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A Summative Assessment of the Pattern-Cutting Task in Laparoscopic Box Trainer using Color Tracking and Fuzzy Logic

Koloud N. Alkhamaiseh[1*], Janos L. Grantner[2], Ikhlas Abdel-Qader[2], Saad Shebrain[3]

[1]Department of Computer Science, Michigan Technological University, Houghton, Michigan, USA
E-mail: kalkhama@mtu.edu
[2]Department of Electrical and Computer Engineering, Western Michigan University, Kalamazoo, Michigan, USA
[3]Western Michigan University Homer Stryker MD School of Medicine, Kalamazoo, Michigan, USA

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***Abstract*—** In Minimally Invasive Surgery (MIS), surgeons should acquire many skills before carrying out a real operation. The Fundamentals of Laparoscopic Surgery (FLS) tasks are currently used as an assessment tool for laparoscopic skills. However, the current training methods still require the presence of an expert surgeon to assess the surgical dexterity of the trainee. This process is time-consuming and may lead to subjective assessment. This research aims to extend the application of image processing and analysis methods to detect and track the tips of the laparoscopic instruments and to localize the circle center to calculate the distance between the scissors' tips and the circle's center in each processed frame. The data obtained will feed the fuzzy system to assess the trainer's performance with a processing speed of 4 frames per second. The proposed system can provide a final text report that lists an error counter value and the fuzzy assessment at each time slot of 0.29 s on average. Additionally, a BMP image that summarizes the tips of the scissors within the predefined circles during the test is created. Finally, a Canny edge detector is applied to detect whether any circle line was cut during the test. This work enables a summative assessment of the precision-cutting task without altering the original setup of the FLS box trainer. Additionally, this can expedite the development of surgery skills and assess the trainees' performance using a single-input-single-output fuzzy logic system. The output of the fuzzy logic assessment is the performance evaluation for the surgeon, and it is quantified in percentages.

***Keywords*—** Laparoscopic surgery; Summative assessment; Precision-cutting task; Image processing; Fuzzy logic; Canny edge detector.

1. INTRODUCTION

In modern operating rooms worldwide, laparoscopic procedures have become a popular and widely accepted method. This technique is highly beneficial and has become an essential component of surgical education programs. Since small incisions are used in tight spaces, laparoscopic procedures require a high level of skill and precision compared to traditional open surgery. As a result, extensive training is necessary to perform them proficiently [1].

Surgeon training is crucial for ensuring safe and successful laparoscopic surgery. Training systems can aid in the development and refinement of a surgeon's skills, as well as allow for assessment of their proficiency in patient-free environments. There are various technologies available for this training, such as physical trainers and simulators that utilize virtual reality (VR) and augmented reality (AR). However, it is important to note that VR and

* Corresponding author

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AR simulators may impose mechanical modifications or add sensors that restrict a surgeon's range of motion and alter their experience, skill development, and performance [2].

Therefore, working with the FLS box trainer [3] is one of the most important approaches for developing laparoscopic skills, where expert surgeons teach basic surgery skills to trainees based on several exercises and tests [4]. The FLS Box trainers are much cheaper than virtual reality simulators, but on the other hand, the expert surgeons must share their limited time with multiple trainees to provide a thorough assessment. However, it is possible to utilize the box trainer's camera along with software development to offer a promising approach to assess surgical skills objectively and efficiently.

Surgical training relies heavily on video cameras as they can accurately analyze data without the need for extra sensors or mechanical devices. The recent advancements in computer vision analysis have led to significant progress in areas like object detection, tracking, motion detection, and analysis. [5].

This proposed work is part of an ongoing research collaboration between the Electrical and Computer Engineering Department and the Department of General Surgery of the Homer Stryker M.D. School of Medicine at Western Michigan University, to develop an intelligent box trainer system by adding several sensors and high-definition digital video cameras along with a fuzzy logic-based performance assessment system [6, 7]. This system is focused on tracking the tip movements of the surgical tools inside the box trainer in a 3D virtual space. The system can provide measured feedback and recorded videos for the residents' performance, which can be used as a performance assessment tool. Work in [8] and [9] are based on deep-learning models to track the surgical tools and other objects for the pattern-cutting test.

To dramatically reduce the cost of the necessary hardware platform, a shoebox is used to mimic the Fundamentals of Laparoscopic Surgery FLS box trainer. An orthogonal camera mounted on the top of the box is used to record the video of the exercise. The setup is illustrated in Fig. 1. A pair of endoscopic scissors are included, as well as a 4-inch by 4-inch piece of pre-marked gauze. The grasper is replaced by four pins in the corners of the gauze.

This simplified box trainer uses a VGA camera with a resolution of 640x480 which is suitable for its size, weight, and image resolution. The connected PC workstation is equipped with a 2.5GHz Intel(R) CPU and 16GB of RAM.

