Engineering Support for Laparoscopic Surgery Training

Intelligent Performance Assessment System for Laparoscopic Surgical Box-Trainer Device – A Research Collaboration Project Between the ECE Department and the Department of Surgery

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The intelligent box-trainer project was sponsored by the Homer Stryker M.D. School of Medicine, WMU (Contract #: 29-7023660)

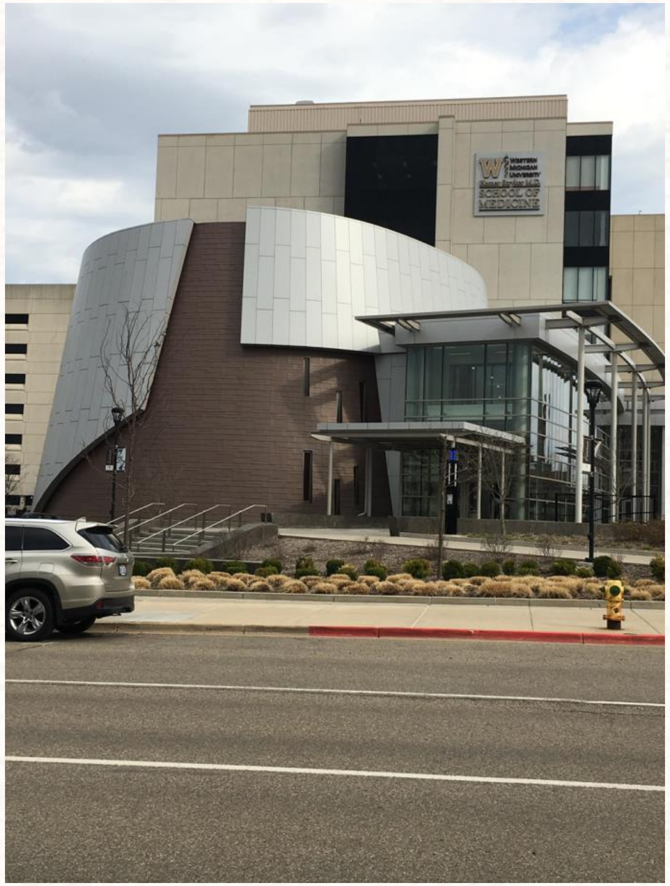
Presentation Outline

- Brief Introduction to CEAS and WMed
- Background and Motivation
- Fundamentals of Laparoscopic Surgery (FLS) Trainer
- Intelligent Box-Trainer System
- Force and Time Measurements
- Tool Tip Tracking
- Fuzzy Logic Performance Assessment System
- Illustrations of Using the Intelligent Box-Trainer System
- Conclusions and Future Research

CEAS Building

CEAS Building (Cont'd)

