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CAMERA CALIBRATION ALGORITHM FOR LUNG NODULE DETECTION IN VIDEO-ASSISTED THORACOSCOPIC SURGERY

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ABSTRACT

Video-Assisted thoracoscopic surgery (VATS) is a minimally invasive camera-guided surgical technique that enables real-time visualization of the lung through small incisions, minimizing risks and enabling accurate diagnosis or interventions. This procedure plays a vital role in early lung cancer detection, facilitating precise biopsies and cell identification. Given the critical significance of this camera-guided technique, the production of high-quality, distortion-free images is of utmost importance for diagnostic accuracy and effective treatment. Therefore, in order to enhance lung cancer diagnostic accuracy and treatment effectiveness, this paper presents an algorithm for calibrating endoscopic cameras in VATS procedures. Based on Zhang Zhengyou's calibration method and utilizing the OpenCV computer vision library, the algorithm aims to optimize image quality, ensuring a clear and precise visualization. Moreover, this project explores potential grids that can be used within Zhang's method in order to refine camera calibration, emphasizing the critical importance of high-quality, distortion-free images in advancing medical practices.

Index Terms— Computer Vision, Videolaparoscopy, Medical Imaging, Algorithms, Endoscopic Cameras.

1. INTRODUCTION

Computer Vision is a pivotal domain when it comes to digital image processing and its applications in medicine are becoming increasingly important day by day [1]. It empowers computers and other systems to extract valuable information from images, videos, and other visual inputs. The aim of computer vision systems in general is to obtain image information from the camera, to calculate the location, shape and information of three-dimensional objects, and thus to identify objects in the space [2].

One of the key features of computer vision systems lies in their ability to mimic human vision by processing visual inputs and making decisions based on extracted information. This capability finds remarkable applications in the field of Biomedical Imaging, where images require meticulous analysis to enhance patient diagnoses and treatments.

Unlike human vision, which intuitively understands scenes thanks to the optic nerves and visual cortex, machines require training to achieve similar capabilities. Therefore, through rigorous training and sophisticated algorithms, computer vision systems can conduct in-depth analyses of images, quickly gathering substantial data from visual inputs.

The research presented in this paper, delves into the intricacies of capturing detailed images of patients' lungs through Video-Assisted thoracoscopic surgery (VATS), a camera-guided surgical procedure that offers real-time visualization of internal organs within the chest through small incisions [3]. VATS is part of the family videolaparoscopic procedures which have revolutionized modern surgery by offering minimally invasive techniques for the diagnosis and treatments of a variety of pathologies, reducing patient trauma, minimizing recovery time, and lowering the risk of complications compared to traditional open surgeries [3].

Although videolaparoscopic procedures offer significant advantages in the field of medicine, their effectiveness relies on the quality of the images captured by the cameras, which are the surgeon's essential visual tool [3]. Therefore, given the critical significance of this camera-guided technique, the production of high-quality, distortion-free images is of utmost importance to ensure a high-quality procedure.

In this project, the focus was on the study of endoscopic camera, a specialized medical device used to capture internal images of the body in VATS procedures. This compact camera is attached to a thin, flexible tube called an endoscope, which is inserted into the body through small incisions or natural openings [4].

Images captured during endoscopic camera-based procedures, such as the VATS, often exhibit distortions, with radial distortion being the primary concern, due to the lens system used in endoscopes [4]. The analysis of distorted images represents a major challenge for doctors and researchers aiming to accurately assess the location of organs, lesions, or tumors. The distortion causes magnification at the center of the image and contraction at its edges, making precise evaluations considerably complex. Realizing the challenges to achieve high-quality, distortion-free images in videothoracoscopy procedures the primary objective of this research was to develop an algorithm designed to effectively calibrate

the endoscopic cameras used in pulmonary VATS procedures. Based on *Zhang Zhengyou's* calibration method [5] and using the *OpenCV* computer vision library, this calibration process aims to improve the quality of images obtained during these procedures, providing clear and precise visual data and enabling accurate medical analysis. Furthermore, the study investigates potential grids that could be employed for calibration using *Zhang's* method.