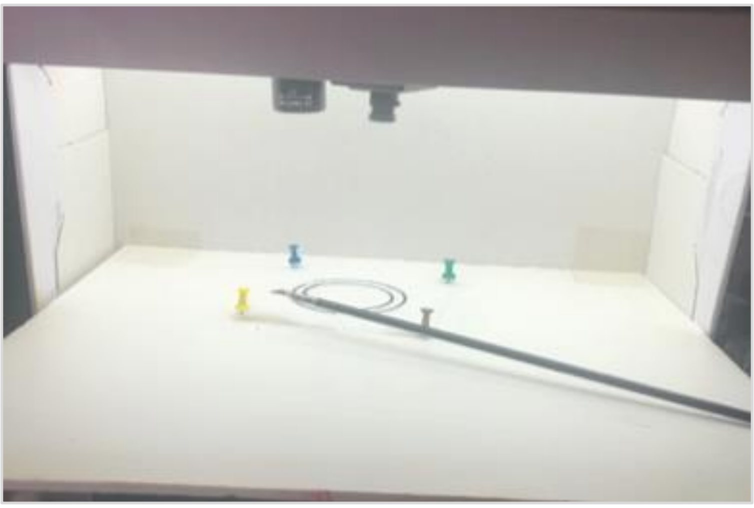


Fig. 1. Setup of the trainer box.

This setup offers a simple manipulation of the instruments and a low-cost solution, that enables capturing of the scissor's tips movements by detecting the red color covering its tip in the workspace, without relying on the instruments' geometry estimation. Additionally, blob detection is applied to each frame extracted from a real-time video to detect and localize the two circles during the training. Then the outcomes from these steps are used to calculate the distance between the center of the circles and the colored scissors tip that will be fed into the fuzzy system to assess the trainer's performance. Overall, this is a very affordable configuration for other researchers, too.

The primary contribution of this work is a sensor-free system to track laparoscopic scissors tips using orthogonal camera real-time videos, color-based detection technique, and fuzzy logic to build a summative assessment system of the trainer's performance for one of the precision-cutting exercises.

This paper is organized as follows: Section 2 provides some background information and reviews recent research on performance assessment techniques for laparoscopic surgery training. Section 3 discusses the methodology of the proposed system, while Section 4 presents the results and analysis. Finally, in Section 5, conclusions and future work plans are outlined.

2. BACKGROUND

The Fundamentals of Laparoscopic Surgery (FLS) box trainer device is widely used to acquire and improve psychomotor skills. The American College of Surgeons (ACS) [11] recognized the FLS and established a set of academic instructions and required manual skills that can help practicing surgeons and surgical residents in improving basic laparoscopic surgery performance [2]. As part of the FLS system, users are required to perform several tasks, including peg transfer, precision cutting, end loop creation, and extracorporeal/intracorporeal suturing.

The proposed system is developed for a precision cut exercise that focuses on hand-eye coordination and ambidexterity. More information on the test exercises can be found in [12]. The platform for precision cutting exercises consists of an artificial tissue with two circles sharing the same center point. The radius of the inner circle is 2.5 centimeters, and it is 3.0 centimeters for the outer circle. A scissors movement must be kept in the space between the two circles. Any movement out of the outer circle circumference or inside the inner circle circumference or any cutting through a circle line counts as an error. In general, the current evaluation of laparoscopic surgical skills works on surgical tools detection and motion analysis with different approaches. Detection and tracking of surgical instruments and objects during training is an important factor in surgical training assessment.

Computer vision offers a viable alternative for training systems and is widely used for tracking surgical tools, as it has been developed by research and commercial institutions. For example, Northern Digital Inc. (Ontario, Canada) [13] and Stryker Inc. (Kalamazoo, MI) [14] both fabricate optical tracking systems, using LED beacons attached to the surgical tool. Such systems are expensive and need hardware changes in the platform. Many research groups have attempted to implement various tracking methods by using geometric constraints for tool shaft identification [15].

Additionally, feature descriptor libraries can be compiled and used to detect objects based on the physical model of the tooltip, but this method is computationally expensive for real-time tracking [16]. Other researchers used color marker segmentation via pixel thresholding [17] and color thresholding across the whole image to extract the tool shaft [18]. Experimental results showed that these methods are computationally efficient and deliver 15-17 FPS performance.

Different approaches are found in the literature based on weights, Linear Discriminant Analyses (LDA), Markov models, and fuzzy classifiers [19]. For example, authors in [20] represented the Clinical-Based Computer Enhanced Laparoscopic Training System (CELTS), as an evaluation method, which is based on weights, concerning the orientation of the tool, the surgical instrument accumulated depth, the instrument path length, and the training time.

Moreover, a Fuzzy C-Means classifier was utilized to evaluate the skill levels of three groups of surgeons, namely expert, intermediate, and novice. These groups learned from past training with surgeons who possess known skills. The outcomes of the evaluation could be utilized to calculate the skill level of a new surgeon [21, 22].

In a research paper cited in [5], a method using an optical flow algorithm was employed to examine real-time surgical videos to monitor surgical instruments. The authors of the article also introduced a dynamic feedback scoring system that assesses the skill level of surgical trainees based on various factors such as the fluidity of their movements, their competency in performing surgical gestures, and the frequency of errors made. To enhance the training process, a secure web-based tool was created to upload and evaluate minimally invasive surgery (MIS) training videos, with the ability to provide performance analysis and assessment scores over time.

