Laparoscopy Smart Tracking Camera (TrakingScope)

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Abstract. Laparoscopic surgery is a minimally invasive technique that improves patient recovery, reduces post-surgical complications, and enhances precision. However, these procedures require an additional assistant to control the laparoscopic camera, which can be inefficient and increase fatigue for medical personnel. This paper presents an autonomous robotic arm that enhances control in laparoscopic surgeries by eliminating the need for a human camera assistant. The proposed system employs an advanced computer vision-based tool tracking method, ensuring continuous and precise tool centering in real time. Unlike existing solutions such as the da Vinci Xi system, this approach leverages a low-cost, efficient, and adaptable mechanism for various laparoscopic procedures. The system integrates real-time object detection using YOLO and OpenCV, coupled with a robotic arm programmed to follow surgical tool movements. Our experimental results demonstrate improved camera stability, reduced procedural time, and enhanced surgeon comfort. This innovation represents a step towards intelligent surgical assistance systems, bridging the gap between autonomous robotics and minimally invasive procedures.

Keywords: Laparoscopic Surgery, Robotic Arm, Autonomous System, AI in Surgery, Medical Image Processing, Tool Tracking

1. Introduction

The area of Laparoscopy is a complex area that presents several challenges, but in turn also brings with us quite advantages such as for example that the surgeries that are minimally invasive which leads to a better recovery since the surgeons employ methods which cause less damage therefore this quick recovery is given and effective. As a result, the patient also gets a shorter hospitalization, it also has the flexibility of patient treatment, since the patient can be external or internal (depending on the doctor's instructions).

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For this examination, you will be given drugs through an IV in order to induce general anesthesia. During the procedure, you will have a tube in your throat that connects to a respirator. A small incision is made in the abdominal wall near the navel, where the laparoscope is placed. A small volume of gas is injected into the abdomen to expand it and facilitate observation of organs. We also have the option of making smaller incisions in the lower belly to insert various cutting instruments for removal or biopsies in abnormal areas, which are then examined in the laboratory.

The performance of the individual assisting the physician with the camera must be extremely precise, serene and anticipate the doctor's movements, since it is he who provides vision to the physician during the operation. Therefore, you must maintain effective but not overly noisy communication so that the doctor can focus and have all these attributes, while also taking time to understand how each specialist physician and each physician operates.

There are currently different types of image formats that help to have a wider vision, higher contrast attenuation to be able to see the colors more vivid and can differentiate organs and tissue in a better way, but there is no mechanism or device to keep an eye on the clamps in the surgical area

Which brings us to work on this smart image capture device, it is planned to carry out thanks to an endoscope of training which are similar to the professional cameras used in the operations of minimal invasion that adapts to a program in phyton, thanks to its libraries of image capture, in this way the camera captures the colors and the shape of the tongs and in that way sends the signal to the motors of the robotic arm which will know thanks to the image where they have to move so that the camera does not lose sight of the tongs, in turn we realize that no such sudden movements are required since being an operation of minimal invasion the space is reduced by it the camera is of zero vision degrees so that the movements are subdued therefore one has the desired vision without the need for have a very large chamber or attachments that make it possible to comply with the regulations established by NOM-006.the robotic arm is so large that it can hinder the doctor's movements

2. Related with the project

The work carried out in the area of laparoscopy is extremely important so care must be taken all details to have many precautions when creating any device that has to do with this area so any device that fits this area brings improvements to make the performance of surgeries as for example the most famous device that has today is the da Vinci Xi. The da Vinci Xi is widely recognized for its high-definition 3D vision, which provides surgeons with a detailed view of internal organs and anatomical structures during interventions. This system, illustrated in Figure 1, allows for greater precision in laparoscopic procedures while minimizing the surgeon's hand tremor through robotic-assisted movements. This high definition and 3D image allows for greater precision and control during operation, among its other great contributions is the precision of the da Vinci Xi system device that allows surgeons to manipulate surgical tools with a precision that is not possible with the human hand alone despite the great pulse control that can reach to obtain specialists in this area; is a robotic platform with robot arms which are very flexible and allow precise movements in angles and directions that would normally be difficult to achieve with conventional techniques [1].

