Correspondence:

Kurt Höller
Central Institute of Healthcare Engineering (ZiMT)
Friedrich-Alexander-Universitaet Erlangen-Nuernberg (FAU)
Henkestr. 91, D-91052 Erlangen
Tel.: +49 9131 85-26868
Fax: +49 9131 85-26862
kurt.hoeller@fau.de

K. Höller, A. Schneider, J. Jahn, J. Guttiérrez, T. Wittenberg, J. Hornegger, and H. Feußner

Clinical evaluation of ENDOrientation: gravity related rectification for endoscopic images

In: P. Zinterhof, 166 Bibliography S. Loncaric, A. Uhl, and A. Carini, Eds., Proc. 6th International Symposium on Image and Signal Processing and Analysis (ISPA'09), ISBN 978-953-184-134-4, pp. 713–717, IEEE Computer Society, Salzburg, Austria, September 2009.

Clinical Evaluation of Endorientation: Gravity related rectification for endoscopic images

Kurt Höller, Jochen Penne, Joachim Hornegger
Chair of Pattern Recognition (LME)
University Erlangen-Nuremberg
Martensstr. 3, 91054 Erlangen, Germany
hoeller@informatik.uni-erlangen.de

Armin Schneider, Sonja Gillen, Hubertus Feußner
Workgroup for Minimal Invasive Surgery (MITI)
Klinikum r.d. Isar, Technical University Munich
Troger Str. 26, 81675 München, Germany
schneider@chir.med.tu-muenchen.de

Jasper Jahn, Javier Gutierrez, Thomas Wittenberg
Fraunhofer Institute for Integrated Circuits (IIS)
Nordostpark 93, 90411 Nürnberg, Germany
jasper.jahn@iis.fraunhofer.de,
thomas.wittenberg@iis.fraunhofer.de

Abstract

Providing a stable horizon on endoscopic images especially in non-rigid endoscopic surgery (particularly NOTES) is still an open issue. Image rectification can be realized with a tiny MEMS tri-axial inertial sensor that is placed on the tip of an endoscope. By measuring the impact of gravity on each of the three orthogonal axes the rotation angle can be estimated with some calculations out of these three acceleration values. Achievable repetition rate for angle termination has to be above the usual endoscopic video frame rate of 25-30Hz. The accelerometer frame rate can be set up to 400 Hz. Accuracy has to be less than one degree even within periods of high movement and superposed acceleration. Therefore an intelligent downsampling algorithm has to be found. The image rotation is performed by rotating digitally a capture of the endoscopic analog video signal. Improvements and benefits have been evaluated in a clinical evaluation: For different peritoneoscopic tasks time was taken and instrument position was tracked and recorded.

1. Introduction

A still unsolved problem with flexible video endoscopy in Natural Orifice Translumenal Endoscopic Surgery (NOTES) [6] is the missing information about the image orientation [3]. While on one hand gastro-enterologist have been trained to using flexible video-endoscopes as their state of the art imaging equipment and are capable to rectify the endoscopic images in their mind in relation to anatomical knowledge, on the other hand surgeons have so far used mainly rigid endoscopes (laparoscopes) where the orientation and rotation is usually fixed and stable with respect to the patient. Thus, as tip retro-flexion of a non-rigid endoscope causes image rotation angles up to ± 180 degree, it is helpful to rectify this rotated image according to a main orientation angle and depict the rectified image.

To solve this rectification problem, e.g. *Koppel et al.* [4] have proposed a three-step vision based approach, which tracks salient points in consecutive images, estimates the camera ego-motion, approximates the scene depth and finally infers the direction of an abstract 'head-up' vector in the cameras current reference frame [5]. As this purely vision based approach is related to high computational costs, which is not supposed to be realizable in real time, we have recently suggested a different method to obtain the parameters for the endoscope's rotation [2].

Our proposed "Endorientation" approach dealt with the determination of the orientation and rotation angle Φ inside the human body (or porcine model) during a NOTES intervention. The innovation consists of integrating a MEMS (Micro Electro-Mechanical System) based inertial sensor device at the distal tip of the endoscope. This MEMS device is capable to measure influencing forces in three orthogonal directions, from which gravity has the highest impact on the device.