A study conducted by [23] involved the creation of an internet-based platform that can evaluate laparoscopic surgical abilities. The platform utilizes computer vision, augmented reality, and artificial intelligence algorithms to track the movement of laparoscopic instruments. The team developed a simulated precision cutting trace to measure the number of transferred points in the transferring task. To achieve this, they employed a Raspberry Pi Board with Python programming language and computer vision libraries. The team trained an Artificial Neural Network (ANN) to analyze the behavior of both experts and non-experts, which resulted in improved accuracy of the assessment process. The transferring task assessment was conducted by applying a predetermined threshold. This innovative approach can potentially revolutionize the evaluation process in laparoscopic surgery.

A study proposed the use of an autonomous fuzzy logic supervisor in [9] to evaluate surgical skills by detecting and tracking laparoscopic instruments during standard FLS pattern-cutting tests. The study trained two state-of-the-art detectors, SSD ResNet50 V1 FPN and SSD Mobilenet V2 FPN, to determine the optimal margin size for the detected instruments and locate the point on which fuzzy logic assessment systems are based. The detectors used bounding boxes centered around the laparoscopic instrument tip with the lowest margins. Laparoscopic instruments were tracked and measured in relation to the circle line during the test to evaluate the surgeon's performance.

In a recent study published in [10], a new dataset of instruments and objects was developed for a box trainer pattern-cutting test. The researchers also implemented a real-time object detection approach using YOLOv7. The results of the experiments indicated that YOLOv7 achieved an mAP score of 95.2, 95.3 precision, 94.1 recall, and 78 accuracy for bounding boxes on a limited-size training dataset.

Thus, there has been a persistent need for a well-established performance assessment system with automatic surgical tool tracking. The purpose of this work is to create a tool for real-time video-based assessment of laparoscopic precision cut training. This tool provides feedback on specific aspects of trainees' preparedness and enables consistent expert-rated judgment.

3. METHODOLOGY

This study introduces a system that utilizes fuzzy logic to provide summative feedback to the user. It tracks the colored tips of scissors in video data and calculates errors. To detect cuts in circle lines during training, a Canny edge detector is also implemented. The algorithm for this tracking and assessment system consists of several main phases, as depicted in Fig. 2.

3.1. Frame Processing

Once the camera starts capturing the video, each frame will be processed by five main methods, i.e., blob detection method, tip tracking method, error calculation method, fuzzy assessment method, and Canny edge detector.

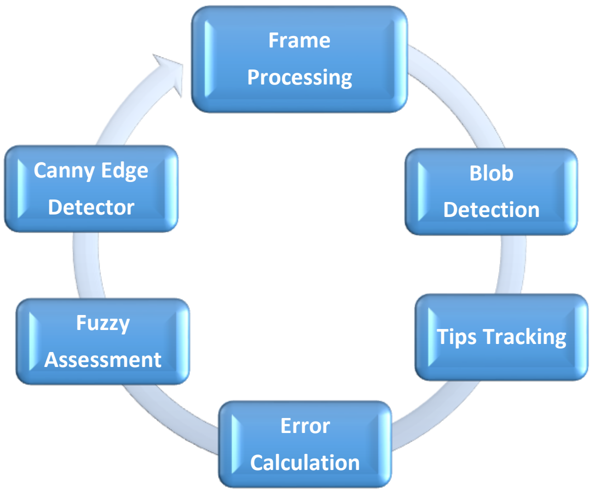


Fig. 2. Main phases of the proposed tracking and assessment.

3.2. Blob Detection

Blob detection is a crucial technique in image processing for pinpointing specific points and regions based on color or brightness. In this project, we utilize Andrew Kirillov's [23] approach, which employs grayscale filtering to create an edge detector for each processed frame. The two circle lines in the image can then be accurately identified and analyzed using the radii and center coordinates of the detected circles. This information will be used in the proposed error calculation step, and it will also highlight the identified circles with distinct green lines.

3.3. Tips Tracking

To detect and track colored scissors in a 2D workspace captured by an orthogonal camera, the AForge.NET framework features a class called EuclideanColorFiltering. This tool filters out pixels with colors outside or inside the RGB sphere, using a specific center and radius. As a result, pixels outside the sphere are replaced with a distinct color while those within it are retained. To enable their detection and tracking, the scissors' tips were coated with the RGB code (51,0,0) of red color during testing. The filter returned the X and Y coordinates of the scissors' center tip, which were then used for the error calculation step.

AForge.NET framework has a class called EuclideanColorFiltering, which is utilized for detecting and monitoring the position of colored scissors in a 2D workspace, as captured by an orthogonal camera. This tool filters out pixels with colors outside or inside the RGB sphere, using a specific center and radius. Consequently, pixels within the sphere are retained, while those outside it are replaced with a distinct color. During testing, the scissors' tips were coated with the RGB code (51,0,0) of red color to enable their detection and tracking. The filter returned the X and Y coordinates of the scissors' center tip, which were then used for the error calculation step.

