Multi-Thread Implementation of Tool Tip Tracking for Laparoscopic Surgical Box-Trainer Intelligent Performance Assessment System

Janos L. Grantner, Aous H. Kurdi, Mohammed Al-Gailani and Ikhlas Abdel-Qader

Department of Electrical and Computer Engineering, Western Michigan University, 1903 West Michigan Ave, Kalamazoo, MI 49008, USA

janos.grantner@wmich.edu; aoushammad.kurdi@wmich.edu; mohammedyasser.algailani@wmich.edu; ikhlas.abdelqader@wmich.edu

Robert G. Sawyer, M.D. and Saad Shebrain M.D.

Department of Surgery, Homer Stryker M.D. School of Medicine, Western Michigan University, 300 Portage Street, Kalamazoo, MI 49007, USA

robert.sawyer@med.wmich.edu; saad.shebrain@med.wmich.edu

Abstract: Laparoscopic surgery has revolutionized medicine, yet it requires specific skills not traditionally taught to surgeons. Early in training, surgical trainees frequently use low-fidelity "box-trainers" to increase their skills. Evaluation of performance, however, is crude, frequently focusing on speed alone or subjective observations. There is a research collaboration between the Department of Electrical and Computer Engineering and the Department of Surgery, of the Homer Stryker M.D. Medical School, at WMU. The objective of this research is to develop an intelligent box-trainer system which incorporates sensory devices and high definition digital video cameras along with a fuzzy logic-based performance assessment system. Two of the key research problems of this work are the implementation of the tool tip tracking task and the associated performance assessment method. This system will more consistently evaluate trainees and their performance in real time without needing the presence of an independent observer. Using fuzzy logic to capture expert knowledge and fusing it with sensory data for performance assessment purposes is a new approach in the area of laparoscopic surgery training.

Keywords: Intelligent Laparoscopic Surgical Box-Trainer; Laparoscopic Surgical Tool Tip Tracking; Fuzzy Logic-Based Performance Assessment System

1   Introduction

Laparoscopic surgery, one form of minimally invasive surgery, is performed through a series of small incisions, through which, plastic ports are placed, allowing the introduction of a camera and specially designed instruments. The avoidance of a single large incision, reduces pain and recovery time. The surgeon's interface occurs through a video monitor that displays images from the camera inside the abdomen. Early training for laparoscopic surgery is more complex than for more traditional (open) surgery, leading to a more specified training curriculum known as Fundamentals of Laparoscopic Surgery (FLS). The FLS program (SAGES/ACS, FLS Program, Los Angeles, CA, USA) [1] [2] consists of five basic laparoscopic tasks that are non-procedure specific and are performed and tested on a surgical box-trainer, a low cost *in vitro* system that uses laparoscopic instruments in a laboratory, bench-top setting [3]. These tasks emphasize ambidexterity, depth perception, eye-hand coordination and controlled instrument movement. The development of excellent eye-hand coordination and cognitive capabilities are crucial for the safe execution of laparoscopic procedures.

When measuring surgical skills during simulation, the users' performance is, generally speaking, assessed by monitoring the precision and the speed of the execution of the tasks. One major disadvantage when using the universally accepted and standard FLS Box-Trainer device [4] [5] is that, outside of crude time to task completion, neither qualitative nor quantitative performance data are measured and recorded electronically. As a consequence, the test results are not easily available for the users in a format which can be reviewed by computer or teaching faculty, who, instead, must depend on subjective assessments performed in real time.

Several attempts have been made to objectively measure and record performance during laparoscopic training exercises (reviewed by Reily et al. [6]). Oropesa et al. [7] proposed an EVA (Endoscopic Video Analysis) tracking system for extracting the motion of laparoscopic instruments based on non-obtrusive video tracking. The feasibility of using EVA in laparoscopic settings has been tested in a box trainer setup. EVA makes use of an algorithm that employs information of the laparoscopic instrument's shaft edges in the image, the instrument's insertion point and the camera's optical center to track the three-dimensional position of the instrument tip. A validation study of EVA comprised a comparison of the measurements achieved with EVA and the TrEndo tracking system. EVA was successfully validated in a BT setup showing the potential of endoscopic video analysis to assess laparoscopic psychomotor skills.

Horeman et al. [8] investigated the added value of force parameters with respect to commonly used motion and time parameters such as path length, motion volume, and task time. Two new dynamic bimanual positioning tasks were developed that not only require adequate motion control but also appropriate force control during simulated tissue manipulation. Their study concluded that it is possible to

distinguish the skill levels of a novice versus an expert with an accuracy up to 100%. The results indicated that the manipulation forces applied by novices often exceeded the established threshold value set for producing tissue damage. This means that a student's focus on task time and instrument motion alone during a skills training exercise may have a negative influence on tissue handling skills. The relatively high forces used by the intermediates in combination with the apparent lack of correlation between force and motion parameters argues for the inclusion of specific training in and assessment of force application in tissue handling in laparoscopic skills training programs.

Although progress has been made in terms of objectively quantifying laparoscopic surgical proficiency, a fair amount of assessment still depends on subjective evaluations by experienced surgeons. To this end, the introduction of fuzzy logic to skills evaluation may help lessen variability in testing. Grantner et al. [9] proposed a fuzzy logic based intelligent decision support system for children, in a similar context. Further, Grantner et al. [10] proposed an intelligent box-trainer system that is enhanced by adding several sensors and high definition digital video cameras along with a fuzzy logic-based performance assessment system. Thus, the combination of technologically advanced measurement of instrument control with fuzzy logic evaluation of performance must be considered a promising new area in the field of surgical skill evaluation.

