Alexander Mrokon*, Volker Steger, and Peter P. Pott*

Endoscopic Pan/Tilt Camera for Thorax Interventions – Design and first results

Abstract: Minimally invasive surgery in some cases suffers from a limited view because certain areas are obscured by others. In this paper, a system is described, which can be used in minimally invasive procedures as an addition to a standard endoscope to improve the range of view. Through FEM simulation a magnetic circuit was designed to position the camera head. Subsequently, a camera positioning system was set up that includes an extracorporeal and an intracorporeal unit. The first controls the intracorporeal system. The latter has a camera inclination angle of up to 65° and an additional vertically downward viewing angle when aligned in parallel (inclination angle 0°). The panning angle is 360° . The camera system was evaluated in lab and cadaver trials. It has been found that the size of the intracorporeal system ($16 \times 10 \times 150$ mm) represents a major problem. Future work will focus on the reduction of the system's size, the improvement of the camera image quality, and design changes considering mechanical stability.

Keywords: pan/tilt-camera, thorax interventions, magnetic anchoring

<https://doi.org/10.1515/cdbme-2018-0130>

1 Introduction

During minimally invasive procedures in the thorax, the lung collapses in a central direction and creates a lumen. Here, the surgeon can navigate instruments and an endoscopic camera and perform surgery. However, the lung forms a convex surface hindering a complete view of the camera over the situs from a single point of view. This loss of viewing angle is

insufficiently compensated for with conventional endoscopic methods. This could be overcome with an additional camera anchored to the thoracic wall providing a second viewpoint.

Looking at the state of the art, a number of drop-in- or additional camera systems with magnetic anchoring can be identified: The system developed by Platt et al. uses magnets to attach the housing to the thoracic wall. These magnets enable a movement in a horizontal plane to the abdominal wall. For the tilt of the camera electric motors were used which are integrated in the housing [1]. The system by Park et al. uses magnets, which are connected via retaining arms to the housing. Panning and tilting is accomplished by moving the intracorporeal magnets with the aid of two external magnets [2]. The system developed by Cheng et al. uses magnetic polarity to allow turning. The rotation of the external permanent magnet along its longitudinal axis generates a rotating magnetic field that drives an opposite rotation of a magnetized internal permanent magnet. Pivoting is generated by rotation of the external permanent magnet [3]. However, all of these cameras either have a vertical viewpoint downwards that can barely be adjusted [1], or an oblique viewpoint that does not cover the entire surgical field [2].

The system proposed in this paper is characterised by its simple design allowing single-use, adjustable field of view, small dimensions, and good manoeuvrability. The following sections describe the proposed system, subsystems, and their experimental evaluation during laboratory and cadaver trials. Finally, possible improvements will be discussed.

2 System Design

The crucial requirements include the adjustable field of view and the dimensions. The latter must not exceed a maximum size of 10 mm for the shortest axis to allow easy insertion through the intercostal space.

***Corresponding author: Alexander Mrokon, Peter P. Pott:**
Institute of Medical Device Technology, University of Stuttgart,
Pfaffenwaldring 9, 70569 Stuttgart, Germany

Volker Steger: University Department of Thoracic and
Cardiovascular Surgery, Hoppe-Seyler-Str. 3, 72076 Tübingen,
Germany

The camera system is shown in Figure 1. The housing is made of polylactide (PLA). The camera system consists of two components. Component 1 defines position and orientation of component 2, which is introduced into the body and fixed there with the aid of magnetic forces. In addition, component 1 allows to define the camera's viewing angle. To do so, a linear slide is used there. This slide is connected to the optical system via support arms and provides for a variation of the viewing angle.

Figure 1: The complete System, with (a) extracorporeal part and (b) intracorporeal part; (1) immovable magnet; (2) movable magnet; (3) linear slide; (4) movable iron; (5) optical system (6) immovable iron

The extracorporeal housing contains two magnet units (Neodym magnets, type Q-30-12-12-Z, Webcraft GmbH, Gottmadingen, Germany, $30 \times 12 \times 12$ mm, magnetization perpendicular to the main axis, degree N52) each combined with an iron yoke to guide the magnetic flux. The force provided by the magnets and the intracorporeal iron part acts through the thoracic wall. The magnetic field and the resulting force were determined using the finite element method (FEMM, Aladdin Enterprises, Menlo Park, California, U.S.A. Version 4.2). The software allows simulation of time-invariant magnetostatic problems in planar systems.