2. THEORETICAL ASPECTS

In a Computer Vision System, cameras serve as the system's eyes, capturing images for subsequent analysis [2]. Unlike human eyes, cameras require calibration to operate effectively and produce reliable images that closely represent the real world. The process of camera calibration involves estimating the camera parameters to establish an accurate relationship between a 3D point in the real world (X, Y, Z) and its corresponding 2D projection in the captured image (x, y), ensuring accurate mapping of real-world objects onto the captured images, enabling accurate analysis and interpretation [5].

Several camera calibration methods have been developed over the years, each with distinct strategies based on the knowledge of the 3D scene. Some techniques involve specialized calibrated 3D setups, known as calibration rigs, where the positions of all 3D points and the camera center are predetermined. These methods are discussed in various papers, such as mentioned in [6]. Alternatively, approaches like *Zhang's* method [5], use multiple views of a 3D pattern with a known structure but whose position and orientation in space are unknown.

By analyzing the correspondences between 2D points in the images and known 3D points on the pattern, *Zhang's* method estimates both the camera intrinsic parameters, such as principal point and radial distortion, and extrinsic parameters such as camera position and orientation [6]. This efficient approach enables precise camera calibration, which is crucial for applications such as object recognition, augmented reality, and autonomous navigation.

The process of camera calibration through *Zhang's* method can be carried out using computer vision techniques available in popular libraries such as *OpenCV* [7]. The latter is an open-source computer vision and machine learning software library that offers a wide range of functions specifically designed for camera calibration tasks, providing tools to capture images, detect features, and compute intrinsic and extrinsic camera parameters.

3. PREVIOUS WORK

In [8] a state-of-the-art camera calibration module with *OpenCV* is proposed, based on a generalized camera and *Zhang's* well-accepted camera calibration method. In the

proposed algorithm, a chessboard pattern serves as the reference object for the calibration process. The distinctive black and white squares of the chessboard create a recognizable and structured grid, making it easier for computer vision algorithms to accurately detect and identify key points.

Although the use of a chessboard pattern for camera calibration offers reliability and accuracy, it comes with inherent limitations, particularly with regard to image edge detection, since accurate detection of chessboard corners is complex [9]. This challenging corner detection problem can have a significantly impact on calibration accuracy, particularly in applications where radial distortion poses a significant challenge in the calibration process as in videolaparoscopic procedures.

To overcome this challenge, researchers often propose additional calibration methods or combine the chessboard pattern with supplementary techniques. In [10] for example, an algorithm was introduced to calibrate an endoscopic camera with radial distortion using a single image of a planar grid, applying the first-order division model to characterize radial distortion. Another approach suggested in [11] involves an automatic corner detection method for endoscopy lens, based on image corner detection and sub pixel corner recognition at the intersection of black and white squares.

Our review of the literature on camera calibration carried out to date for this article revealed an lack of work specifically on *ChAruco* grids for medical purposes. Therefore, as an alternative approach, the algorithm proposed in this paper presents a calibration method for endoscopic cameras, utilizing a *ChAruco* grid as the calibration reference pattern, instead of the Chessboard.

4. ALGORITHM

The proposed algorithm utilizes the *ChAruco* grid as the calibration reference pattern. It consists of a hybrid calibration grid that combines the characteristics of Chessboard and *ArUco* markers, which are binary square markers, similar to QR Codes, composed by a wide black border and an inner binary matrix which determines its identifier (id). Figure 1 illustrates a 4×4 *ChAruco* board.

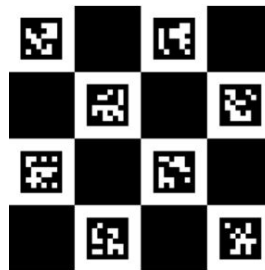


Fig. 1. 4×4 *ChAruco* board

In order to recognize the *ChAruco* board accurately, the algorithm was required to detect not only the corners of the

Chessboard pattern but also each unique ArUco identifier embedded within the grid. Therefore, to accomplish accurate recognition of the ChAruco board, the algorithm was divided into three distinct stages: (1) Image capture, (2) Recognition of the ChAruco with OpenCV and (3) Camera Calibration.