One challenge to producing objective evaluations based on imaging is the fact that modern imaging systems can generate a massive amount of data in a short time span defined by the frame rate. In order to provide real-time intelligent assessment capabilities, the dynamic performance of the fuzzy logic-based system must be able to maintain a pace that matches that of image data generation. We, therefore, propose a hardware accelerator framework for fuzzy logic edge detection.

This paper is organized as follows: Section II describes the concepts of tool tip tracking for the FLS BT tests. Section III presents the fuzzy logic knowledge base for the tool tip tracking system. Section IV reports on the software design and its implementation. Section V outlines simulation and live test results. Section VI lays out a proposed framework for developing a hardware accelerator for edge detection. Conclusions and plans for further research are given in Section VII.

2   Tool Tip Tracking System for FLS Box-Trainer Tests

The following tasks should be carried out during the FLS tests: Peg Transfer, Precision Cutting, Endoloop, Extracorporeal Suture and Intracorporeal Suture [1]. For assessment purposes, in all five of them, it is very important that the surgical tool tips exhibit smooth movements in a limited three-dimensional space. The simplified block diagram of the tool tip tracking section and the test execution

J. Grantner *et al.*

Multi-Thread Implementation of Tool Tip Tracking for
Laparoscopic Surgical Box-Trainer Intelligent Performance Assessment System

monitoring section of the Intelligent Box-Trainer System [10] is depicted in Fig. 1. The capacitive force sensors mounted on the graspers along with their interface electronics, the START/STOP push button and the microcontroller system which sends the force measurement data and the execution time to the Main PC are omitted.
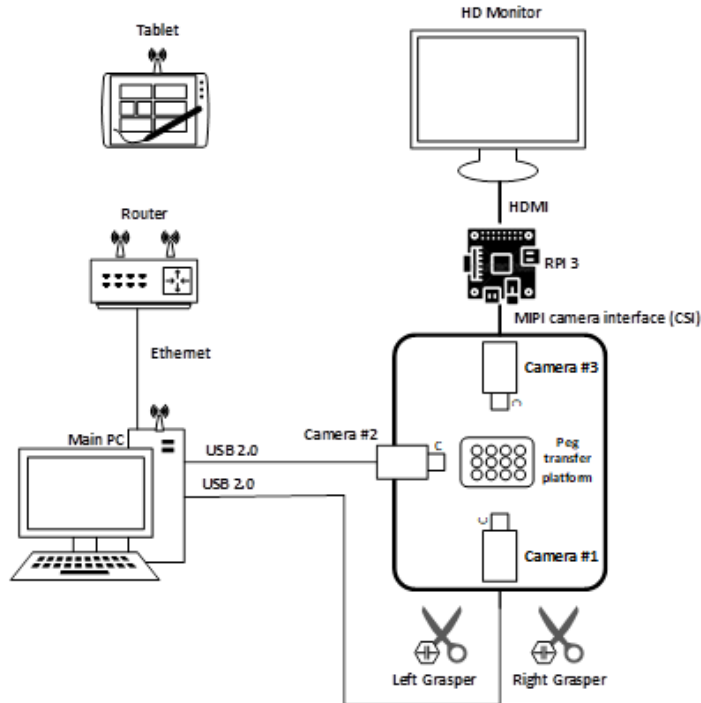

Figure 1
Tool tip tracking system

The tool tip tracking system encompasses two image sensors, a computer system and specific laparoscopic surgical tools suited for a particular FLS test. Currently, each image sensor is a 5-megapixel USB 2.0 camera with a variable-focus lens. The cameras are positioned perpendicularly inside the BT to facilitate a three-dimensional tracking of the tool tips movements. The center of each camera lens is calibrated to point to the center of the actual test platform inside the BT. The cameras are configured to produce a video stream at the rate of approximately 30 frames per seconds with resolution of 1028x720 pixels per frame. The BT is retrofitted with extra LED strips for better lighting conditions. The back side of the BT is closed with a white piece of plastic to avoid any outlier tracking of objects outside the BT. During the tests the video streams produced by Cameras 1 and 2 are recorded.

Camera 3 along with the Raspberry Pi 3 (RPi3) microcomputer provide visual feedback for the test taker on the HD monitor. This video stream is not recorded. The tablet is used by the supervising medical personnel to register the user for the test and to select the type of test to be taken as well as the skill level. During the test the tablet displays the results of the performance assessment system in real time. Those results are created by programs running on the Main PC. The wireless communications between the tablet and the Main PC are implemented through the Router. At the conclusion of the test, the supervisor may accept, or reject, the assessment outcome by the intelligent system and, in addition, may add comments by using the tablet. Those comments will be included in the text file in which the assessment results are stored.

3   Knowledge Base for Tool Tip Tracking System

The concept to track and assess the movements of the tool tips during laparoscopic surgery skill tests using a BT is new. At present time there is no other, published, comparable intelligent BT system available than that which is presented in this paper. As a consequence, no public data sets are available to work with. However, there is expert surgeon knowledge about the desirable tool tip movements. Using camera images, there are various algorithms and software tools available to track the tool tip movements. In this research the color tracking feature has been chosen because it is less computationally intensive than other approaches and the objective of this project is to provide real-time skill assessment capabilities. The tracking is carried out in pixel space but the results can be converted into distance measurements in a coordinate system.

Fuzzy set theory provides a mathematical framework, in which, expert knowledge can be fused with measured data in an uncertain environment. Even in the case of non-existent experimental data sets by interviewing domain experts a fuzzy knowledge base can be created.