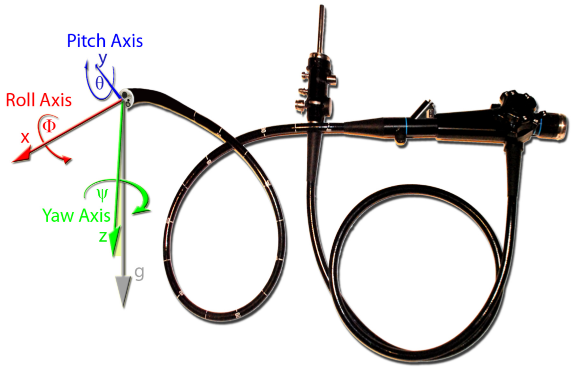

Figure 1. Roll, pitch and yaw description for endoscopic orientation

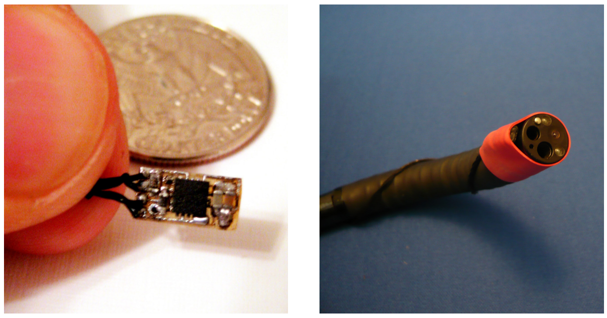

Figure 2. Prototyping with an external MEMS sensor (l) on the endoscope's distal tip (r)

During normal movements, the gravity force is at least one order higher than other accelerations. The rotation angle Φ can be computed out of acceleration values F_y and F_z on the two axes y and z orthogonal to the endoscopic line of view in x-direction as shown in fig. 1:

$$\Phi = arctan2(F_y, F_z) \tag{1}$$

The employed MEMS sensor delivers a uniform quantization of 8 bit for a range of $\pm 2.3g$ for each of the three axes. This implies a quantization accuracy of $0.018g$ per step or 110 steps for the focused range of $\pm g$. Thus, the applied quantization is precise enough to achieve a sustainable accuracy even to a degree within relatively calm movements [1]. This is possible as the roll angle Φ is calculated from the inverse trigonometric values of two orthogonal axes.

2. Experimental Setup

During a porcine animal study, the navigation complexity of a hybrid endoscopic instrument during a NOTES peritoneoscopy with the well established trans-sigmoidal access [8] was compared with and without automated image rotation. The endoscopic inertial measurement unit was fixed on the tip of a flexible endoscope as shown in fig. 2. Additionally Ascension's "Flock of Birds", a pulsed DC magnetic tracking sensor with a resolution of $0.02''$ and an accuracy of $\pm 0.07''$, was fixed on the hybrid instrument holder for recording the position of the surgeon's hands. To evaluate the benefit of automated real-time MEMS based image rectification, four different needle markers were inserted through the abdominal wall to the upper right, lower right, lower left and upper right quadrants. These four needle markers had to be grasped with a trans-abdominal introduced endoscopic needle holder under standardized conditions.

First, only the original endoscopic view was presented to the surgeons, navigating the transcutaneous inserted instrument. In a second run, the image view with the automatically corrected image horizon was displayed on a control monitor, while the surgeons performed the grasping of the needles again. For some test persons the order of original and rotated images was changed. There was no learning effect. The second turn with the original view still took longer time. During the study an unmanipulated image was available exclusively for the endoscopist to navigate the flexible scope. In the end the time required to navigate the surgical instrument to the four markers was recorded and statistically evaluated.

3. Evaluation Results

The participating test persons were surgeons with different levels of surgical experience and expertise, including beginners, well-trained surgeons and an expert. All of them considered the automated image rectification to be very useful to navigate the transcutaneous inserted instrument towards the previously inserted needle markers (fig. 3).

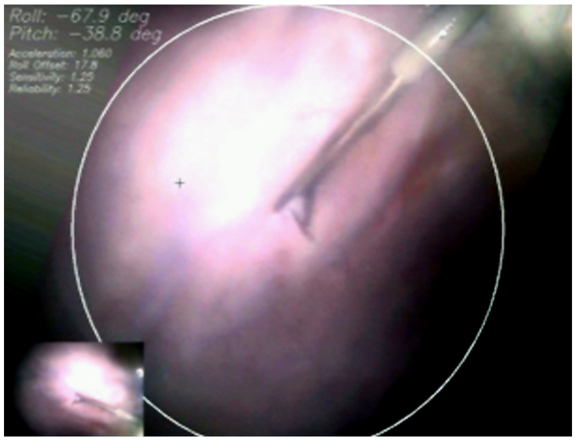

Figure 3. Grasping a needle with a needle holder

However, the time delay between reality and the display of the manipulated and rectified video signal on a video monitor was considered to be the most disturbing factor in the process.