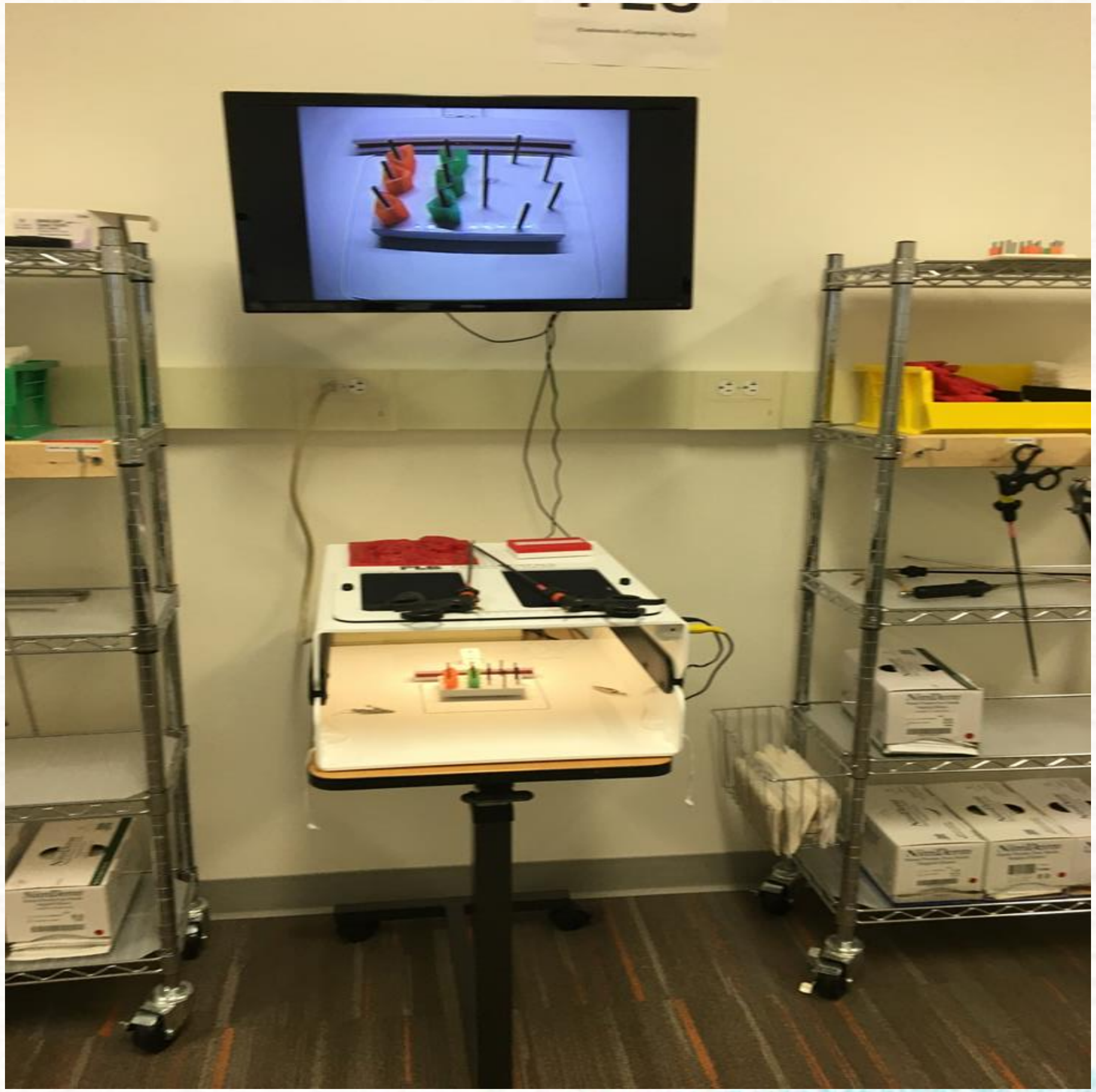
Upjohn Building of WMed



Background and Motivation

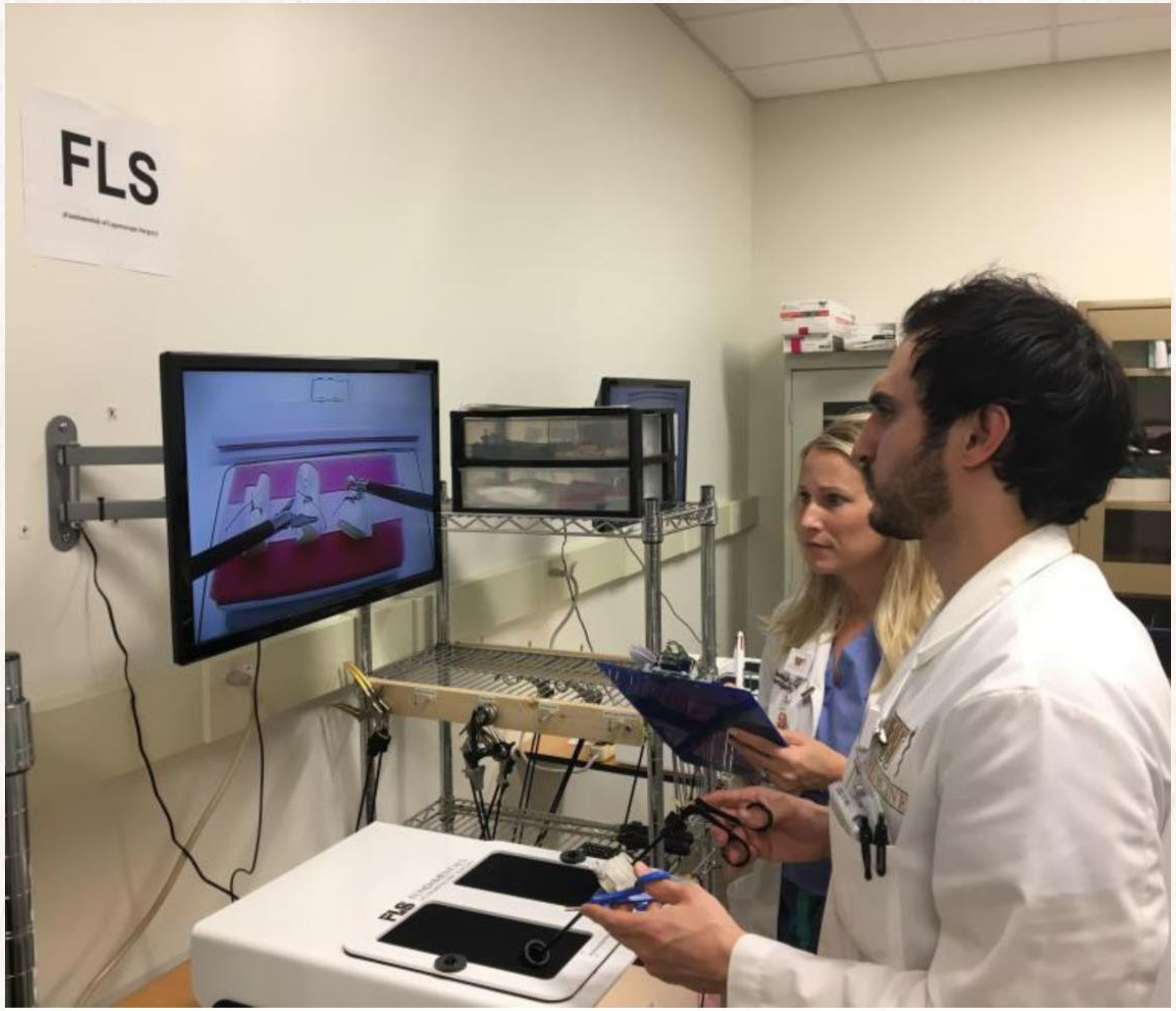
- In surgery practice, the number of procedures carried out using laparoscopic and robotic surgery methods keeps increasing
- Surgery residents should pass standardized laparoscopic surgery skill tests. In addition, there is need to classify laparoscopic skill levels of practicing surgeons when they are hired by hospitals
- The performance assessment method using available low-level trainers may be subjective and inconsistent
- High-end skill-level test systems using Virtual Reality simulators are rather expensive (cost over $100K) and are lack of the "touch and feel" experience
- There is a growing need for the development of relatively inexpensive laparoscopic skill test systems which provide quantitative measurements, recorded video of the tests for review and a more objective and consistent approach for performance assessment