The discussion which follows is based upon the Peg Transfer test. The right-hand grasper tool tip is painted red while the left-hand grasper tool tip is painted yellow for object movement tracking. To make the color tracking more robust the red color may be replaced by a more composite one, like cyan or magenta, in the future. A crucial aspect of executing a laparoscopic surgery procedure is that tool tip movements should be confined into a three-dimensional (3D) space which should be of limited size. If the tips were moving without imposed 3D constraints, they might cause unintended damage to internal organs near to the target of the procedure. The idea for creating a fuzzy model for tool trip tacking is illustrated in Fig. 2. The test platform is surrounded by three virtual 3D boxes. The physical sizes of these boxes depend upon the chosen skill level of the user and are decided by expert surgeons. The actual sizes are subject of further research and will be fine-tuned for each skill level category to reflect the opinions of expert surgeons.

The coordinate system is set up as follows: X stands for horizontal movements, Y stands for vertical movements and Z stands for depth movements (away from the test platform), respectively. The origin of the virtual coordinate system is fixed to the geometric center of the test platform.

The virtual 3D spaces are divided into symmetrical left and right sub-spaces. The input and output fuzzy sets for tool tip tracking are depicted in Figs. 3a-3c. Both the recorded left-hand and the right-hand tool tip movements are fuzzified in the same way. The membership functions for the X and Y movements have the same properties for the linguistic labels Excellent, Good and Bad, respectively. The labels for the Z movements are defined in a somewhat different fashion.
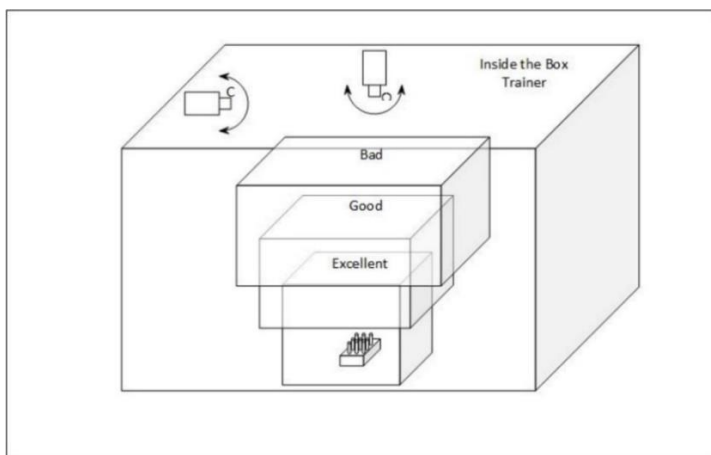

Figure 2
Virtual 3D spaces for tool trip tracking
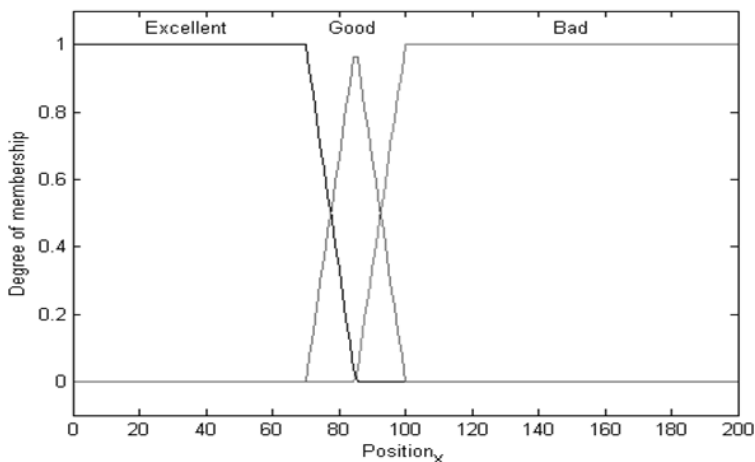
Figure 3a
Membership functions for X movements

The membership functions for performance assessment using letter grades are shown in Fig. 4. A stands for the top grade and E stands for the failing grade. The fuzzy IF-THEN rules for the tool-tip tracking performance assessment system are given in the form of Fuzzy Associate Memory (FAM) matrices which are depicted in Table 1.
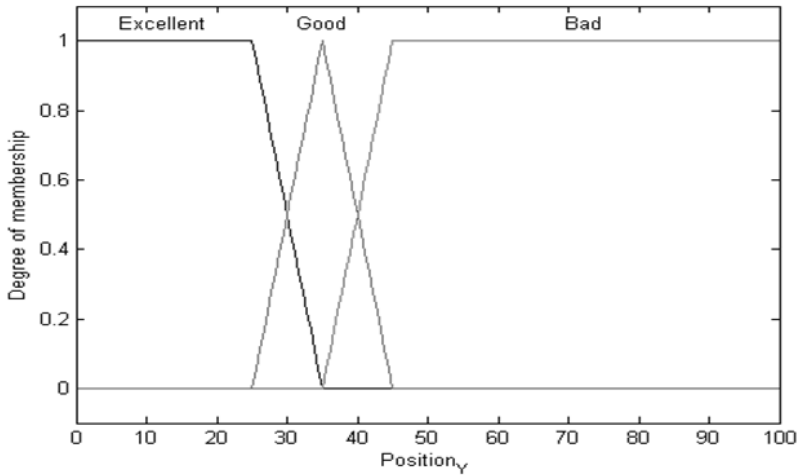

