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Enhanced Vision System for Laparoscopic Surgery

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Abstract— **Laparoscopic surgery offers benefits to the patients but poses new challenges to the surgeons, including a limited field of view. In this paper, we present an innovative vision system that can be combined with a traditional laparoscope, and provides the surgeon with a global view of the abdominal cavity, bringing him or her closer to open surgery conditions. We present our first experiments performed on a testbench mimicking a laparoscopic setup: they demonstrate an important time gain in performing a complex task consisting bringing a thread into the field of view of the laparoscope.**

I. INTRODUCTION

Laparoscopic surgery, a minimally invasive technique for interventions on the abdominal cavity, has gained popularity in the past years because of the number of benefits it offers to the patients, e.g. less blood loss, shorter hospital stay, very tiny scars [1]. The technique consists in performing small incisions on the patient's abdominal wall, which has been inflated with gas to create space for the intervention. The incisions allow for the insertion of an endoscope and surgical instruments through trocars, which avoid gas leaks. This technique is however more complex for the surgeon than open surgery: focusing only on the difficulties linked to using an endoscope,

- The endoscope field of view is limited;
- The surgeon's viewpoint is constrained by the endoscope's entry point;
- Unless a 3D endoscope is used in combination with an appropriate 3D vision system, the surgeon cannot rely on his depth perception since the visual feedback is only the 2D image provided by the endoscope;
- When an assistant is required for mobilizing the endoscope during the intervention, the coordination with the surgeon can be challenging.

Robotic systems can help overcome some of these limitations. For instance, robotic endoscope holders (e.g. Endocontrol-Medical's ViKY® robotic endoscope holder) provide a stable image and allow the surgeon to control the endoscope himself. Complete telesurgery systems (e.g. Intuitive Surgical's da Vinci®) immerse the surgeon in a 3D environment thanks to the use of a stereoscopic endoscope.

This paper focuses on the problem of the endoscope's limited field of view by presenting a device that complements the classical endoscopic view by a "global view" of the surgical site. We focus on the presentation of our prototype which includes two large field-of-view (51°) 5 mm × 5 mm × 3.8 mm CMOS cameras encapsulated in a system that can be added to a standard trocar. Hence, the system can be used with a simple endoscope, in combination with a robotic endoscope holder and could even be compatible with single port surgeries. The system has been designed to allow for an easy insertion, deployment and removal of the cameras. Once the system is deployed, the cameras provide a panoramic view of the abdominal cavity, with the same point of view as the endoscope. They stand like a pair of *glasses* around the traditional endoscope (see Fig. 1). We have validated our approach on a laboratory testbench (porcine organs placed within a training box in order to simulate the abdominal cavity). The mini-cameras are similar to the cellphone cameras (a few US $ in large scale manufacturing), and the system could be affordable and disposable.

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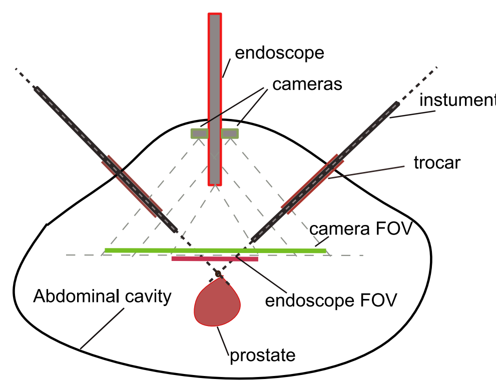

Fig. 1. Schematic illustration of the disposition of the novel multiple view system.

II. STATE OF THE ART

Several systems have been proposed in the literature in order to enhance traditional endoscope. In [2][3], the authors have proposed articulated pan-and-tilt stereo-camera systems to improve the surgeon's visualization and depth perception. However, with this approach, if the surgeon is close to an organ, in order to perform a precise dissection, the field of view remains similar to that of a standard stereo-endoscope. [4] and [5] have developed systems known as "port-cameras". The idea is to combine the traditional laparoscopic camera with an additional camera mounted on a surgical instrument or surgical trocar. These systems are mainly developed for single-port laparoscopy, where the proximity of the instruments with the laparoscope makes the navigation extremely challenging. In the objective of completing the traditional laparoscopic view, the limitation of this kind of systems is that the point-of-view provided by the port camera is different from the point-of-view of the laparoscope. The surgeon must make a mental registration between the images to navigate inside the abdominal cavity.