3.4. Error Calculation

In the precision cutting activity, participants are tasked with creating a circular cut on a piece of gauze while ensuring that the cut remains within the boundaries of two circles. To assess the accuracy of the trainer's cut, the Blob detection method is utilized to identify the center X and Y coordinates of the circles. Additionally, the tip tracking technique is employed to determine the center tip X and Y coordinates of the scissors. The equations provided can be utilized to calculate the distance between the 2D position coordinates of the scissors' tips and the center 2D position of the two circles in each frame.

$$\mathrm{dx} = \mathrm{X.xCoordinate} - \mathrm{C.xCoordinate} \quad (1)$$

$$\mathrm{dy} = \mathrm{X.yCoordinate} - \mathrm{C.yCoordinate} \quad (2)$$

$$\mathrm{Distance} = \sqrt{(\mathrm{dx} * \mathrm{dx} + \mathrm{dy} * \mathrm{dy})} \quad (3)$$

where dx is the difference between the scissors' center tip X-coordinate and the two circles' center X-coordinate, and dy is the difference between the scissors' tip Y-coordinate and the two circles' center Y-coordinate. According to Fig. 3, the C.x and C.y coordinates mark the center of the circle, while the X.y and X.y coordinates mark the center of the scissors-colored area. The yellow line represents the distance of the scissors from the center of the circles as calculated in Eq. (3).

An error will be counted if the distance between the center point and the tip position of the scissors falls below 2.5 cm or exceeds 3.0 cm.

Throughout the training process, the distance value calculated in 3 will be utilized to determine the distance error value, as shown in Eq. (4):

$$d_e = \mathrm{Distance} - d_s \quad (4)$$

where d_s is the desired distance to cut, that has a value of 2.75 cm (in between 2.5 and 3.0 cm).

3.5. Fuzzy Assessment

Fuzzy logic, though seemingly simple in concept, represents a significant shift in mathematical theory. Its origins can be traced back to L. Zadeh, a professor at the University of California, Berkeley, who introduced the concept in 1965 [25]. Fuzzy sets, which serve as the foundation of this theory, are unlike crisp sets and can be viewed as "concepts" in both physical and abstract domains. These sets consist of elements with varying degrees of membership (in the closed interval of [0, 1]) when it comes to belonging to those "concepts." As a result, uncertainty, and imprecision in defining these "concepts" can be modeled with great precision. Moreover, fuzzy logic enables human knowledge and measures but potentially imprecise data to be combined within the same mathematical framework.

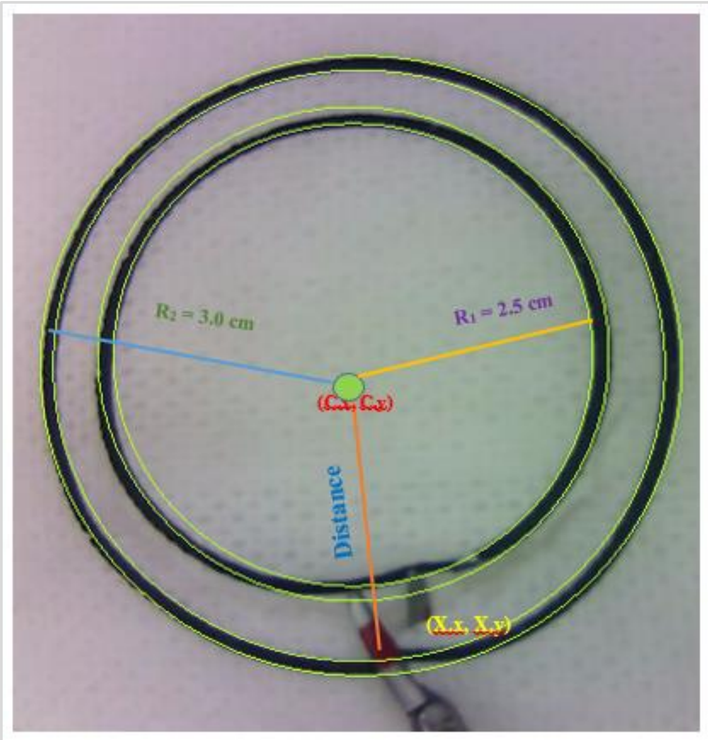


Fig. 3. Illustration of the distance measurement.

Utilizing fuzzy logic alongside other computational intelligence and artificial intelligence methods is a common practice in decision support systems. A study conducted by [26] involved the construction of two motor drives using field-oriented control techniques in Simulink software. These motors were then utilized to propel identical vehicle body models with the aid of a fuzzy logic controller that regulated the vehicle's speed. In this work, fuzzy logic is employed as a method for developing an autonomous system for assessing the skills of laparoscopic surgery.

In this work, fuzzy logic is utilized to assess the trainee's performance in the precision cut task based on the calculated distance in the previous step. Triangular and trapezoidal fuzzy sets are used for both input and output membership functions. Although various mathematical formulas can represent membership functions, trapezoidal and triangular membership functions are commonly preferred to reduce computational complexity.