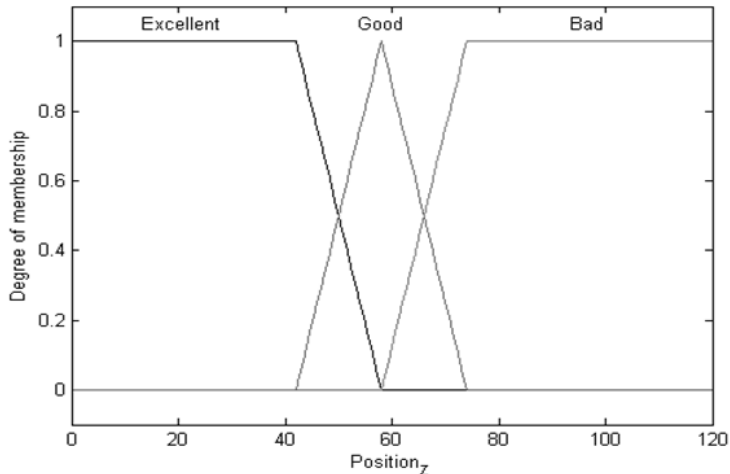
Figure 3b
Membership functions for Y movements

Figure 3c
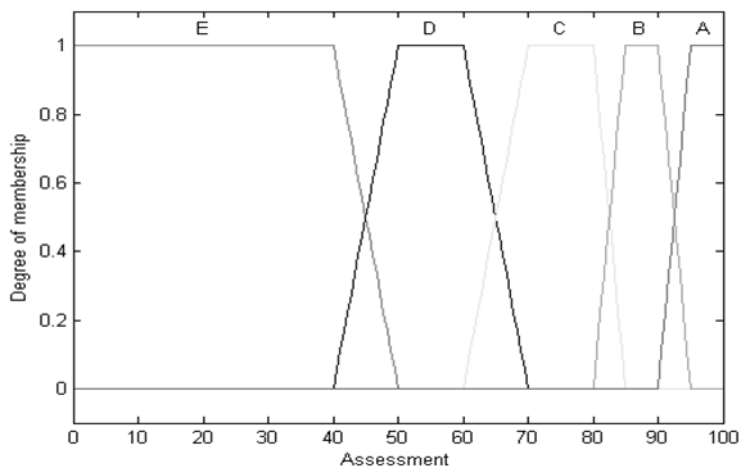Membership functions for Z movements

Figure 4
Membership functions for performance assessment

The membership functions and the fuzzy knowledge base have been devised by collecting data from peg transfer tests executed by first year residents and also by interviewing expert surgery faculty about their perceptions on the residents' performance. Hence, the membership functions and the FAM matrices included in this paper reflect the current status of the research project. As more test data, along with expert surgeons' performance assessment, becomes available, the membership functions and the FAM matrices will be fine-tuned to improve the quality of the assessment system. In addition, fuzzy membership functions and associated FAM matrices will be developed for users of other skill levels as well, like novices, second and third year residents and expert surgeons.

The research work will continue to extend the intelligent assessment system to support all five standard tests which are established in the FLS program.

Table 1
FAM Matrices for tool-trip tracking performance assessment

Input			Output
X	**Y**	**Z**	**Assessment**
Bad	Bad	Bad	E
Bad	Bad	Good	E
Bad	Bad	Excellent	E
Bad	Good	Bad	E
Bad	Good	Good	D
Bad	Good	Excellent	D
Bad	Excellent	Bad	E
Bad	Excellent	Good	D
Bad	Excellent	Excellent	C

Input			Output
X	**Y**	**Z**	**Assessment**
Good	Bad	Bad	E
Good	Bad	Good	E
Good	Bad	Excellent	C
Good	Good	Bad	D
Good	Good	Good	C
Good	Good	Excellent	C
Good	Excellent	Bad	D
Good	Excellent	Good	B
Good	Excellent	Excellent	B
Input			**Output**
X	**Y**	**Z**	**Assessment**
Excellent	Bad	Bad	E
Excellent	Bad	Good	D
Excellent	Bad	Excellent	C
Excellent	Good	Bad	D
Excellent	Good	Good	C
Excellent	Good	Excellent	B
Excellent	Excellent	Bad	C
Excellent	Excellent	Good	B
Excellent	Excellent	Excellent	A

4   Software Design and Implementation

The software running on the main PC workstation consists of three major modules as follows: data acquisition and recording, data processing and decision making. The data acquisition and recording software module connects to the two USB HD video cameras and records the two video feeds by using the open source C# library Aforge.net [11].

The video cameras run at the rate of approximately 30fps with the resolution of 1028x720 pixels per frame. The format mpeg4 is used to record the video streams with .avi file extension.

Tracking the movements of the laparoscopic tool tips in the defined virtual 3D spaces is the main task to be carried out by the data processing module. The Euclidean color filtering algorithm [12] is employed for tool tip tracking. The actual color tracking is implemented by properly setting up RGB filters in the relevant Aforge.net function calls.

J. Grantner *et al.*
Multi-Thread Implementation of Tool Tip Tracking for
Laparoscopic Surgical Box-Trainer Intelligent Performance Assessment System

The tool tip tracking program is implemented as a multi-thread environment. The main, or parent thread is the one where all other threads are created and maintained while the system is running. Each time a camera has sent a new frame an event-based thread is launched. In this thread, the new frame is placed in a waiting queue for processing. There are two waiting queues in the system, each of them is assigned to one particular camera.

Two similar threads are tasked to process the frames for identifying the tool tip positions, one for each camera. The thread is designed to implement the functions as follows: check the status of the waiting queue for a new frame to process, execute the algorithm to find the dedicated tool tip position (either right or left, respectively) in the 3D spaces and save the result in a queue. After the completion of these functions, the thread is scheduled to go into sleep mode for 10 ms. After that it executes the same algorithm again, all the time.

A third thread is designed to check the status of the queues holding the tool tip position results and feed the tool tip position data as crisp inputs to the fuzzy logic-based assessment system. The fuzzy logic-based assessment system carries out the fuzzification task for those inputs, performs Mamdani-type [13] inference operations using the fuzzy knowledge base, executes the Center of Gravity defuzzification algorithm and, finally, generates crisp assessment output values in the form of a percentage scale.