Others have also proposed systems that replace the laparoscope. [6] has developed a robotic camera that can be inserted inside the abdominal cavity and navigate like an all terrain vehicle on the abdominal organs. Five cholecystectomies were successfully performed on a porcine model with such a system, which offers a solution to the viewpoint constraint. However, the problem of the limited field of view of the camera is not addressed: like for traditional endoscope, the vision system has to move to provide a different field of view, increasing the risks of damaging tissues.

Finally, [7] have proposed a system where the traditional endoscope is replaced by several mini-cameras positioned strategically inside the abdominal cavity in order to create virtual views of the operation theater by fusing geometrical and color information provided by the cameras. This kind of approach seems very promising but the feasibility of the approach in clinical conditions (insertion and deployment of cameras, real-time 3D reconstruction) still has to be addressed.

III. Materials and Methods

A. Enhanced Vision Prototype

The materials used to develop enhanced endoscopy vision system include two miniatures and high resolution cameras in addition to the classical mono-view endoscope. The cameras are based on two 5 mm $\times$ 5 mm $\times$ 3.8 mm complementary metal oxide semiconductor (CMOS) sensors with a high resolution of 1600 $\times$ 1200 pixels, a frame rate of $\approx$ 30 frames/second, a low noise/signal ratio, a good exposure control of +81 dB, a large field of view of 51° (compared to a field of view of a classical endoscope) and significant depth of field (see Fig. 2).

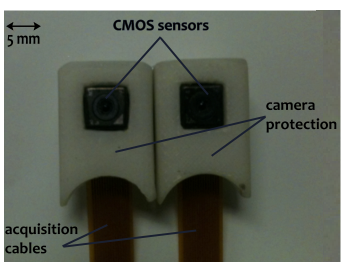

Fig. 2. Photography of the CMOS cameras.

Obviously, our approach is not to remove completely the traditional endoscope, which is popular and widely used in the operating rooms, but propose significant/efficient improvements of this system, without changing the usual practice of surgeons, and also without recourse to additional learning phases before handling the new vision device. Consequently, we decided to adapt our vision system to existing endoscopes (resp. trocars). To do so, the proposed vision system is mounted as a pair of *glasses* around the endoscope (see Fig. 3) and offers a panoramic view associated to the endoscopic view, since it is fixed on the trocar at a fixed insertion depth, while the endoscope translates within the trocar depending on the required zoom.

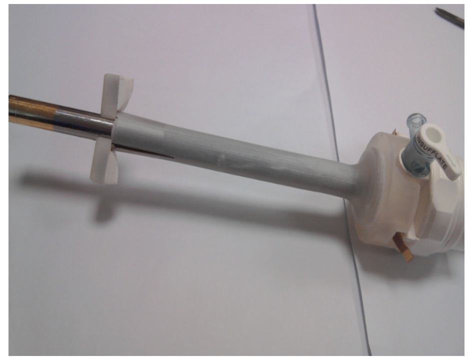

Fig. 3. Photography of the proposed multiple view system.

It is also essential to insert the developed system without performing additional incisions (i.e. using the endoscope trocar). Therefore, a deployment/extraction system has been designed to insert, to fix (stabilize) and to extract the multiple view system quickly and easily.

After having studied several design options, we designed and developed the prototype showed in Fig. 4. In this version of our vision device, the cameras are already prepositioned in a hollow tube with sliding rails (see the exploded view in Fig. 4), in which the trocar is inserted. To deploy the vision system, the surgeon inserts the endoscope that will push cameras out of the sliding rails (see step 1 in Fig 5). When both cameras are out of the sliding rails (see step 2 and step 3 in Fig. 5), and the endoscope is fully inserted, the proposed vision system is completely introduced in the abdomen cavity. However, at this stage of deployment, the cameras are not fully stabilized yet (see step 4 in Fig. 5). By pulling on the acquisition/power cables of the system, the surgeon fixes the cameras in place (see step 5 in Fig. 5 which shows the obtained deployment for one camera), and the cameras now have a point of view very close to that of the endoscope. To extract the global vision system, the surgeon removes the endoscope first, then he simply pulls on the power/acquisition cables to remove the cameras one after the other. Indeed, the cylindrical element positioned on the upper part of each camera (see the exploded view in Fig. 4) guide each camera back inside the trocar.