4.1. Image Capture

First, during the image capture phase, the system acquired the necessary images for calibration purposes. The algorithm automatically captures images from the video stream recorded by the camera. Moreover, it offers the flexibility to specify the desired number of images and the interval at which these captures occur. This automation allows users to customize the data recording according to their specific needs, gathering the necessary data for accurate calibration while ensuring the convenience of an automated workflow.

4.2. Recognition of the ChAruco with OpenCV

Then, in the recognition phase, the algorithm focused on identifying the ChAruco board by detecting both the corners of the Chessboard pattern and each unique ArUco identifier within the grid. OpenCV provides two essential functions for this purpose: *aruco.detectMarkers* and *aruco.interpolateCornersCharuco*. These functions play a crucial role in identifying both the unique ids associated with the markers and the grid corners of the ChAruco board.

4.3. Camera Calibration with the ChAruco board

Finally, in the calibration stage, the recognized ChAruco board was used to efficiently calibrate the camera. The calibration process involving the ChAruco board shares similarities with the Chessboard method [5], with a distinction lying in the usage of specialized OpenCV functions from the ArUco library designed specifically for this grid. These functions take the previously identified grid corners and associated ids as inputs, processing this data to generate camera parameters encapsulated within a matrix.

5. EVALUATION OF THE ALGORITHM

In order to validate the algorithm, two *Logitech C270 HD WEBCAM* cameras were used to capture the images from two different perspectives (left and right) and simulate the endoscopic camera. These cameras were aligned with a specific baseline in order to perform the calibration. It was also essential to select an appropriate grid size for testing. As described in [5], camera calibration involves capturing multiple perspectives of a planar calibration pattern, with known dimensions. Each image comprises N reference points, assumed to be located in the XY -plane. Thus, all basic mathematical work for establishing the $2D/3D$ relationship in *Zhang's* method relies on the quantity N of points acquired from the images.

The algorithm evaluation process therefore involved experimenting with various grid configurations, each yielding different quantities of N points. Based on the 7×7 chessboard used in [8] the tests for the algorithm were conducted with an 8×8 ChAruco grid, which contains a larger quantity of points, a 4×4 grid, and a distinctive 3×3 grid known as the diamond grid.

To test this, for each grid, a video of approximately one minute was recorded moving the board around the camera. Once the recording is done, each video was loaded into the algorithm, which was set with the desired number of images, as well as the interval of capture, starting always from a small number of captures. Then, the recognition and calibration were performed.

Finally, in order to validate the accuracy of the calibration process, the 2D points marked in the images from grid recognition were triangulated using DLT (Direct Linear Transformation). This process enabled the determination of corresponding 3D points in space. The results were analyzed in terms of the z coordinate, which represents the distance from the grid to the camera and whose well-known value is 50 cm.

6. RESULTS

The Figure 2 below shows the recognition result of the 8×8 ChAruco grid by our algorithm, where it is possible to note that some of the ids were not recognized.

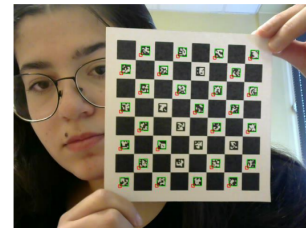
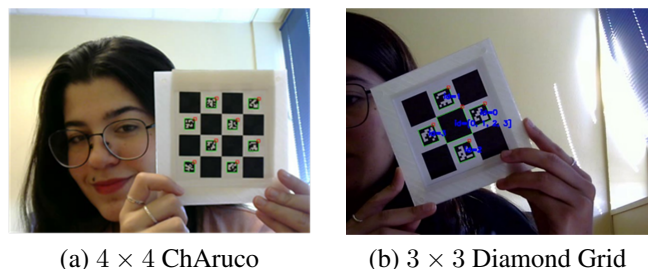


Fig. 2. 8×8 ChAruco grid experimental recognition

In comparison, figure 3 below shows the recognition results on the 4×4 and 3×3 grids. The grids are well recognized.