There are additional supporting threads as well. Those threads implement utility functions as follows: recoding the video feeds to the PC hard-drives, controlling the communications between the main PC and the supervisor tablet and providing console information for the supervisor medical personal on the system status. The block diagram of these threads are shown in Fig. 5.

The supervisor tablet software is also based upon the multi-thread paradigm. Its main thread controls a set of threads such as the Graphical User Interface (GUI) update thread, wireless communication with the main PC thread and the performance assessment results archiving on the main PC thread.
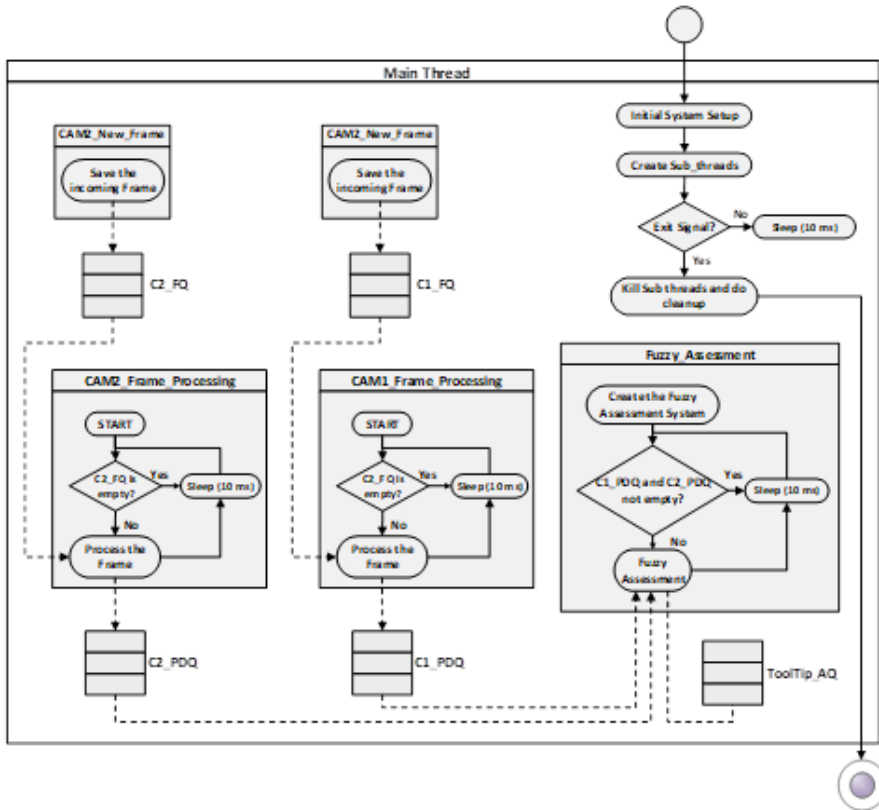
Figure 5
Software threads

5   Simulations and Live Test Results

The fuzzy logic-based tool tip movement assessment system was simulated using MATLAB. The multiple-input-single-output (MISO) system consists of three fuzzy inputs, a type-1 Mamdani [13] fuzzy inference system, and a single output. The knowledge base in the fuzzy inference system was represented by 27 fuzzy IF-THEN rules. The MATLAB system simulation architecture using the Fuzzy Logic Toolbox is shown in Fig. 6.

Figure 6
MATLAB simulations architecture

The intelligent BT system in a laboratory environment is depicted in Fig. 7. It is shown in preparation for a live experiment. During a test, a snapshot of the real time assessment results are displayed on the supervisor tablet in Fig. 8. After a test session has been completed the assessment results are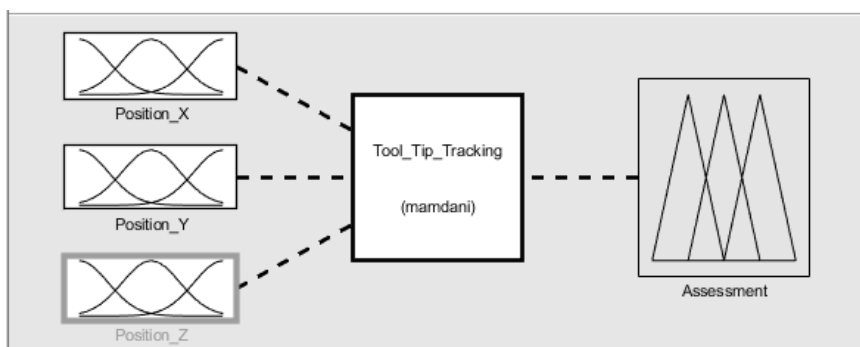 stored in a text file as given in Fig. 9. RHTA and LHTA stand for Right Hand Tool Assessment and Left Hand Tool Assessment, respectively. In addition, the recorded video streams by both cameras are also made available for review. A monitor screenshot of the Camera 1 replay is shown in Fig. 10.

Regarding the tool tip tracking assessment capability provided by the intelligent BT system, Department of Surgery faculty are very much satisfied by the performance of the new intelligent BT device. The test outcome assessments are basically in agreement with their own. Since no similar device is available for use at this point, the results delivered by the intelligent assessment system cannot be compared with anything else. The fact that the system allows the recording (both camera video streams and also the fuzzy assessment results in a text file) of the performance of the residents during their tests opens a new chapter in teaching laparoscopic surgery skills. If requested, the residents could be provided with the recorded session results on a flash drive. That will allow them to study the tests' outcomes, by reviewing the records on their own computers. As an expected result, the quality of the laparoscopic surgery training program will significantly improve. That should benefit surgery patients and the society for the long run.