Typical Laparoscopic Surgical Box-Trainer Device



FLS Trainer

- Residents should pass standardized tests (5 different types total using the FLS Trainer) successfully to get certified for performing laparoscopic surgical procedures
- The performance of the resident is monitored by a medical educator who also takes the test execution time by a stop watch
- Neither the time, nor the video recorded electronically (no playback is available)



Intelligent Box-Trainer System

- The key components of the system are as follows: FLS Trainer box along with various test tools and digital video cameras, Main Station Computer (MS) with a 32" HD monitor, Microcomputer System (CB) with force sensor and push button interfaces, MS SP4 Pro Tablet as Control Panel (CP) to the system and a Router.

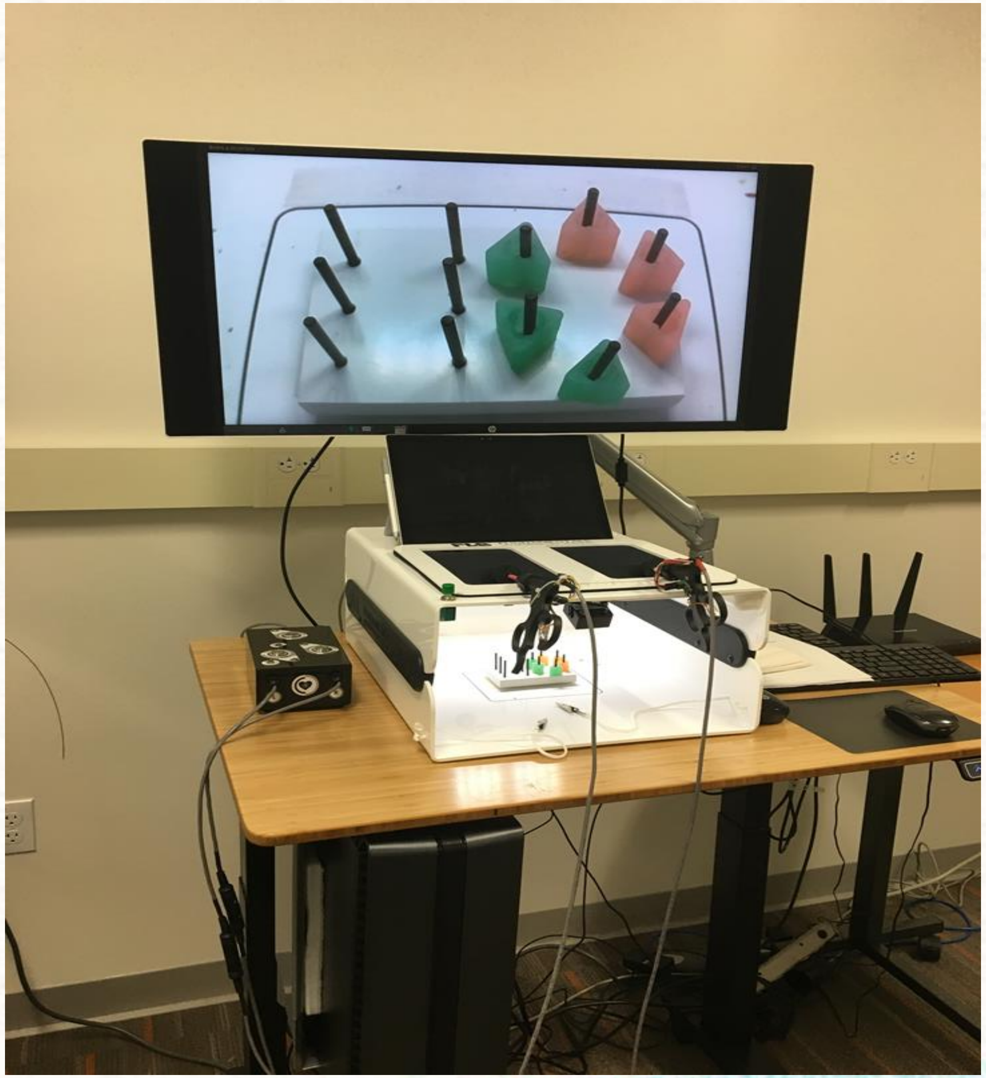
- Inside the FLS Trainer Box there is two HD webcams for tool tip tracking and video recording (one more will be added for pattern cutting tests). They are interfaced to the MS via USB interfaces. There is also a third HD webcam which is interfaced to a Raspberry Pi 3 B microcomputer (RP3). The RP3 sends the video images to one of the two HDMI inputs to the monitor so the residents can view what they are doing with the test platform. The grasper tools have force sensors mounted on them.