The result of the simulation of the magnetic circuit is shown in Figure 2. The thickness of the thoracic wall correlates with BMI. For a normal BMI of 18.5 to 25, the anterior thickness of the thoracic wall is between 10 mm and 18 mm [4]. Therefore, the force was simulated on various iron thicknesses d over distances r of 10 mm to 30 mm in 5 mm increments.

The results of the simulation are shown in Figure 3. It can be seen that there is no substantial increase in force for the thickness exceeding $d=4$ mm. The cubic decrease in force over distance is also clearly visible. An iron yoke with a thickness

Figure 2: Magnetic flux density in a magnetic circuit, with (1) extracorporeal part and (2) intracorporeal part. In this exemplary structure, $r=10$ mm and $d=4$ mm.

Figure 3: Force over air gap distance r

of $d = 6$ mm thus was selected. Doing so, the best force-to-weight relation can be achieved.

Based on the simulation results two iron blocks with a thickness of $d = 4$ mm were used in the intracorporeal part.

Figure 4: Intracorporeal part of the camera system in open (1) and closed (2) states

A simple 1/6" CMOS technical inspection camera ($\varnothing 8 \times 50$ mm, Voltcraft BS-24, Conrad Electronics SE, Hirschau, Germany) was chosen providing a resolution of 1280×720 pixels and 30 frames/s. It is connected through a USB 2.0 interface and has four built-in white LEDs with a brightness of 1000 lux at a distance of 20 mm. The field of view is 54° and a well-focussed image is provided within a

distance of 30 to 60 mm in front of the lens. In addition, the camera is waterproof to according to the IP67 standard.

The angle of the camera head can be adjusted by moving the magnet from 0° (horizontal view parallel to the housing) to 65° downwards. Also, a 90° downward view can be provided by moving the camera to the 0°-position looking straight into a mirror attached to the intracorporeal slide. The two different viewing angles are shown in Figure 4.

3 Experimental evaluation

In a first experimental setup, the camera system is placed on a wooden stand with an oriented strand board (OSB) of 15 mm thickness. As shown in Figure 5, the intracorporeal part of the camera was placed under the wooden plate and the extracorporeal part was placed above the wooden plate.

Figure 5: (1) Laboratory experiment and (2) cadaver trial

The adhesion was tested by placing the extracorporeal part on top of the board and the intracorporeal part below. Then it was maintained and tested whether a permanent fixation is possible. And if attachment is possible, the fastening force is measured with a dynamometer.

The manoeuvrability was tested by placing the intracorporeal housing in different positions with the aid of the extracorporeal housing. In addition, it was assessed whether the intracorporeal housing can be rotated by 360° with the help of the extracorporeal housing in a plane parallel to the wooden board.

The behaviour of the linear guide for adjusting the viewing angle was checked by changing the distance between the extracorporeal magnets. A reduction of the distance corresponds to a larger viewing angle.

The image of the camera was examined by positioning and moving various objects under the camera

After the first attempt was made on a wooden board, the body of a body donor was examined in the second part of the test. The experiment was performed in the Department for Anatomy at the University Hospital of Tuebingen under the general ethics approval. In this experiment it should be assessed whether the camera system works under real operating conditions. The thorax was prepared for a minimally invasive procedure and the intercostal space was opened. It was assessed how the camera can be inserted and moved into the body. The image of the camera was displayed by a computer. Finally, it was investigated how the intracorporeal housing can be removed again.

4 Results

It was found during the lab experiments that the force between the magnets in the extracorporeal housing and the iron in the intracorporeal housing is large enough to fix the intracorporeal housing under the extracorporeal housing. The measured fastening force at 15 mm board thickness is 1.5 N. The manoeuvrability parallel to the OSB board posed no problem. The intracorporeal housing could be rotated with the help of the extracorporeal housing to the required 360°. The intracorporeal housing could be moved in parallel with the aid of the extracorporeal magnets. To change the position of the intracorporeal housing, the extracorporeal magnets had to be shifted a minimum distance of 10 mm. Below this threshold, no movement occurred. As a result, the position of the intracorporeal housing deviated from the position of the extracorporeal body in some cases. Consequently, it was not possible to make fine changes to the position. When changing the position, however, the stiffness of the cable did not cause any difficulties.