In addition, the approach to develop a fuzzy logic-based performance assessment support system will allow another major benefit. As more test data and experts' opinions will have been collected over time, the assessment results will become more consistent and more objective. It will represent a great improvement over the current, potentially subjective assessment methods.
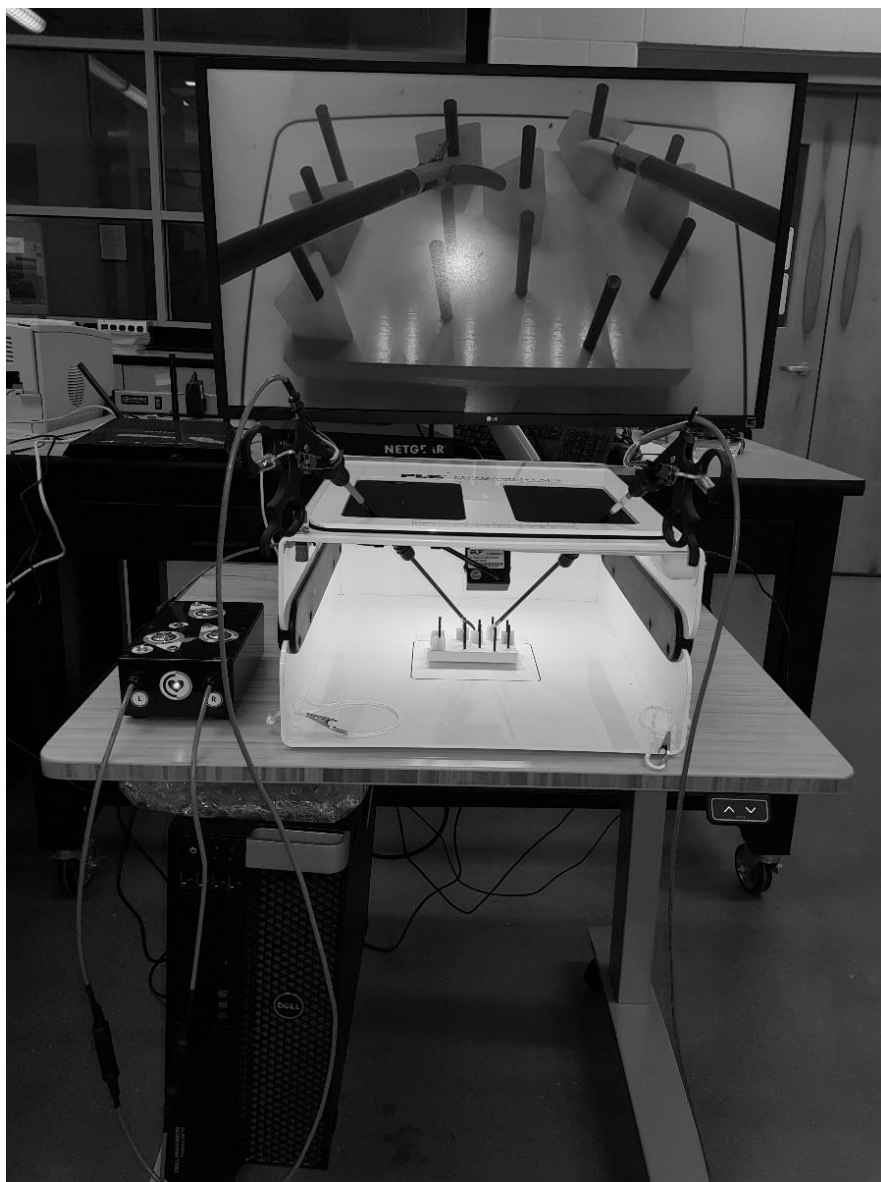
Figure 7
Intelligent BT system

Figure 8
Real time display of assessment results during a test

```
---------------------------------------------------------------------------
|                         Box Trainer Session Report                      |
---------------------------------------------------------------------------
Date: Wednesday, August 7, 2019 1:50 PM
Trainee Name: Me Me
Experiment: PEG_TRANSFER
Level of Experience: VeryHigh
---------------------------------------------------------------------------
Experiment Time: 82.86 Seconds
Right Hand Tool Tip Assessment: 60%
Left Hand Tool Tip Assessment: 28%
Right Hand Force Assessment: 78%
Lef Hand Force Tip Assessment: 77%
Time Assessment: 33%
Final Assessment: 45%
Comments: Accepted
Assessment Approved: Yes
---------------------------------------------------------------------------
Time          RHFA          LHFA          RHTA          LHTA          TIMEA
---------------------------------------------------------------------------
0.03          100%          100%           0%            0%           100%
0.33          100%          100%          100%          100%          100%
0.63          100%          100%          100%          100%          100%
0.93          100%          100%          100%           0%           100%
1.23          100%          100%          100%          100%          100%
1.53          100%          100%          100%          100%          100%
1.83          100%          100%          100%          100%          100%
2.13          100%          100%          100%          100%          100%
2.43          100%          100%          97%           100%          100%
2.73          100%          100%          91%            0%           100%
3.03          100%          100%          88%            0%           100%
3.33          100%          100%          94%            0%           100%
3.63          100%          100%          93%            0%           100%
3.93          86%           84%           79%            0%           100%
4.23          94%           82%           61%            0%           100%
4.53          75%           75%           24%           100%          100%
4.83          70%           74%           24%            0%           100%
5.13          64%           73%           23%           100%          100%
5.43          68%           68%           23%           100%          100%
5.73          75%           68%           23%            0%           100%
6.03          74%           74%           23%            0%           100%
6.33          78%           74%            0%           100%          100%
6.63          78%           75%            0%           100%          100%
6.93          79%           74%           23%           100%          100%
7.23          81%           75%           23%            0%           100%
7.53          83%           75%           23%           100%          100%
7.83          86%           77%           23%           100%          100%
8.13          86%           75%           23%            0%           100%
8.43          93%           76%           23%            0%           100%
8.73          93%           76%           23%            0%           100%
9.03          91%           76%            0%            0%           100%
9.33          94%           77%           23%            0%           100%
9.63          93%           77%           23%            0%           100%
9.93          93%           77%           23%            0%           100%
10.23         88%           77%           26%           100%          100%
```

