Wireless Capsule Endoscope Location and a Robotic Validation Experiment

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Abstract. We present results concerning the validation of a novel approach for wireless capsule endoscope localization, using as ground truth a simulated biological/mechanical environment experiment. The approach relies essentially on image-based methods. It involves a hybrid multiscale affine and elastic image registration procedure which is afterwards appropriately complemented with calibration and visual odometry techniques. The capsule was fixed at the extremity of a robotic arm and moved along a part of an *ex-vivo* mammalian bowel. The first validation results indicate a good correlation between the ground truth velocity and distance traveled by the capsule and the velocity and distance given by the proposed approach.

Keywords: Image processing · Image registration · Calibration · Visual odometry · Endoscopy

1 Background

Wireless Capsule Endoscope (WCE) [1] is a medical device which enables the interior visualization of the gastrointestinal tract for diagnosis purposes. The capsule consists of one or more miniaturized cameras, light sources and a wireless system for the acquisition and transmission of images [2]. In a WCE exam, a patient ingests the capsule, and as it moves in the gastrointestinal tract, propelled by peristalsis (contractions of the bowel muscles that move its contents), images are transmitted to a tape recorder, placed on a belt outside the body. It is particularly important for the examination of the small intestine, since this organ is not easily analyzed by conventional techniques.

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However, one of the difficulties of this WCE diagnostic technique is the impossibility of knowing the precise location of the capsule when an abnormality is detected. Clearly, location of the lesions is a relevant information for physicians, in order to plan treatment and surgery procedures. Therefore lack of information about the location of the capsule, or alternatively, its distance measured from landmark anatomical points, is a strong limitation of WCE (see for instance [3] for an extended review on WCE location and also [4–6] for other papers on the same topic).

This WCE drawback is even more important for images of the small bowel, which is a long organ (the size is in average 6.5 to 7 m in adults). It does not have any intermediate reference points, except the pylorus, that connects the stomach to the small bowel, and the ileocecal valve, a sphincter muscle valve that separates the small intestine and the large intestine.

2 Methods

Recently, in [7] we have proposed an hybrid multiscale affine and elastic image registration approach towards wireless capsule endoscope location [2]. This methodology [7] enables a fast and global interpretation of a video by converting it into a curve. This curve gives also a qualitative information about the speed of the capsule. In fact, each point in the curve represents the degree of similarity between two consecutive frames in the video, after being registered with the proposed image registration procedure, and by using an appropriate similarity measure. So, in this curve, a very low value indicates that the image content does not change in the corresponding pair of consecutive frames, thus this means that the capsule is almost still or rotates/moves slowly, because it is capturing the same scene. On the other hand, a high value in the curve indicates abrupt scene changes in the two consecutive frames, therefore the image content is changing, and consequently the capsule should have moved, or the background has changed dramatically due to peristalsis.

By combining the above image registration procedure with calibration (for determining capsule specific measurements) and visual odometry approaches (for deriving the change in position over time), see for example [8] for a detailed explanation of these techniques, we evaluate, in an experimental simulated biological/mechanical environment, the ability of this image registration procedure, for estimating the capsule location and motion, in physical units.

3 Preliminary Results

The experimental setup, providing the ground truth information (which is always inaccessible in real-life WCE videos), consisted of a WCE (MiroCam®, with one camera), that was fixed at the extremity of a robotic arm and moved along a part of an *ex-vivo* porcine bowel. The preliminary results show a good agreement between the ground truth path and the estimated path traveled by the capsule, obtained with the proposed image-based methods.

Figure 1 shows three examples of the images of the mammalian bowel, acquired by the capsule during the experiment.

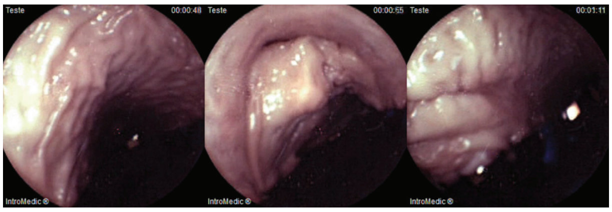

Fig. 1. Examples of WCE images.

Figure 2 shows a comparison between the ground truth capsule velocity and that given by our method [7], for a part of a video generated by the capsule between frames 134 and 257. Figure 3 displays, for the same frames, the comparison concerning the distance traveled by the capsule along the mammalian bowel. In both Figures the horizontal axis represents the 124 frames, numbered from 1 until 124. It is evident the similarity between the ground truth and the results provided by our proposed methodology [7].