3.1. Time comparison

In the performed experiments, it could clearly be shown that grasping a needle marker with an automatically rectified image is much more easier and therefore faster than with the originally rotated endoscopic view (Fig. 4). For accomplishing the experimental grasping task $n = 20$ times without image correction, a mean time of $\mu_{\text{orig}} = 53.95s$ with a variance of $\sigma_{\text{orig}} = 41.55s$ has been observed. For the same operational task ($n = 20$) using the proposed image correction scheme a mean procedure time of $\mu_{\text{rect}} = 29.65$ with a variance of $\sigma_{\text{rect}} = 21.15$ could be achieved.

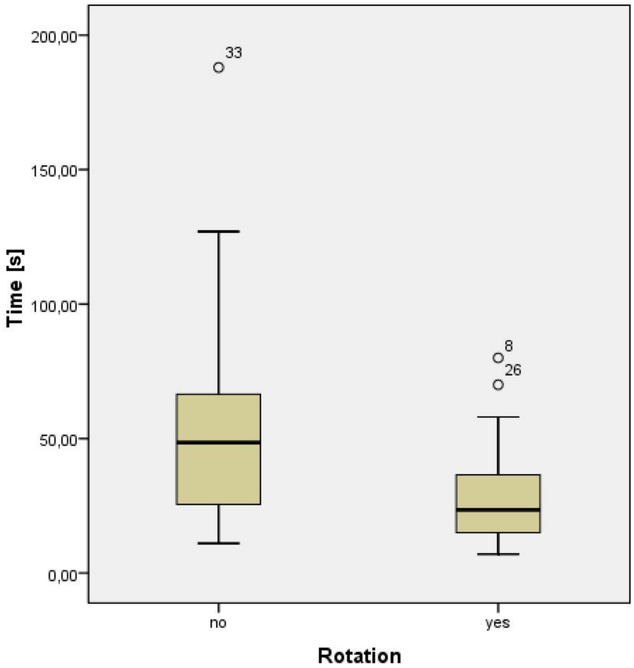

Figure 4. Average time comparison without and with image rectification

More detailed analysis of the specific tasks separated in the four abdominal quadrants, shows that the highest benefit of image rectification could be achieved during manipulations in the lower abdomen (fig. 5). Grasping the needle in the upper right abdomen takes a mean time of $\mu = 72.00s$ ($\pm 67.13s$) *without* image manipulation versus a mean grasping time of $\mu = 38.8s$ ($\pm 23.27s$) with correction of the image horizon. In the lower right abdomen quadrant the grasping procedure took $62.2s$ ($\pm 40.54s$) vs. $24.6s$ ($\pm 12.05s$). On the left patient side the task could be accomplished in the lower abdomen with the original (unrectified) image in $38.8s$ ($\pm 22.25s$) vs. $15s$ ($\pm 9.41s$) with the modified image, respectively $42.8s(\pm 24.89s)$ vs. $40.2s$ ($\pm 28.38s$) in the upper abdomen.

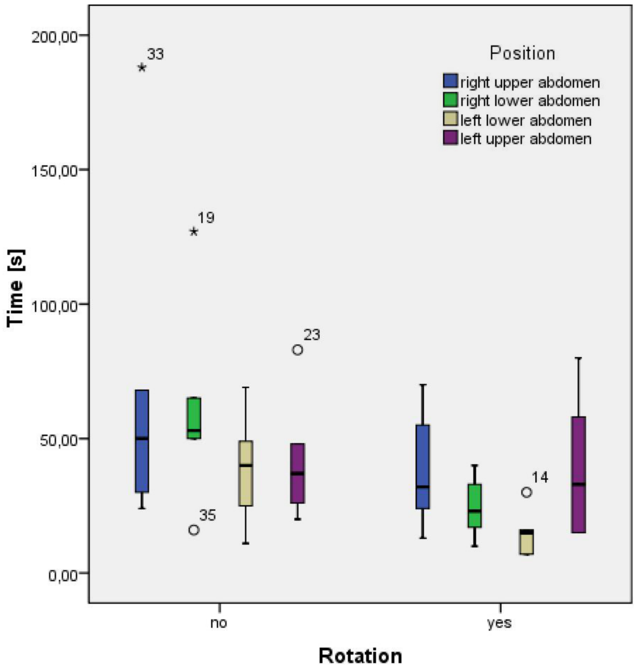

Figure 5. Comparison of time needed to grasp each needle target without and with the proposed image rectification scheme

