensate for this, the amplitude data can be corrected by the following statement described in the study of Oprisecu et al. [18]:

$$A'(i,j) = A(i,j)D^2(i,j) \quad (4)$$

where $A(i, j)$ are the amplitude values of each frame, $D(i, j)$ are the distance values and $A'(i, j)$ represents the corrected amplitude value of a pixel. This formula can be additionally modified to optimize the results with an adaptive-neighbourhood filter (ANF). The basic principle of ANF is to derive, for each pixel, a neighbourhood variable in size and shape that, ideally, contains