It is equipped with four robotic arms mounted on a mobile trolley that is positioned over the patient (although not all of them are used simultaneously in each surgery). These arms have multidirectional joints, allowing them to mimic and improve the movements of the human hand. Specialized surgical instruments such as tweezers, scissors, scalpels or cameras are placed at the ends of the arms. These instruments are interchangeable depending on what the surgery will require or what the doctor in charge of this, The surgeon controls the robotic arms from an ergonomic console remotely, observes the surgical field in high-definition 3D and uses special controls to move the arms, the surgeon's movements are translated in real time to robotic arms, but with filters that eliminate tremors and allow smoother and more precise movements

Figure 1. The da Vinci Xi robotic surgical system, known for its high-precision control and 3D visualization capabilities. *Source: Adapted from Abex Systems.*

Speaking more specifically of mink, a camera is placed in one of the 4 available arms and this arm is the one that serves as the role of "guide arm" which is extremely important because without the vision of the camera they only have 3D vision and lose a very important part of the whole system that makes up the da Vinci Xi [2].

High-definition resolution with contrast

Endoscopic camera system with intelligent vision which defines with color contrast uses the latest system developed by Mindray that is the UX5 series 4K/NIR, Integrates the next generation hardware platform with novel software algorithms greatly increases image performance. Autofocus, automatic scene recognition and intelligent image algorithm work together to present high-quality images. The Mindray UX5 system provides a 4K imaging experience with Near-Infrared capabilities, making it an essential tool for laparoscopic procedures (Figure 2). Advances in fluorescence imaging technology make hidden lesions and stained boundaries truly visible, allowing for more precise surgical navigation.

Ultra-high fluorescence sensitivity

The dual excitation and image optimization reduces the sensitivity of the fluorescence signal capture at the level of the nanomoles, which favors the clinical detection of small metastatic lesions at low doses and offers a higher penetration capacity at the same dose.

These improvements in vision are very useful when we can do the suture which provides us with a better performance thanks to the different contrasts that can be applied depending on the required need [3].

Figure 2. The 4K/NIR Mindray Series UX5 laparoscopic imaging system, featuring intelligent vision, autofocusing, and fluorescence imaging technology for enhanced surgical navigation. Source: Adapted from [Mindray](https://www.mindray.com/mx/products/laparoscopic-products/hypixel-ux5).

3. Description of project development

Our project takes care of the area that is not yet explored much which is to focus more on the help of the surgeon's concentration by reading vision and signals sent from the image captured by the camera that has the program designed in python that we allows by image capture recognize the tweezers we want to follow at all times of surgery and for that we take into account all the equipment that can be required in the space of minimal invasion and do not alter the processes just like the rules already established.

We have enough and varied equipment in Laparoscopic, but for this the patient should already be prepared for surgery therefore had to follow the instructions already indicated as not to eat food before the surgery as well as avoid drugs marked as analgesics.

The surgeon makes a small incision below the navel, which involves the insertion of a needle or hollow probe known as a trocar. Carbon dioxide is supplied to the abdomen through the probe or needle. The gas helps to enlarge the area, giving the surgeon more space for his work and allowing him to visualize the organs more clearly.

A small video camera (laparoscope) is inserted through the trocar and used to examine the inside of the pelvis and abdomen. Smaller incisions are possible if other instruments are required to improve vision in some organs [4].

Optical and display equipment

Laparoscope: A laparoscope is a surgical instrument used to observe the inside of the abdominal and pelvic cavity during surgery.

Cold light source: Cold light lamps use a halogen or xenon light source and are designed to provide cooler light that reduces heat emission and prevents tissue dehydration

High definition monitor: is display equipment whose main function is to show clear texts and images for any health professional.

System of inflating

CO2 Insufflator: It is a general purpose insufflator unit for use in laparoscopic examinations and operations. Controlled insufflation of the peritoneal cavity is used to achieve the required working space for laparoscopic surgery by stretching the antero-lateral abdominal wall and depressing the hollow organs and soft tissues.