Especially for the both needles in the lower abdomen image rectification enables better performance, but also the results in the upper abdomen are better with rotated images.

3.2. Movement comparison

The tracked position of the hybrid instrument holder with our MEMS device performed by a well-trained test person is displayed in a 3-D plot (fig. 6). Increased movement activities are visible at four distinct points. There have been accumulated movements of the surgeon's hand at each of these points. These movements are translated through the fixed point of the trocar to the rigid instrument's tip inside the peritoneal cavity. With these translated movements the needles in each quadrant had to be grasped.

In comparison to the procedure based on the original image the movements based on rectified images are significantly more accurate with shorter paths as one can see in fig. 7.

Obviously the two parameters duration and path length are strongly correlated and can be regarded as a significant measure for the complexity of surgical procedures. Since duration and path length are decreased with the application of image rectification, the complexity of the complete procedure can be reduced.

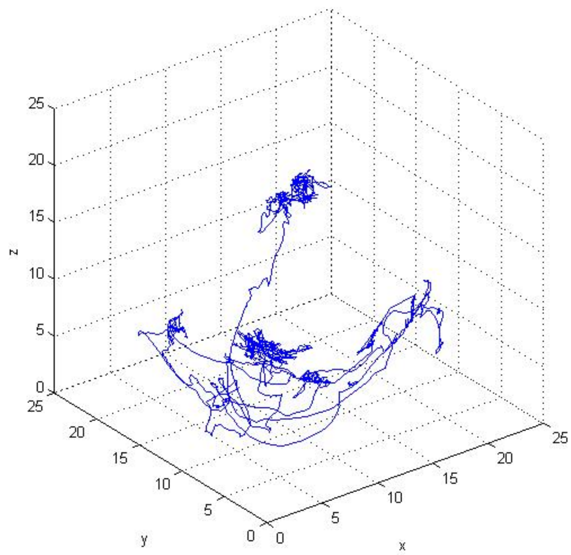

Figure 6. Original images cause movements with a total path length of 650 inches

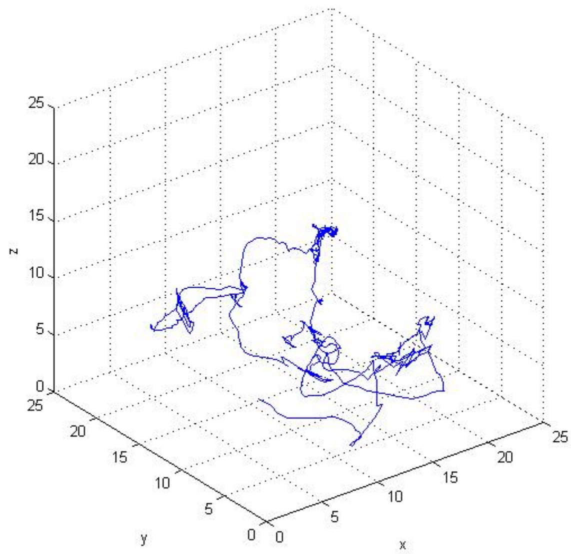

Figure 7. Rectified images cause movements with a total path length of 317 inches

3.3. Technical restrictions

As the test persons complained on the time delay correlated with the image rectification process, a simple method for measurement was found. Instead of an endoscopic image a video stream with $25fps$ showing the actual frame number was fed into the frame grabber and simultaneously shown on a display. On a second display the rotated video stream was depicted. Both displays were recorded with a camera. On a snapshot a delay of 10 frames can be observed. This means a time delay of 400 ms.