B. Validation Protocol

Our validation was performed on a testbench mimicking a laparoscopic setup. Porcine organs were placed into a black box. The traditional endoscope was carried by a robotic endoscope holder (Endocontrol-Medical's ViKY® system) [8], allowing us to record the displacements performed by the endoscope and the vision system (number of commands issued, amplitude of the endoscope's displacements, and time needed to perform these displacements) (see Fig. 6). As shown in the figure 6, the feedback from the endoscope and the proposed system was very simple: The endoscopic view was placed between the CMOS cameras images in order to

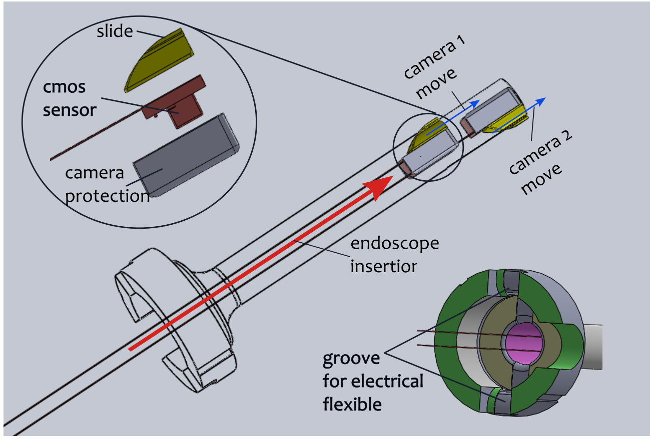

Fig. 4. CAD model of the proposed multiple view device illustrating the different elements with compose the system.

offer a panoramic view (with an overlap). More evolved user interfaces involving image fusion could be considered in the future, but thanks to the positioning of the innovative device around the endoscope, the point of view of the three cameras are very similar by construction.

An experimented urologic surgeon participating in the project was asked to repeat six times the same experiment which consisted in performing a specific surgical task, once with the traditional endoscope alone, and once with the innovative vision system alone. At each realization of the experiment, the surgeon started randomly with the endoscope or with the vision system, to avoid a learning bias. The surgical task consisted in

- localizing a suture needle placed in the abdominal cavity;
- bringing it to a fix target point (representing the organ of interest for the task).

At each beginning of the task, the needle was positioned randomly at a fixed distance to the target point. The distance was chosen such as the initial needle position was not visible in the laparoscopic image. We recorded the time required to perform the task, the number of orders given by the surgeon to the ViKY® robot in order to move the endoscope or the vision system and the log files of the ViKY® robot indicating the actual displacements of the robotic holder's motors (3 degrees of freedoom : θ a rotation of the endoscope around the robot's base, ϕ the inclination of the endoscope and z the manual zoom of the endoscope).

IV. Results

Table I summarizes the total number of commands sent to the ViKY robot in order to move the endoscope or the developed system to complete the entire experiment (6 repetitions of the task). It can be noticed that using our device, the number of communications between the surgeon and the ViKY robot was reduced by a factor of 6. Consequently, the time required to complete the entire experiment was significantly impacted, as illustrated by Table II : the surgeon was capable of dividing by a factor of 6 the time required

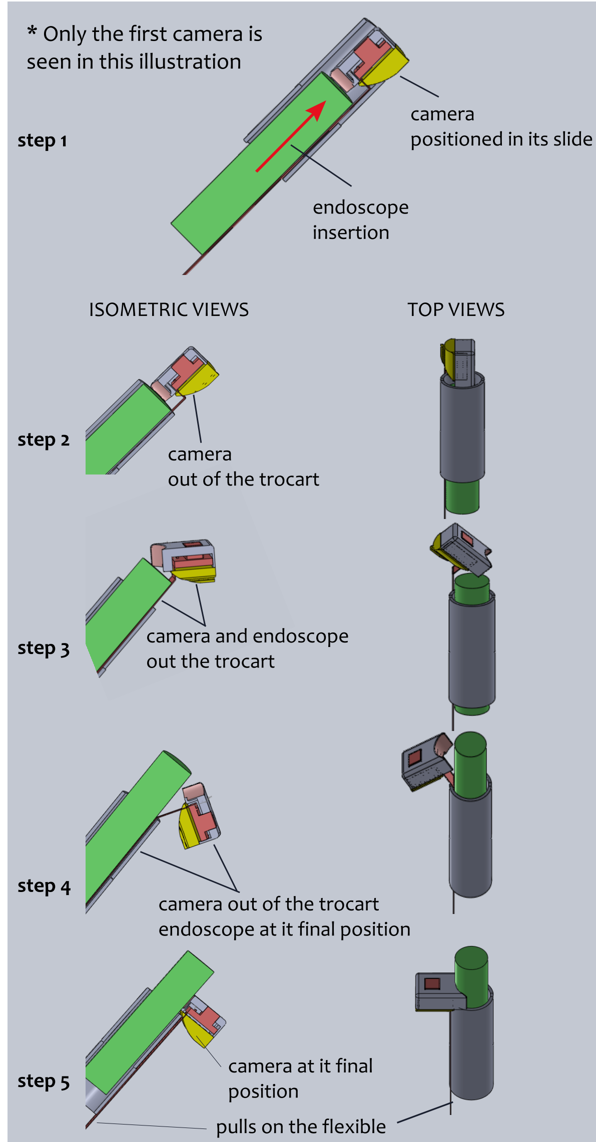

Fig. 5. Illustration of the different steps of the functioning of the developed deployment/removal system. For a better understanding, only one camera was used in this illustration.

to perform the experiment with the proposed vision system compared with an endoscope alone.