Inflator tube: A device that connects the inflator with the inflator trocar to administer CO.

Access and surgical ports

Trocars: Is a pen-shaped instrument with a pointed triangular tip at one end, typically used inside a hollow tube, known as a cannula or sleeve, to create an opening in the body through which the sleeve can be inserted, to provide an access port during surgery.

Sealing valves: Prevent CO leakage through the trocars.

Laparoscopic instrumental

Laparoscopic Forceps: The intestinal laparoscopic forceps, also known as intestinal forceps, are a form of gripping instrument designed to safely manipulate delicate abdominal tissue during laparoscopic procedures. One of its main functions is to facilitate proper access to the surgical site by keeping the intestinal tissue free from the operating field.

Laparoscopic scissors: A disposable laparoscopic instrument with ratchet function when opening and closing for greater control and comfort of the surgeon.

Electrocautery: A device that cuts and coagulates tissues using electrical current or ultrasound.

Hemostatic clips or sutures: Materials used to close blood vessels or tissues without the need for traditional sutures.

Dissectors and separators: Instruments that allow separate anatomical structures without damaging them.

Vacuum/irrigator: A device that sucks liquids and allows the abdominal cavity to be washed during surgery.

Surgical table and hinged arms: Adjustable surface where the patient is positioned to optimize surgical access [5].

Laparoscopes are essential tools in minimally invasive surgeries, providing high-definition visualization of the surgical field (Figure 3). These devices allow surgeons to navigate through narrow spaces with precision, reducing patient trauma and improving recovery time.

Figure 3. High-definition laparoscope used in minimally invasive surgeries. These devices provide enhanced visualization and precision. Source: Adapted from [St-Endoscopia](https://st-endoscopia.es/productos/endoscopia-rigida/familia-opticas-rigidas/laparoscopios/laparoscopio-hd/).

The impact of our project can help people to reduce the concerns they may have when having to resort to an operation of this type, because people feel more relaxed if they know that the process is more automated and does not depend on the synchrony of two people, we also have the advantage of small clinics that do not have the inputs, can acquire the device we also have the advantage that the equipment train together with the device what can provide them safety and preparation for a surgical operation medical they can get used to in a simpler way to this type of operation they can also

The project also proposes and has the possibility of being able to adapt to the market since it has a support for technologies already existing on the market in turn the project may seem attractive to companies that have devices for laparoscopy and look for the form of adapt it to your teams to make them more attractive and adapt it to different markets to expand your repertoire of options to offer.

Hardware

The movement of the robotic arm is based on the use of servomotors which are highly specialized motors designed for precise control of rotary or linear movements. It is a rotation or translation motor which employs a feedback mechanism to ensure accurate positioning, usually by means of a control signal that dictates the movement of the motor to a desired position. This mechanism allows for precise control of several components, making servo motors crucial in applications that require precise positioning and smooth movement.

For the above points of the servo motor is that we adapted this component to be able to develop effectively the project

At the heart of every servo motor lies its ability to precisely control the position of its output axis. This is achieved through sophisticated interaction between several key components of the servo motor:

Control signal: It is the starting point of the operation of the servo motor. This is an electrical signal sent by the controller, which specifies the desired position or movement. The signal is usually a variable width pulse, known as pulse width modulation (PWM), which encodes the target position.

Motor and gear mechanism: Once the control signal is received, the internal circuit of the servomotor drives the motor to move it to the desired position. The motor is usually connected to a gearbox to increase torque and control the precise movement and speed of the output shaft [6].

Software

The main programming language to be used is python for its use of computer vision which refers to the process by a machine or an automated system that interprets visual information from the environment, like how it would be done by the human eye. This field includes a wide range of applications, from object recognition to autonomous vehicle navigation. The implementation of these systems requires the use of advanced algorithms to process and analyze digital images [7].