By using the fuzzy logic package of the Accord.Net framework, two linguistic variables are defined, Iv_Distance_Error and Iv_Assessment, where Iv_Distance_Error is the distance error as calculated by Eq. (4). Based on the inner and outer circles line borders, five fuzzy overlapping labels were created, namely, "Very_Near_Inner", "Near_Inner", "Desired", "Near_Outer", and "Very_Near_Outer".

As illustrated in Fig. 4., when the error is between -0.25 and -0.2cm, the cut is very close to the inner circle's circumference, hence the label is Very_Neer_Inner. In the Near_Inner set, the error is -0.2cm, while in the Desired set, the error is between -0.175 and 0.175cm, which is the best distance to cut between the two circles. The "Desired" linguistic variable is expressed through a trapezoidal membership function. This means that even if an error occurs within a fraction of a millimeter to the left or right, it is still considered part of the Desired distance. When it comes to the Near_Outer set, the error is 0.2cm. However, if the error range is between 0.2 and 0.25cm, the label is referred to Very_Neer_Outer.

IvAssessment measures the output variable on a scale of 0 to 100 percent and categorizes it as "Bad," "Good," or "Excellent," depending on the assessment results. The fuzzy knowledge base, including the membership functions and FAM matrix, can be adjusted based on feedback from expert surgeons. The fuzzy sets for the outcome assessment are displayed in Fig. 4 (b). The fuzzy inference system's knowledge representation utilizes 5 IF-THEN rules, which are presented in the FAM matrix in Table 1.

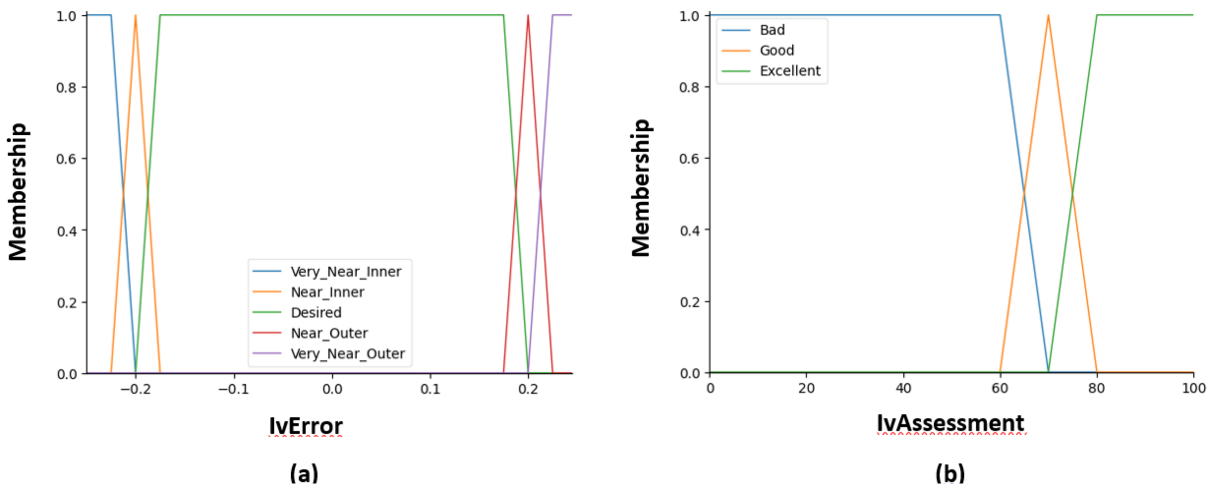


Fig. 4. Membership functions for the tool tip tracking assessment: a) for IvError; b) for IvAssessment

The process of fuzzy inference involves using fuzzy inputs and a fuzzy knowledge base to generate outputs with uncertain or ambiguous values. To achieve this, the input fuzzifier unit applies the Singleton fuzzifier method [27], while the Mamdani method [28] is used as the preferred inference technique. Finally, the centroid defuzzification method is employed to determine the center of the output fuzzy set's area on the x-axis, which is then represented as percentages in a crisp value format.

Table 1. FAM matrix for tool tip tracking assessment.

Input	Output
IvError	IvAssesment
Very_Near_Inner	Bad
Near_Inner	Good
Desired	Excellent
Near_Outer	Good
Very_ Near_Outer	Bad

Fig. 5 displays two fuzzy assessment simulations. The first simulation indicates that the performance assessment percentage is highest when the distance error is lowest, as seen in

Fig. 5(a). Conversely, the second simulation depicts that the distance error is at its highest, as displayed in Fig. 5(b). The shaded regions precisely indicate the activated rules during the inference process.

