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Quality of stereo matching with structured light in dependence of projecting light sources

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Abstract: Minimally invasive surgery enables fast and secure interventions. A further development step might be image-guided laparoscopy, machine-learning-based tumor detection and autonomous robotic surgery. These applications require surface reconstruction of the affected organs which must be highly accurate. A stereoscope might achieve this in combination with structured light. This paper explores two different light sources that generate random patterns to assist stereo matching algorithms in poorly structured environments. The experiment includes a stereo laparoscope, a folded white paper, a laser module and a digital light processing projector. The results show that the projector outperforms the laser.

I. Introduction

Laparoscopic surgery can be seen as state-of-the art procedure for most surgical interventions, e.g., liver resection. Laparoscopes can be equipped with monocular or binocular camera heads. Stereoscopic laparoscopes outperform monocular ones because of the ability to visualize depth. A further advantage is the ability to measure depth (distance from camera to object surface). This opens the door to more advanced applications in minimally invasive surgery such as image-guided interventions, virtual 3D organ models and autonomous robotic surgery [1].

I.I. Depth measurement by stereoscopy in combination with structured light

Optical depth measurements can be performed by different technologies. One possibility is stereoscopy where stereo matching algorithms detect corresponding pixels in the stereo camera´s left and right image. By this, the disparity d between the left and right image is computed pixelwise so that a disparity map can be created. By triangulation, depth z is calculated which requires the intrinsic and extrinsic camera parameters stereo base b and focal length f, as in (1).

$$z = \frac{b \cdot f}{d}. \qquad (1)$$

The target of stereo matching is a dense disparity map and depth map (3D point cloud). Some objects lack high structured and textured surfaces making feature detection challenging. Moreover, in-vivo organs suffer among others from shine, reflections and movement [2]. In such a difficult environment, structured light could assist in feature detection by projecting light patterns onto the organ surface [3]. The following section presents a comparison between a laser and a digital light processing (DLP) projector regarding its application in stereo matching.

II. Material and methods

Two experimental set-ups (A and B) were distinguished to explore the effect of different structured light sources on stereo matching. The experimental set-up A consists of a TIPCAM 1 S 3D stereo laparoscope with a 0° optic (KARL STORZ SE & Co. KG), a folded white paper as well as a laser module in a combination with a diffractive optical element (DOE) (Laser Components Germany GmbH). In set-up B a DLP projector replaced the laser.

The laser´s DOE created a random dot pattern and emitted light with a wavelength of 660 nm shown by Fig. 1.

Figure 1: Photograph of a folded white paper and the laser projection (random pattern) as part of the experimental set-up A.

The beamer projected a random pattern (random distribution of dots in black and white), as in Fig. 2. The distance from camera to paper was 70 mm in set-up A and B. For stereo camera calibration and stereo matching, algorithms of the open-source library OpenCV were taken and applied in python. Visualization was performed with the open-source library vtk.

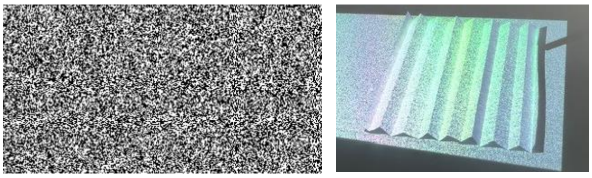

Figure 2: Demonstration of a random dot pattern in black and white which is projected onto the paper´s surface by a DLP projector.

III. Results and discussion

The stereo matching results are presented in form of a disparity map and a 3D point cloud. Set-up A (laser) created a sparse disparity map which also ends in a sparse and inaccurate 3D point cloud (Fig. 3 and Fig. 4). The poor quality is obvious, especially when observing the many outliers in Fig. 4. The shape of the folded paper cannot be recognized when looking at the 3D point cloud.

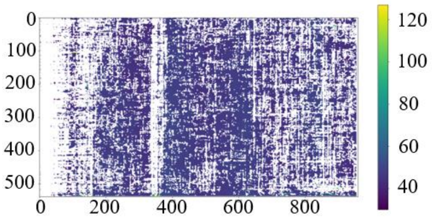

Figure 3: Screenshot of disparity map of set-up A. Many white spots, which correspond with Not a Number (NaN) values, are present. The blue colored spots represent disparity values around 40 Pixel.

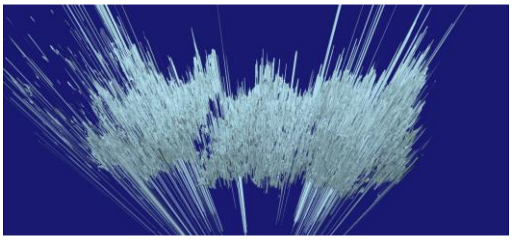

Figure 4: Screenshot of 3D point cloud of set-up A. The blue colored area works as background and in grey the 3D points are represented. Many outliers can be observed.

In comparison to that the beamer causes a dense disparity map as well as a dense and accurate 3D point cloud (Fig. 5 and 6). The folded paper can be clearly recognized. In the lower right corner many NaNs occur due to a blurred projection and blurred image quality.

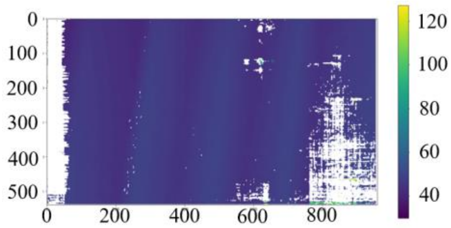

Figure 5: Screenshot of the disparity map of set-up B. White spots correspond with Not a Number (NaN) values of which only a few are present. The blue colored spots mean disparity values around 40 Pixel. The brighter the color the bigger the disparity and the higher the depth value.

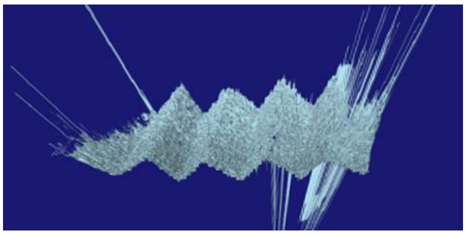

Figure 6: Screenshot of 3D point cloud of set-up B. The blue colored area works as background and in grey the 3D points are represented. Only a few outliers can be observed.

An explanation for the huge quality difference between laser and DLP projector is the appearance of speckles when laser light (coherent light) touches the surface. Speckles appear differently in the left and right image which complicates stereo matching. The advantage of laser modules is their miniaturization, e.g., BELICE-850 (ams OSRAM) with 3.4 mm x 3.5 mm x 3.56 mm footprint. A DLP projector within these dimensions cannot be found in the market to the best of our knowledge.

Within this work, no quantitative analysis has been done which must be considered during next analysis. Moreover, speckle reduction options should be examined as well as miniaturizing a DLP projector or alternative light sources. Related research approaches suggesting structured light with new pattern compositions, as in [4], could be reviewed and tested. An open assignment remains the comparison of structured light against other optical depth measurement methods.

IV. Conclusions

Achieving highly accurate surface reconstruction of the abdomen and its organs is challenging especially in poorly structured environments. Projected structured light assists stereo matching algorithms regarding feature detection. This preliminary research in a laboratory setting shows that projected light sources via DLP beamer may be superior to laser with DOE under certain conditions.

Author's statement

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