Figure 9
BT session report

Figure 10
Replay of recorded video stream by Camera 1

6 Hardware Accelerator Design for Fuzzy Logic Based Edge Detection

Another possible approach for tool tip tracking, is based upon the edge detection method. The proposed fuzzy logic edge detection system is based upon a Mamdani-type MISO fuzzy system [13]. The system has four fuzzy inputs and one crisp output. The fuzzy knowledge base is made up of seven IF-THEN rules. Inputs one and two are the gradients regarding the X-axis and the Y-axis out of a kernel of 3×3 pixels. The respective fuzzy sets are denoted as GX, and GY.

$$GX = \sum_{x=1}^{3} \sum_{y=1}^{3} \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \cdot I(x, y) \tag{1}$$

$$GY = \sum_{x=1}^{3} \sum_{y=1}^{3} \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} \cdot I(x, y) \tag{2}$$

$$LP = \sum_{x=1}^{3} \sum_{y=1}^{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \cdot \frac{1}{9} \cdot I(x, y) \tag{3}$$
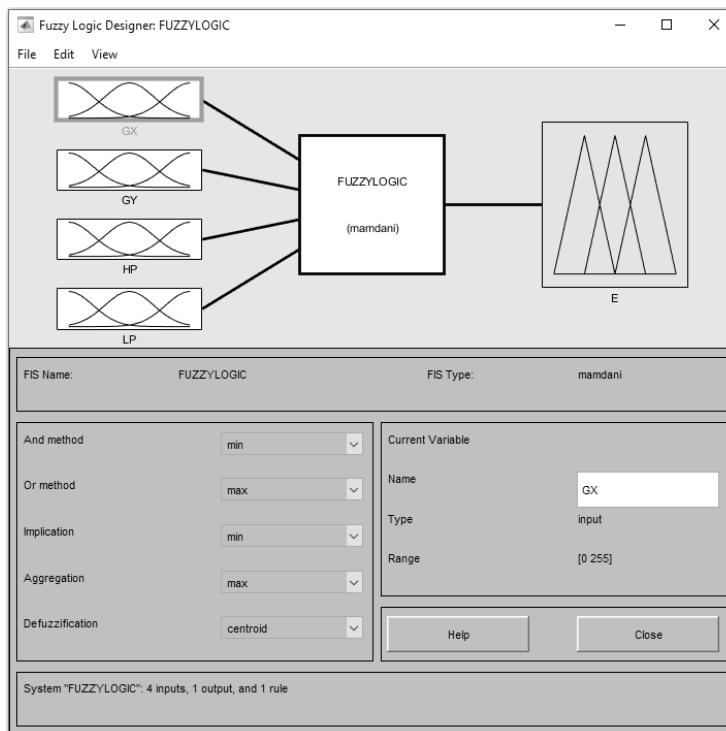
$$HP = \sum_{x=1}^{3} \sum_{y=1}^{3} \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} \cdot \frac{1}{9} \cdot I(x, y) \tag{4}$$

Figure 11
MATLAB simulations architecture for edge detection

Input three to the system is the output of a low-pass filter. The associated fuzzy set is denoted as LP. Input four to the system is the output of a high-pass filter and the associated fuzzy set is denoted as HP. The preprocessing system calculates GX, GY, LP and HP, respectively, using Equations (1) to (4). The performance of this system was simulated using the MATLAB Fuzzy Logic toolbox, shown in Fig. 11.

The proposed hardware accelerator architecture for this system consists of four modules as follows: preprocessing subsystem where raw grayscale values of the input pixels pass through four different linear spatial filters, fuzzification subsystem in which four fuzzy input variables are created by a fuzzification algorithm, fuzzy inference subsystem and defuzzification subsystem by which a single crisp output is generated. The knowledge base is implemented using seven IF-THEN rules. Various, different defuzzification methods were experimented with to assess the performance of the system.

The proposed pipelined hardware accelerator was designed and implemented on a number of Xilinx 7000-series Field Programmable Gate Array (FPGA) devices using the Xilinx Vivado Design Suite. For speedup, the architecture is made up of seven pipeline stages. The preprocessor subsystem is implemented by the first three stages, the inference subsystem utilizes two stages and the fuzzification and defuzzification subsystems, respectively, take just one each. Each stage requires just one clock cycle of execution time. The dynamic performance of the system was simulated using various Xilinx 7 Series FPGA devices.

Simulation results using 11 ns clock cycle time (i.e., the clock rate is slightly lower than the nominal maximum external clock frequency of 100 MHz) showed that the system needs 77 ns (7 cycles) to fill up the pipeline and after that it takes just 11 ns of execution time to process a pixel. For a pure software performance comparison, a MATLAB program-based implementation was running on a PC with an Intel Core i7 processor and 8 GB of memory. The software tests required 1.3178 millisecond execution time per pixel.