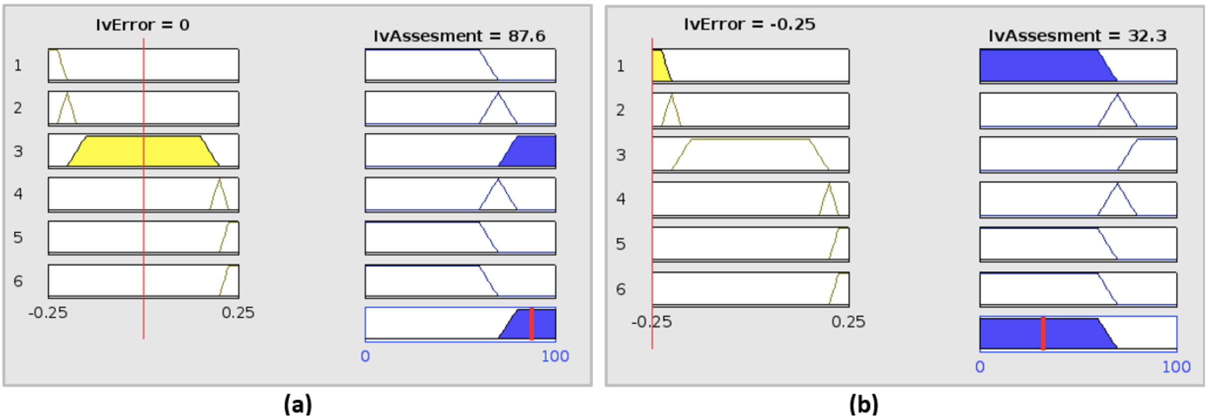


Fig. 5. Fuzzy logic assessment system simulation results.

3.6. Canny Edge Detector

In image processing applications, edge detection plays a critical role as it reduces data volume and preserves structural properties. This allows for more advanced image processing to take place.

The utilization of Canny is essential in identifying edges with accuracy and precision. By establishing multiple Canny filters with various resolutions and implementing them on vascular images, Authors in [29] create an edge image that enhances the centerline features of vessels. Each filter is customized to a specific section of the vessel, producing a broad range of responses across different filter resolutions. These responses are then merged to create an edge map that can be optimized for edge detection.

In this work, the method proposed by John F. Canny in 1986 (JFC) [30] is utilized to detect edges in an image and suppress noise. Any circle line cuts that may have occurred during the exercise are identified. The algorithm involves four distinct stages [31]. The first stage involves smoothing the image by employing Gaussian filtering to eliminate noise. In the second stage, the gradients of the image with a significant magnitude are identified. Third, non-maximum suppression is carried out based on gradient directions. Finally, double thresholding is applied to potential edges, and the final edges are determined by suppressing all edges that are not connected to a specific (strong) edge. This method can detect any cuts in the lines of the two circles that may have occurred during testing by analyzing the final frame.

4. RESULTS AND DISCUSSION

The data acquisition, data processing, and decision-making of the proposed software implementation are performed using AForge.NET [32, 33] and Accord.NET [34] C# libraries. Fig. 6 illustrates the system application window, where the picture box displays the detected circles and the colored scissors in real time during the precision cut training exercise. The colored scissors are sometimes not detected, but this occurred when the marker was too far from the camera.

Furthermore, a BMP image is created at the end of the exercise that draws the scissors' tips within the predefined circles during the exercise as shown in Fig. 7. This image depends on the returned position coordinates of the colored scissors' tips and the detected circles' center, and it clearly shows the scissors' path during the exercise.

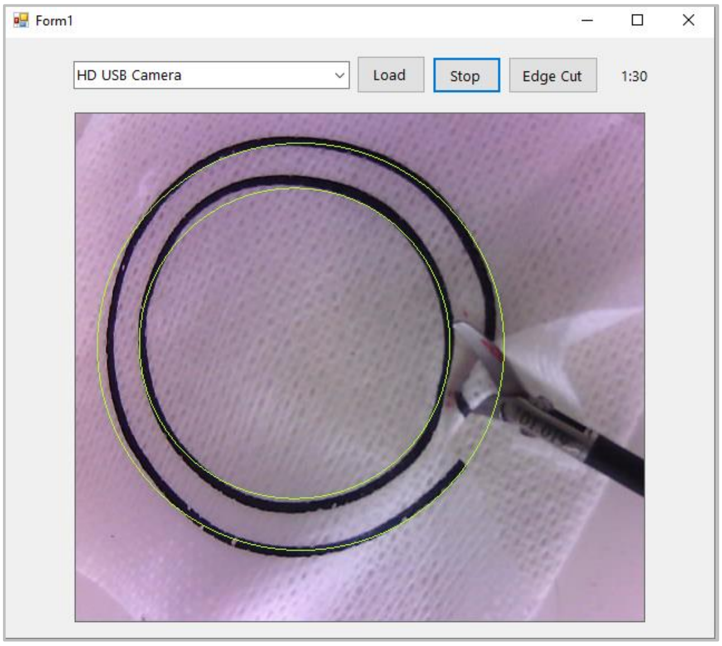


Fig. 6. The system application window.