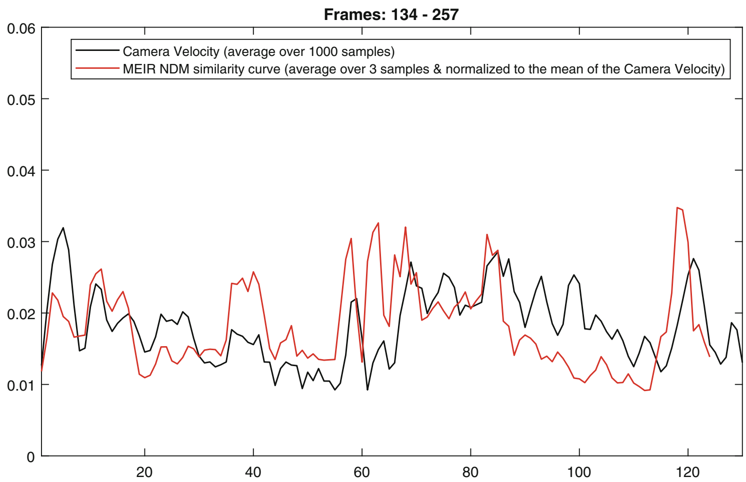

Fig. 2. Comparison between the ground truth WCE velocity (in black) and the WCE velocity given by our method (in red).

Using Structure-from-Motion (SfM) techniques [8] the position of the capsule in three-dimensional (3D) space can be reconstructed from image information, specifically, by using the correspondences between points in consecutive

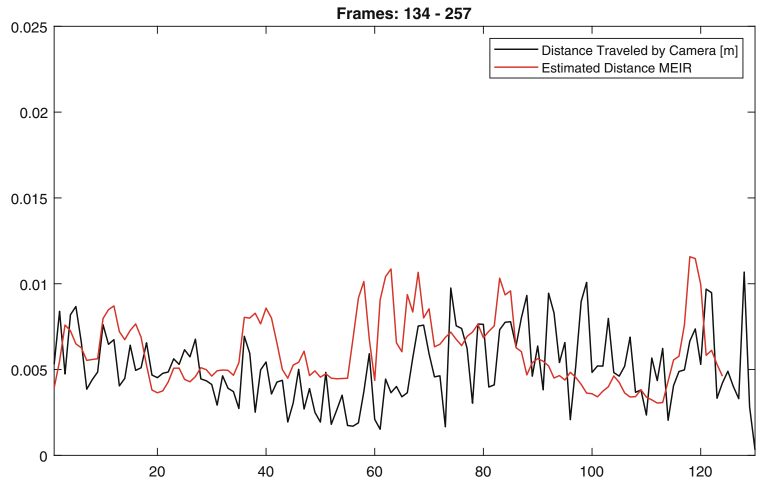

Fig. 3. Comparison between the ground truth distance traveled by the WCE (in black) and the one given by our method (in red).

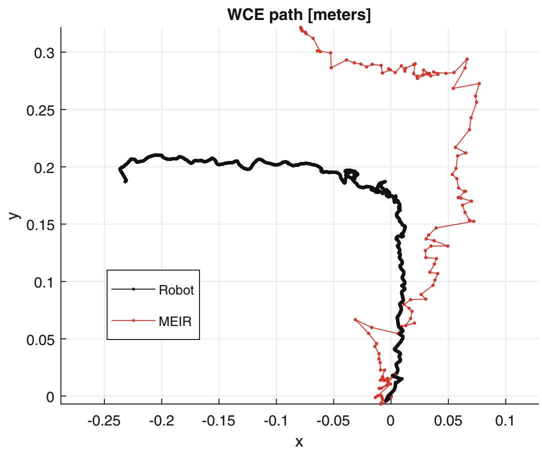

Fig. 4. Comparison between the ground truth trajectory (in black), provided by the robot data, and the recovered capsule trajectory (in red). The figure shows the projection of both trajectories onto the XY plane, which corresponds to the "ground" plane.

images, established from the hybrid image registration of [7]. Figure 4 shows the ground truth WCE path (in black), obtained from the robot data, and the SfM reconstructed path. Both 3D trajectories are projected onto the $Z = 0$ plane, corresponding to the "ground" plane.

It should be noted that the 3D trajectory of the capsule can only be reconstructed up to an unknown scale factor, due to a fundamental limitation of SfM. Despite that, the similarities between ground truth and estimated paths are easily seen, with the overall shape of the real trajectory being successfully reconstructed.

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