When investigating the mechanism to adjust the camera's angle of view (Figure 4), the cable impeded this movement due to its stiffness. The camera could be adjusted for viewing angles of 5° to 30° with the help of the magnets. For viewing angles greater than 30°, this was not possible. For angles between 0° and 5° the camera could not be adjusted due to the singularity of the folding mechanism. Sufficient forces could only be applied by the extracorporeal magnets by moving them in a fast stop-go manner. The intracorporeal housing could thus not easily be unfolded by the extracorporeal magnets.

Using the mirror, a satisfactory view directly from the top can be generated.

The assessment of the camera image showed that the lens provides a clear focus at 30 mm to 60 mm distance. Objects outside this interval were out of focus. The lighting unit of the camera provided sufficient illumination of the situs – also in combination with the mirror. The rinsing nozzle was visible in the camera image obstructing the view of the situs at around 20 % of the image.

In the cadaver trial, tweezers and a scalpel were used to gain access to the thorax for the camera system. Both appeared to be attracted by the magnets.

Furthermore, it became clear that the length of the intracorporeal housing prohibited the simple insertion in the thorax. The intracorporeal housing could only be fully inserted with considerable effort.

Consequently, the intracorporeal housing could not be maneuvered as desired and also alignment with the extracorporeal magnet was not possible. Still, the attractive force of the magnets was noticeably high (see Figure 5). Finally, removing the intracorporeal part was leading to damage on the plastic parts. However, no parts remained in the thorax.

The high definition image resolution (HD720) was sufficient for first trials.

5 Discussion

The presented intracorporeal camera system offers many new opportunities and food for thought. In summary, this work has developed a system that provides the surgeon with the necessary additional perspectives for a minimally invasive operation. The device offers simple adjustment of the angle of view in a wide range – even vertically downwards and high user-friendliness due to its intuitive handling. It will be the base for future implantable camera systems designed to ease thoracic surgery by providing a second point of view, likely lowering the rate of complications and shortening intervention times.

Nevertheless, during the cadaver experiment, it became clear that the actual size is a substantial problem. Here, considerable effort to miniaturize the dimensions has to be made.

The simulation of the magnetic field allowed a good prediction of the available forces but showed room for improvement. The magnetic flux not yet runs completely through the intracorporeal yoke and back iron and an

important fraction of the magnetic field lines are not guided in the desired direction.

These field lines do not contribute to the attractive forces, they also cause unwanted interactions with other ferromagnetic materials. In the current camera system, the magnets are provided with laterally adjacent iron. In the simulation, it has been shown that larger iron increases the amount of deflected field lines – but also increases overall mass. A good trade-off has to be found: An increase of the width from 6 to 10 mm (67 % mass increase) would lead to a 10 % increase in force.

Permanent magnets are inexpensive and do not develop heat. However, the force is proportional to $1/r^3$, leading to rather high forces at small distances, which cannot be controlled. This leads to the situation, that in patients with high BMI the attractive force is insufficient while in patients with very low BMI, tissue can be damaged by excessive forces.

Therefore, future devices should provide some kind of force control mechanism that averts excessive and insufficient forces. In addition, future devices must be considerably smaller, since especially the length was an issue and to prevent injuries to the lungs, rounded edges should be used. Furthermore, the angle of view and the resolution of the camera should be increased in future developments. Besides, unlike the prototype, a device for clinical trials should be sterilisable.

Author Statement

Research funding: The author state no funding involved.

Conflict of interest: Authors state no conflict of interest.

References

- [1] S. R. Platt, J. A. Hawks, and M. E. Rentschler, "Vision and task assistance using modular wireless in vivo surgical robots," *IEEE transactions on bio-medical engineering*, vol. 56, no. 6, p. 1700, 2009.
- [2] S. Park, R. A. Bergs, R. Eberhart, L. Baker, R. Fernandez, and J. A. Cadeddu, "Trocac-less instrumentation for laparoscopy: magnetic positioning of intra-abdominal camera and retractor," *Annals of surgery*, vol. 245, no. 3, p. 379, 2007.
- [3] T. Cheng, X. Zhang, C. S. H. Ng, P. W. Y. Chiu, and Z. Li, "A novel magnetic anchored and steered camera robot for single port access surgery," in *2018 IEEE International Conference on Robotics and Automation (ICRA)*, 2018, pp. 1406-1412: IEEE.
- [4] A. R. McLean, M. E. Richards, C. S. Crandall, and J. L. Marinaro, "Ultrasound determination of chest wall thickness: implications for needle thoracostomy," *The American journal of emergency medicine*, vol. 29, no. 9, pp. 1173-1177, 2011.