Together with the OpenCV library, Python, created by Guido van Rossum in the late 1980s, stands out as an interpreted, high-level, and multi-paradigm programming language [8]. It was developed at the Centrum Wiskunde & Informatica (CWI) in the

Netherlands as a successor to the ABC programming language, aiming to offer clear syntax, exception handling capabilities, and interaction with multiple operating systems.

We also utilize the YOLO system, the latest version of the "You Only Look Once" object detection algorithm, which has been applied in various domains, showcasing its applications, improvements, and performance in different scenarios [9].

YOLO Applications

Intrusion Detection Systems Intrusion Detection Systems

YOLO segmentation has demonstrated high precision in various domains, including intrusion detection systems and UAV-based object tracking (Figure 4). This model's capability to detect and classify objects in real-time makes it a valuable tool in numerous AI-driven applications. By leveraging datasets, YOLO can accurately recognize and categorize intrusions, achieving high precision and recall rates. Integration with Python and OpenCV allows seamless incorporation into existing security frameworks, enhancing surveillance technology across various environments [10].

UAV Aerial Photography

In unmanned aerial vehicle (UAV) aerial photography, YOLO has been optimized to address the challenges of detecting small objects. The UAV-YOLO model incorporates Wise-IoU for better localization and an attention mechanism to enhance the processing of critical information. This results in improved detection performance and reduces missed detection rates, making it suitable for civilian, commercial, and military applications [11].

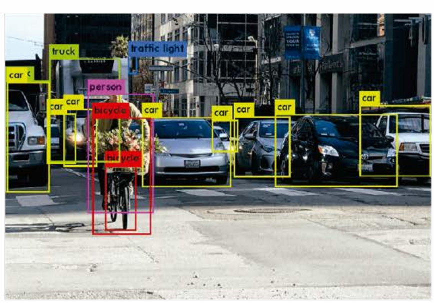

Figure 4. YOLO segmentation applied to real-time object detection in AI-driven systems. The model enhances object classification through convolutional neural networks. Source: Adapted from [VisionPlatform](https://visionplatform.ai/es/yolov8-deteccion-de-objetos-de-ultima-generacion-en-reconocimiento-de-imagenes-computer-vision/).

Code

This project implements a computer vision system to detect and track blue objects in real time using the OpenCV library. In addition, it uses serial communication to send commands to a microcontroller based on the position of the object in the image.

The process starts with live video capture using OpenCV. Then, the image is converted to HSV color space, and a filter is applied to detect blue tones within a specific range (Figure 5). This technique allows real-time object detection and tracking, which is fundamental in applications such as robotic-assisted surgery and medical imaging. From this filtered image, the contours of the blue objects are identified, and their centroid is calculated to determine their position in the image.

Based on the X-coordinate of the detected object, decisions are made to send commands through the serial port, indicating movements in different directions. Subsequently, the system displays on screen the processed image with the contours and position of the detected object, allowing the user to visualize the tracking in real time. In addition, the program has a termination option using the 's' key, which closes the serial connection and frees the camera resources.

The developed system can accurately detect blue objects and calculate their position in the image, enabling its use in applications such as the control of robots or automated devices. As future enhancements, multiple color detection, dynamic threshold adjustment and optimization of data delivery can be added to improve the efficiency and accuracy of the system.

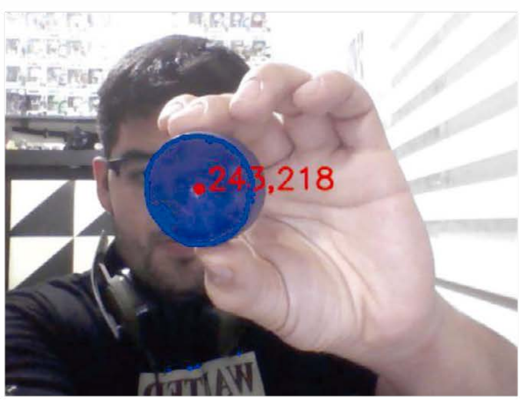

Figure 5. Real-time video capture and processing using OpenCV in Python. This system detects and tracks objects dynamically through HSV filtering and contour recognition

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