(a) 4×4 ChAruco

(b) 3×3 Diamond Grid

Fig. 3. Experimental results for grid recognition on the 4×4 and the 3×3 Diamond Grid

Our algorithm estimates the matrix of intrinsic camera parameters. The matrix 1 below gives an example of the intrinsic parameters estimated in one of our experiments.

$$\begin{bmatrix} 843,903 & 0 & 318,388 \\ 0 & 835,344 & 209,854 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

In this matrix, the values 843.903 and 835.344 represent the focal lengths (f_x, f_y) in pixels, indicating the camera's magnification along the horizontal and vertical axes, respectively. The coordinates 318.388 and 209.854 denote the principal point (c_x, c_y), representing the image center on the sensor plane.

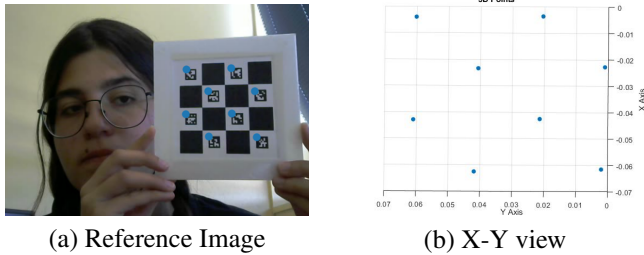


Fig. 4. Reference image with 2D points and X-Y view of the 3D mapped points

The Tables 1 and 2 below indicate the 2D points (in Pixels) marked for Figure 4 and its corresponding 3D points in space (in meters) after reconstruction.

Table 1. 2D Image Points in Pixels

px	py
418.0	222.0
491.0	220.0
454.0	257.0
529.0	257.0
417.0	295.0
492.0	294.0
455.0	331.0
532.0	332.0

7. DISCUSSION

Analysis of Figures 2 and 3 reveals that while the algorithm accurately identified the 4×4 and 3×3 grids, it encountered difficulties with the 8×8 grid. This difficulty can be attributed to external conditions such as lighting, brightness, and grid positioning that affect detection accuracy. Furthermore, the combination of small square sizes and numerous IDs further complicated the accurate recognition of ArUcos. But in any

Table 2. 3D space points in meters

tx	ty	tz
-0.061509	0.002021	0.500658
-0.022759	0.001078	0.492219
-0.042522	0.021365	0.494667
-0.003624	0.020518	0.487088
-0.062534	0.041844	0.497541
-0.023413	0.040712	0.486542
-0.042929	0.060938	0.488674
-0.004018	0.060157	0.478868

case, when comparing the ChAruco detection with the chessboard utilized in [8], it is observable that the ChAruco algorithm better identifies the edges of the image.

Finally, in terms of calibration, it can be noted that, as expected, the distance from the camera obtained, represented by tz (2) was adequate with an average of 49.08 cm. Furthermore, Figure 4 visually demonstrates the congruence between the 3D points and the exact pattern of the 2D points indicated in the reference image. This result indicates that the 2D points were correctly mapped in the three-dimensional space, accurately representing the distance between the camera and the grid.

8. CONCLUSION

This paper presents an efficient approach to endoscopic camera calibration utilizing a sophisticated and robust grid, the ChAruco board, rather than the conventional chessboard pattern. The results obtained indicate the algorithm's capability to recognize both the Chessboard and ArUco markers on the ChAruco board, accurately marking the points and locating them in 3D space, confirming the successful calibration of the camera.

Despite facing administrative challenges preventing the use of endoscopic images directly, the focus now shifts towards further developing the algorithm using authentic medical images. The ongoing project aims to enhance the algorithm's functionality, incorporating features such as blur detection and grid classification. Once the algorithm undergoes testing with endoscopic images from the VATS procedures, it will enable a comprehensive comparison with other calibration methods. This evaluation will not only provide insights into the algorithm's efficacy but also highlight its potential contribution to early lung cancer detection.

9. COMPLIANCE WITH ETHICAL STANDARDS

This is a numerical simulation study for which *no* ethical approval was required.

10. ACKNOWLEDGMENTS

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