4. Discussion

Most benefit of the proposed horizon correction and image rectification could be achieved in the lower abdomen. To reach these positions the flexible endoscope has to be positioned in a so-called *inversion* position. During this inversion it is impossible to adjust the image horizon by rotation of the endoscope. In that case, other structures would be displayed. In comparison, during visualization of structures in the upper abdomen, the flexible video-endoscope is in a more or less straight position where small image rotation corrections could be achieved by rotation of the scope. Since combined laparoscopic-endoscopic rendez-vous techniques are more and more performed [9], also here the use of horizon correction for the laparoscopic surgeon should be considered.

5. Conclusions

With our suggested Endorientation approach it is possible to make NOTES surgery with non-rigid endoscopes faster and more precise. This was shown by recording both, duration and path length during a simulated procedure. The minimum time, the mean time and the maximum time have been lower with image rectification for every position. All participating surgeons considered the complexity lower using our Endorientation technique. However, the original non-rotated image is still necessary, since the gastro-enterologist is adapted at working with an variable horizon and needs the non-transformed view to control the bending.

6. Outlook

The main focus of this work was to achieve a good angle estimation and to set up a working prototype for a first evaluation. In order to keep the overall development cost short the system was built of out-of-the-box hardware and software components. The results of the clinical evaluation showed some technical differences between the laboratory sample used for software development and the evaluation prototype. Overall the main problems of time delay can be solved by improving the software design and the sensor link. The main hardware, frame grabber, graphics card, memory and processor could remain unchanged. There was presented a live video manipulator (LVM) for NOTES procedures by Tang et al. in 2008 [7] which includes a video stream rotation tool. They report a time delay of $50-120ms$ for standard hardware which would be acceptable even for surgery. So there is no physical restriction to get the digital rotation faster which was the only complained factor in our evaluation.

References

[1] K. Höller, J. Penne, A. Schneider, J. Jahn, H. Girgis, J. Guttierrez, T. Wittenberg, H. Feussner, and J. Hornegger, "Suppression of shock based errors with gravity related endoscopic image rectification", In *Proc. 5th Russian-Bavarian Conference on Bio-Medical Engineering*, pp. in press, Munich, Germany, July 2009.

[2] K. Höller, J. Penne, A. Schneider, J. Jahn, J. Guttierrez, T. Wittenberg, H. Feussner, and J. Hornegger, "Endoscopic orientation correction", In *Medical Image Computing and Computer Assisted Intervention, 12th International Conference Proceedings MICCAI'09*, pp. in press, London, UK, September 2009.

[3] K. Höller, M. Petrunina, J. Penne, A. Schneider, D. Wilhelm, H. Feußner, and J. Hornegger, "Taking endoscopy to a higher dimension: Computer Aided 3-D NOTES", In *Proc. 4th Russian-Bavarian Conference on Bio-Medical Engineering*, Zelenograd, Moscow, July 2008. MIET.

[4] D. Koppel, Y. Wang, and H. Lee, "Image-based rendering and modeling in video-endoscopy", In *IEEE International Symposium on Biomedical Imaging, Proceedings of the*, pp. 272–279, Arlington, VA, 2004.

[5] D. Koppel, Y.-F. Wang, and H. Lee, "Automated image rectification in video-endoscopy", In *Proc's 4th Int. Conf. on Medical Image Computing & Computer-Assisted Intervention (MICCAI)*, pp. 1412–1414. London, UK, Springer-Verlag, 2001.

[6] D. Rattner and A. Kalloo, "ASGE/SAGES working group on Natural Orifice Translumenal Endoscopic Surgery: White Paper October 2005", *Surg. Endosc.*, 20, 2006, pp. 329–333.

[7] S.-J. Tang, R. Bergs, S. F. Jazrawi, C. O. Olukoga, J. Caddedu, R. Fernandez, and D. J. Scott, "Live video manipulator for endoscopy and notes", *Gastrointest Endosc*, 68, Sep 2008, pp. 559–564.

[8] D. Wilhelm, A. Meining, S. von Delius, et al., "An innovative, safe and sterile sigmoid access (ISSA) for NOTES", *Endoscopy*, 39, 2007, pp. 401–406.

[9] D. Wilhelm, S. v. Delius, M. Burian, A. Schneider, E. Frimberger, A. Meining, and H. Feussner, "Simultaneous use of laparoscopy and endoscopy for minimally invasive resection of gastric subepithelial masses - analysis of 93 interventions", *World J Surg*, 32, June 2008, pp. 1021–1028.