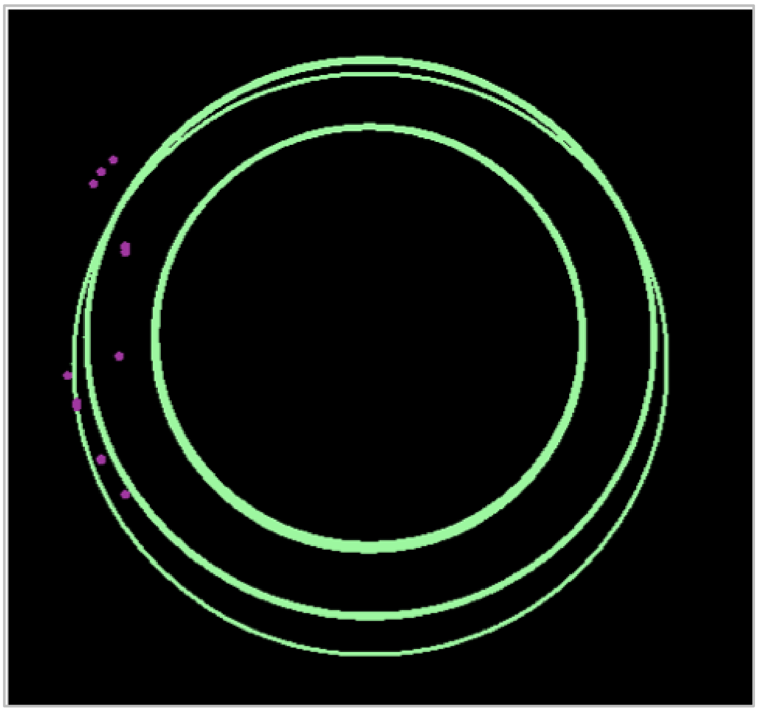
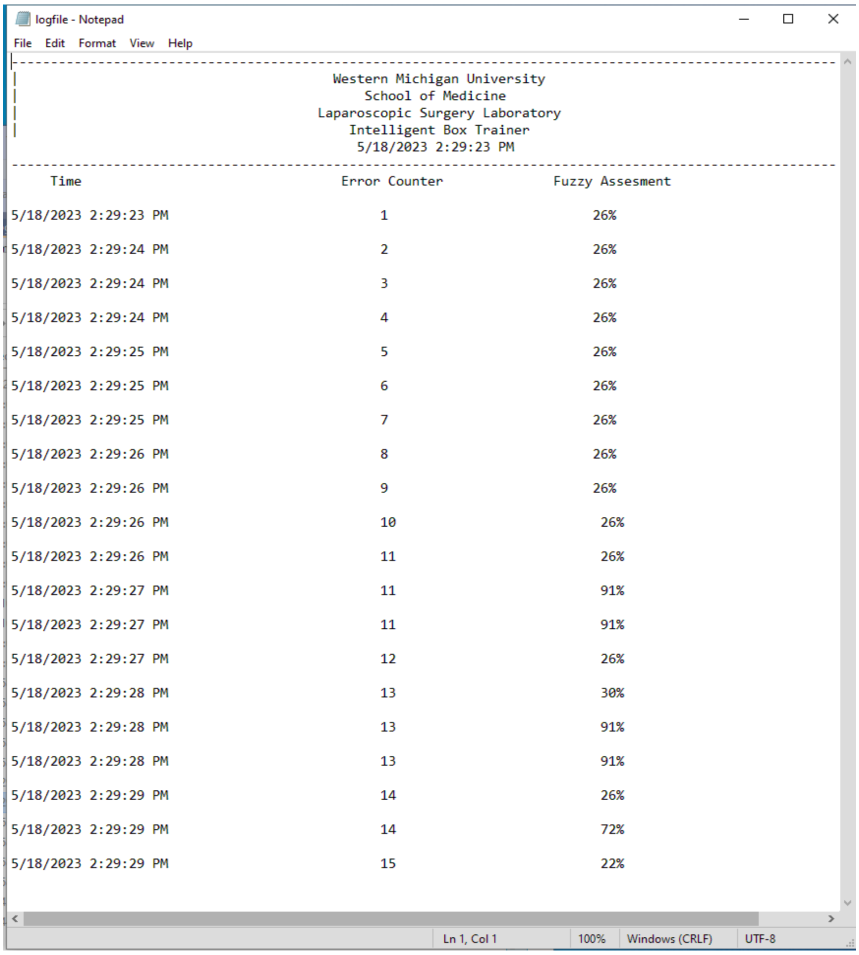


Fig. 7. A BMP image showing the scissors tips' path during the exercise.

After each session, a detailed text report is created which includes the error counter value and the fuzzy assessment for every time slot (approximately every 0.29 s) as shown in Fig. 8. This report provides valuable feedback on the surgeon's performance during exercise.



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Western Michigan University
School of Medicine
Laparoscopic Surgery Laboratory
Intelligent Box Trainer
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Time	Error Counter	Fuzzy Assesment
5/18/2023 2:29:23 PM	1	26%
5/18/2023 2:29:24 PM	2	26%
5/18/2023 2:29:24 PM	3	26%
5/18/2023 2:29:24 PM	4	26%
5/18/2023 2:29:25 PM	5	26%
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5/18/2023 2:29:29 PM	15	22%

Ln 1, Col 1 100% Windows (CRLF) UTF-8

Fig. 8. The final assessment text report.