Conclusions and Future Research

The concepts of the tool tip tracking section of an intelligent, fuzzy logic-based performance assessment support system for the FLS BT device are presented. We propose tracking of the tool tip movements over the various test platforms in three dimensional virtual spaces of constrained sizes. By taking this approach the performance of surgery residents executing the certified FLS tests can be assessed in a quantifiable, objective and consistent way. The system provides files of recorded video clips from both cameras and also measured and processed sensory data. By using those files, the residents may review their performance which will help them to improve their laparoscopic surgery skills.

The quality of the assessment results can be improved by fine-tuning the membership functions and the fuzzy logic rule base, with the help of more test data and expert surgeon opinions. The plan is that in a research collaboration with

the Department of Surgical Research and Techniques, of Semmelweis University (SU), and the Antal Bejczy Center for Intelligent Robotics, of Obuda University, a fully equipped Intelligent BT System will be rented to SU. SU has a large number of residents in their surgery program and that will help in collecting large amount of data in a relatively short amount of time.

In the continuation of this project, we will be working on adding the Pattern Cutting Test and the three Suturing Tests, to the intelligent performance assessment system. The latter will be a very challenging project. Also in future research, hardware accelerators based on System-on-Chip (SoC) devices [14] will be investigated to potentially replace the main PC which is currently being used to perform the computationally extensive functions of the system. Using an SoC based system would facilitate the implementation of more complex and custom algorithms, at much higher processing rates.

Acknowledgement

References

[1]　Fundamentals of Laparoscopic Surgery, developed by Daniel J. Scott, MD, FACS – UT Southwestern Medical Center, Dallas, TX and E. Matt Ritter, MD, FACS – Uniformed Services University, Bethesda, MD, pp. 1-5, http://emorysurgery.org/docs/technicalcurriculum.pdf, approved by the SAGES FLS Committee 4/25/06

[2]　M. C. Vassiliou, G. A. Ghitulescu, L. S. Feldman, D. Stanbridge, K. Leffondre, H. H. Sigman, G. M. Fried, The MISTELS program to measure technical skill in laparoscopic surgery, Surg Endosc (2006) 20: pp. 744-747, DOI: 10.1007/s00464-005-3008-y © Springer Science+Business Media, Inc. 2006

[3]　S. L. de Montbrun and H. MacRae, Simulation in surgical education, Clinics in Colon and Rectal Surgery, 25(3), 2012, Sept., pp. 156-165

[4]　User Guide, Fundamentals of Laparoscopic Surgery Trainer System & Accessories by Limbs and Things Inc., pp. 1-12, Issue 5, Oct 2017

[5]　S. Muller et all, Simulation Training in Laparoscopic and Robotic Surgery, DOI 10.1007/978-1-4471-2930-1_1, © Springer-Verlag London, 2012

[6]　Carol E. Reily, Henry C. Lin, David D. Yuh and Gregory D. Hager, Review of Methods for Objective Surgical Skill Evaluation, Surg Endosc (20111) 25: pp. 356-366

[7]　Ignacio Oropesa, Patricia Sánchez-González, Magdalena K. Chmarra, Pablo Lamata, Alvaro Fernández, Juan A. Sánchez-Margallo, Frank Willem Jansen, Jenny Dankelman, Francisco M. Sánchez-Margallo, Enrique J.

Gómez, EVA: Laparoscopic Instrument Tracking Based on Endoscopic Video Analysis for Psychomotor Skills Assessment, *Surgical Endoscopy, 27*(3), pp. 1029-1039. DOI:10.1007/s00464-012-2513-z

[8] Horeman, T., Dankelman, J., Jansen, F. W., & Dobbelsteen, J. J. (2014) Assessment of Laparoscopic Skills Based on Force and Motion Parameters, *IEEE Transactions on Biomedical Engineering, 61*(3), pp. 805-813, DOI:10.1109/tbme.2013.2290052

[9] Janos L. Grantner, George A. Fodor, Ramakrishna Gottipati, Norali Pernalete and Sandra Edwards, Intelligent Decision Support System, IFSA 2007 World Congress, Cancun, Mexico, 18-21 June 2007, in Advances in Soft Computing, Vol. 41, Analysis and Design of Intelligent Systems, Patricia Melin, Oscar Castillo, Eduardo Gomez Ramirez, Janusz Kacprzyk and Witold Pedrycz (Eds.), ISBN: 978-3-540-72431-5, pp. 549-557

[10] Janos L. Grantner, Aous H. Kurdi, Mohammed Al-Gailani and Ikhlas Abdel-Qader Robert G. Sawyer, M.D. and Saad Shebrain M.D., Intelligent Performance Assessment System for Laparoscopic Surgical Box-Trainer, Electronic Proceedings of the 2018 WCCI/FUZZ-IEEE Conference, July 8-13, 2018, Rio de Janeiro

[11] Kirillov, A. (2013) Aforge.net framework, 2010-03-02, 2010-12-20

[12] Tomasi, Carlo, and Roberto Manduchi. "Bilateral filtering for gray and color images." In *Computer Vision, 1998. Sixth International Conference on*, pp. 839-846, IEEE, 1998

[13] E. H. Mamdani, Application of Fuzzy Logic to Approximate Reasoning Using Linguistic Systems, IEEE Transactions on Systems, Man, and Cybernetics, 1976, 26(12) pp. 1182-1191

[14] Aous H. Kurdi, Janos L. Grantner, and Ikhlas M. Abdel-Qader, "Fuzzy Logic Based Hardware Accelerator with Partially Reconfigurable Defuzzification Stage for Image Edge Detection," International Journal of Reconfigurable Computing, Vol. 2017, Article ID 1325493, 13 pages, 2017, https://doi.org/10.1155/2017/1325493