Laparoscopic image analysis for automatic tracking of surgical tools
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Introduction
Laparoscopy is a surgical technique nowadays embedded in the clinical routine. Recent researches have focused on analysing video information captured by the endoscope for extracting cues useful for surgeons, such as depth information. In particular, the 3D pose estimation of the surgical tools presents three important added values: (1) to extract objective parameters for the surgical training stage, (2) to develop an image-guided surgery based on the knowledge of the surgery tools localization, (3) to design new robotic systems for an automatic laparoscope positioning, according to the visual feedback.

Tool’s shape and orientation in the image is the key to get its 3D position. This work presents an image analysis for automatic laparoscopic tool’s detection along the recorded video without extra tool markers, using an edges detection strategy. Also, this analysis includes a previous stage of barrel distortion correction for video-idealistic exposure.

Methods
Correction of Barrel distortion
Laparoscopic images present a geometrical distortion, known as barrel distortion, caused by endoscope’s optic. This distortion produces a non-linear radial distortion in the image.

The correction method proposed uses only image processing technique, and consists on the definition of a mapping function to make a geometrical transformation of pixels from a distorted image. This function is defined by means of the comparison between the pixels’ position from a distorted pattern image, captured by the endoscope, and the corrected pattern, which geometry is already known. This pattern image consists on a square reticule with 21x29 dots. This correction uses an iterative algorithm to extract each dot’s position from the distorted reticule, and assign it the new position in the corrected reticule. Finally, the mapping function is defined as a polynomial function to approximate the non-linear error between both reticules.

Tool’s edge identification
The contours of the laparoscopic tool can be approximated by straight lines. In this sense, we developed a tool’s edge detection method based on a searching algorithm of straight lines, such as Hough and Radon Transforms, and it has been optimized to minimize computing cost for consecutive frames.

Image analysis is divided in two stages. The first step of edge detection requires a previous localization of the tool in the image based on colour analysis, limiting searching area for edge detection and getting more accuracy. Afterwards, “Edge tracking stage” uses the knowledge of the previous detected edges to reduce the search environment in the transform domain. Thus, image analysis is less complex, reducing time consuming.

Results
In order to evaluate the correction effects of the proposed barrel distortion method, dots distributions in reticule images (original and corrected) are analyzed. Figure 1 shows a representation of the distance between consecutive dots of the image. The dotted lower line corresponds to the distance analysis of the original image with barrel distortion. This line keeps a constant distance only in the centre of the image, located in optical centre, and this distance decrease when moving to the boundaries areas. The solid upper line represents the distance between dots calculated after image correction, avoiding the divergence at boundaries areas.

This method requires a previous calibration stage to define the mapping function for each specific endoscope. However, the simplicity of the method based only on the use of image processing, makes it an optimal solution to correct the endoscope’s distortion in a calibration stage previous to the operation.

Tool’s tracking method has been validated using laparoscopic surgery image sequences of different scenes (300 frames). Accuracy has been assessed comparing the estimated straight line with the real tool’s edge, and defined as the maximum error between them. Proposed method offers a good accuracy, 4 pp. average error and 84% successful detection, enough for a posterior 3D localization.

Computing-cost analysis shows a 30% reduction of required time for the “Edge tracking stage” respect to the first edge detection, but the reliability is slight lower. This lack of reliability is more frequent for complex scenes where presence of shine in the tool and/or fast tool movement makes false positives detection. The great variability of these surgical images make very difficult to design a general method valid for getting high accuracy for each scene. Finally, results show a slight better behaviour for Radon Transform in stability and accuracy than Hough Transform, even for partial occlusion of the tool’s edges.

An example of successful tool’s edge detection for the first frame is shown in Figure 2(a), and edge tool tracking for posterior frames #11 and #21 in Figure 2(b-c).

Conclusion
A new laparoscopic image analysis method for surgical tool tracking along an endoscopic video has been proposed as a first step towards laparoscopic tools 3D position estimation. This method involves a pre-processing stage to correct barrel distortion based exclusively on image processing. Moreover, the automatic laparoscopic tool’s tracking performs an edge detection strategy without extra markers. Experimental results validate this edge tool detection method for non-real time applications, such as surgeon’s skills evaluation programs.