TABLE I
SUMMARY OF THE NUMBER COMMANDS GIVEN TO VIKY'S DOFS USING THE TWO TYPES OF VISUALIZATION SYSTEM.

vision system	total moves	mean moves
endo.	139	23.16
dev. system	**28**	**4.6**

If we analyze more closely the commands sent to the ViKY robot in both configurations (endoscope *vs.* proposed vision system), we can note that the amplitudes were much larger with the endoscope compared to the proposed vision system (see Table III and Table IV). This is due to the wide field of view offered by the CMOS cameras that covers a

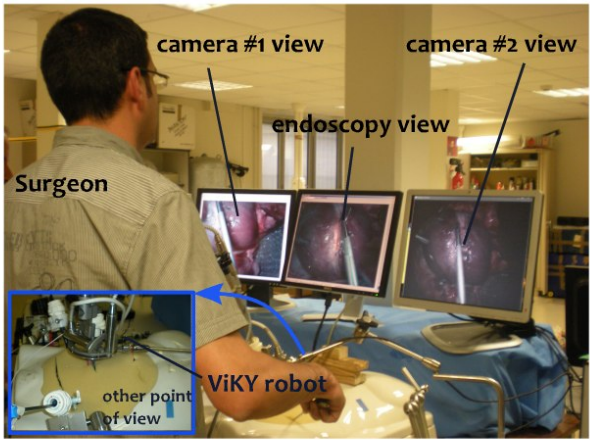

Fig. 6. Illustration of the testbench used to perform the validation tests.

TABLE II
SUMMARY OF THE TIME-CONSUMED FOR 6 DIFFERENT TESTS USING THE BOTH VISION SYSTEMS.

vision system	total time (s)	mean time (s)
endo.	1140	190
dev. system	**147**	**24.5**

large portion of the abdominal cavity and therefore requires less and smaller movements of the ViKY robot.

TABLE III
SUMMARY OF THE VIKY'S MOVES MAGNITUDE (ENDOSCOPE).

endo.	Z (mm)	ϕ $(\circ)$	θ $(\circ)$
total	0	1780.8	1490.2
mean	0	296.7	248.3

TABLE IV
SUMMARY OF THE VIKY'S MOVES MAGNITUDE (DEVELOPED VISION SYSTEM).

dev. system	Z (mm)	ϕ *(degrees)*	θ *(degrees)*
total	**0**	**410**	**384.53**
mean	**0**	**82.10**	**79.90**

It can also be noted that that the images acquired by our high resolution CMOS cameras which equipped the proposed vision system present a better field of view, a higher resolution, and a lower image distortion than the images provided by the standard laparoscope providing an increased visualization comfort.

V. CONCLUSION AND FUTURE WORKS

A novel multiple view system was developed in the aim of compensating some of the difficulties faced by surgeons when using a classical endoscope (limited field of view). The proposed system consists of the use of two miniatures and cheap CMOS cameras mounted as *glasses* around the traditional endoscope. Thus, the obtained system presents a large field-of-view (increased by a factor of 3), better resolution (improved by a factor of 2), and high contrast (improved by a factor of 2.5). The surgeon can rapidly adapt to the use of this new vision system. On the one hand, a simple and efficient deployment/extraction system has been developed which adapts to a conventional trocars (10 mm, 12 mm, and 15 mm of diameter). On the other hand, the advantage of positioning the cameras as *glasses* around the endoscope allows to the surgeon to have a large additional vision to that of the endoscope without the need of complicated registration/fusion methods.

This system was validated thanks to preclinical experiments. Our validation tests demonstrated quantitatively that, in addition to a significant gain in image quality, the time required to perform a classical laparoscopic task was reduced by a factor of 6 with our vision system compared to a the same task performed with a traditional endoscope. The system was designed to make the installation/removal procedure as easy as possible but its duration still needs to be accounted for. We also need to validate further the clinical feasibility of the proposed system (setup, extraction, removal and usage) and to work on a more user-friendly display interface (e.g. a mosaic of the different images provided to the surgeon).

VI. ACKNOWLEDGEMENTS

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