The Canny edge detector, however, can be deployed at any time during the test to detect any cut in circle lines. As illustrated in Fig. 9, the broken circle lines are highlighted with red circles, which is a very sharp and accurate view of the failures.

(a) (b) (c)

Fig. 9. The Canny edge detection output: a) the captured frame without any processing; b) the highlighted circles gained from the Blob detection process; c) the cuts in the circle lines by applying the Canny edge detector on the captured frame.

Various techniques described in the literature aim to improve the Laparoscopic training system using computer vision, artificial intelligence, and Fuzzy Logic. Table 2 provides a brief comparison of some relevant approaches with the proposed model, highlighting the model constructed, the FLS test category, and the outcomes.

Table 2. Comparison between the proposed model and the related reported - in the literature - approaches.

Approach	Criteria		
	Model	FLS Test	Results
The proposed model	A Single-Input-Single-Output Fuzzy Logic system based on, color-based detection and tracking technique, and a canny edge detector	Pattern cut	Summative feedback listing an error counter value and the fuzzy assessment every 0.29 s on average. A BMP image that summarizes the tips of the scissors within the predefined circles during the test. Detecting any circle line was cut during the test using a Canny detector
Grantner et al. [6, 7]	A fuzzy logic-based performance assessment support system by tracking the tooltip movements around the test platforms in a 3D virtual space	Peg transfer	Recorded visual and measured feedback of the trainer's performance
Fathabadi et al. [9]	A fuzzy logic supervisor for surgical skills assessment based on a multi-class detection and tracking of laparoscopic instruments	Pattern cut	Identifying each instrument at the confidence score of 70% and fidelity at 90%
Islam et al. [5]	An optical flow algorithm that analyzes a surgeon's hand and surgical tool movements and detects features like smoothness, efficiency, and preciseness	Intracorporeal suture, Peg transfer and Pattern cut	Real time, summative feedback, and a web-based tool to upload MIS training videos and receive evaluation scores
Stylopoulos et al. [19]	A computer-based system CELTS consists of a mechanical interface, a customizable set of tasks, and an Internet-based software interface	Peg transfer, Suturing and knot-tying	Tracking the motion of laparoscopic instruments, and providing real time feedback by identifying the depth perception, smoothness of motion, instrument orientation, and the outcome of the task
Hajshirmoha-mmadi et al. [20]	Two fuzzy classifiers trained and tested based on MIST VR surgical simulator data	Suturing and knot-tying	A highly nonlinear relationship between the inputs (performance metrics) and output (fuzzy score) of the system
Huang et al. [21]	A fuzzy classifier trained and tested based on MIST VR surgical simulator data	AcquirePlace and TransferPlace	The classifiers did not provide accurate results for both tasks
Alonso-Silverio et al. [22]	A basic laparoscopic skills evaluation system based on implementing an artificial neural network (ANN) executed in a Raspberry Pi board	Peg transfer and Pattern cut	The results of the classifier indicate an average accuracy of 90.98% and a receiver operating characteristic curve value of 0.93. Using an ANN, the psychomotor skills of users were classified into two categories: experienced and nonexperienced

This work demonstrates the feasibility of using a computer vision system with an orthogonal camera for skill assessment. While performing the precision cut task, it was evident that the system able to detect and track the two circle lines and the colored scissors, which gives valuable information about the surgeon's proficiency, since the cut path, its size, and duration of the cut test are all important factors to assess.

The primary contribution of this work is its ability to process the captured frames directly during the test at a processing rate of 4 FPS. It was achieved by using several functions that combined a series of well-known computer vision algorithms that reduced the computational cost of image processing, to accurately track the scissors' tips. The color code used for the scissors was suitable for the detection of the instruments during the tests. It can also open up the possibility of detecting more instruments simultaneously with different colors applied.

Learning the essential skills for laparoscopic surgery can be accomplished by practicing in a comfortable and cost-effective environment. The proposed system ensures an impartial and precise assessment, with prompt delivery of results. Furthermore, this video-based tracking system can be smoothly incorporated into any training facility without the need for significant modifications.

5. CONCLUSIONS

This paper involved the development of a system that tracks the movement of colored endoscopic scissors and two circles. An orthogonal camera and video image processing module were used to gather information, which is then fed into a fuzzy logic system that assessed a trainee's performance during the FLS box trainer precision cutting task. This assessment was done at a processing rate of 4 FPS.

The system provides summative feedback and a performance assessment of the trainee during the test, generating a final text report that lists the error counter value and fuzzy assessment every 0.29 s on average. Additionally, a BMP image is created to summarize the scissors' tips within the predefined circles during the test. The Canny detector is also applied to detect whether any circle line was cut during the test.

This video-based tracking system automatically detects the 2D position of the colored scissors within the camera's workspace. The system does not require any modifications to the box trainer device, which allows future work to combine geometric computer vision techniques for 3D coordinate extraction with feature detectors.

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