- The MS carries out essentially all computing tasks for the system, archives the results and communicates with both the CB and the CP

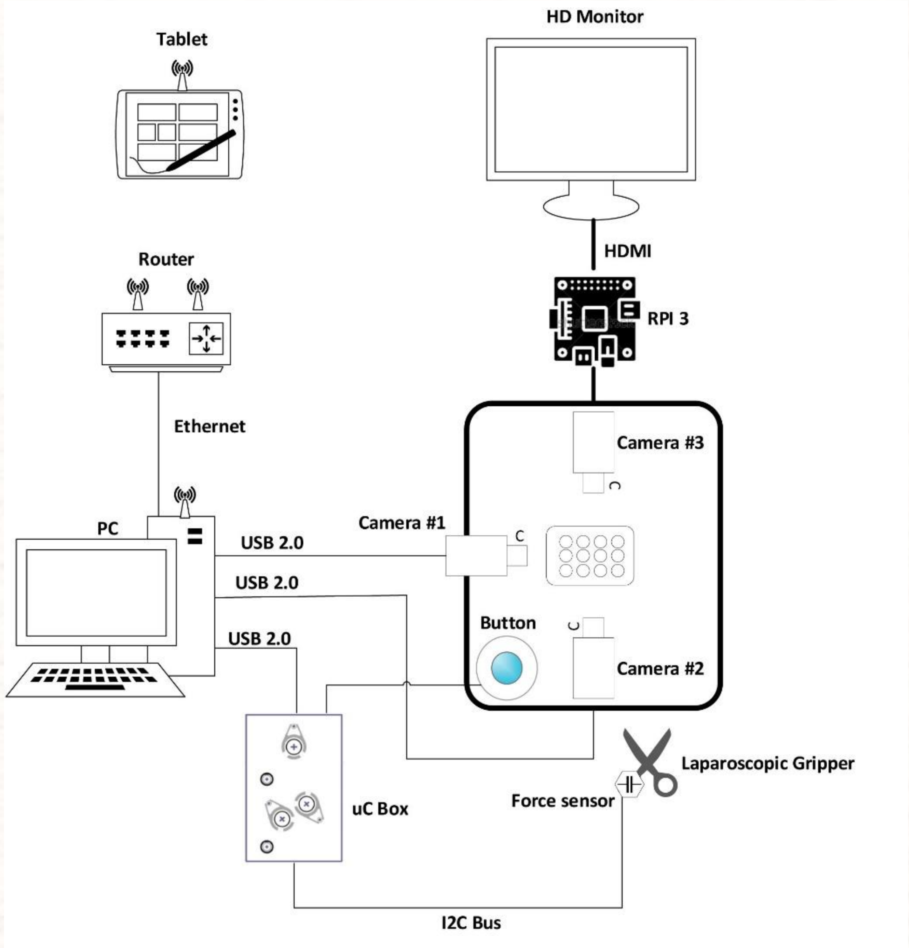
- The CB is tasked with force and time measurements

- The CP provides for a GUI interface to the system and functions as a control and display panel for the supervising medical faculty

Intelligent Laparoscopic Surgical Box-Trainer System



Intelligent Box-Trainer System Block Diagram

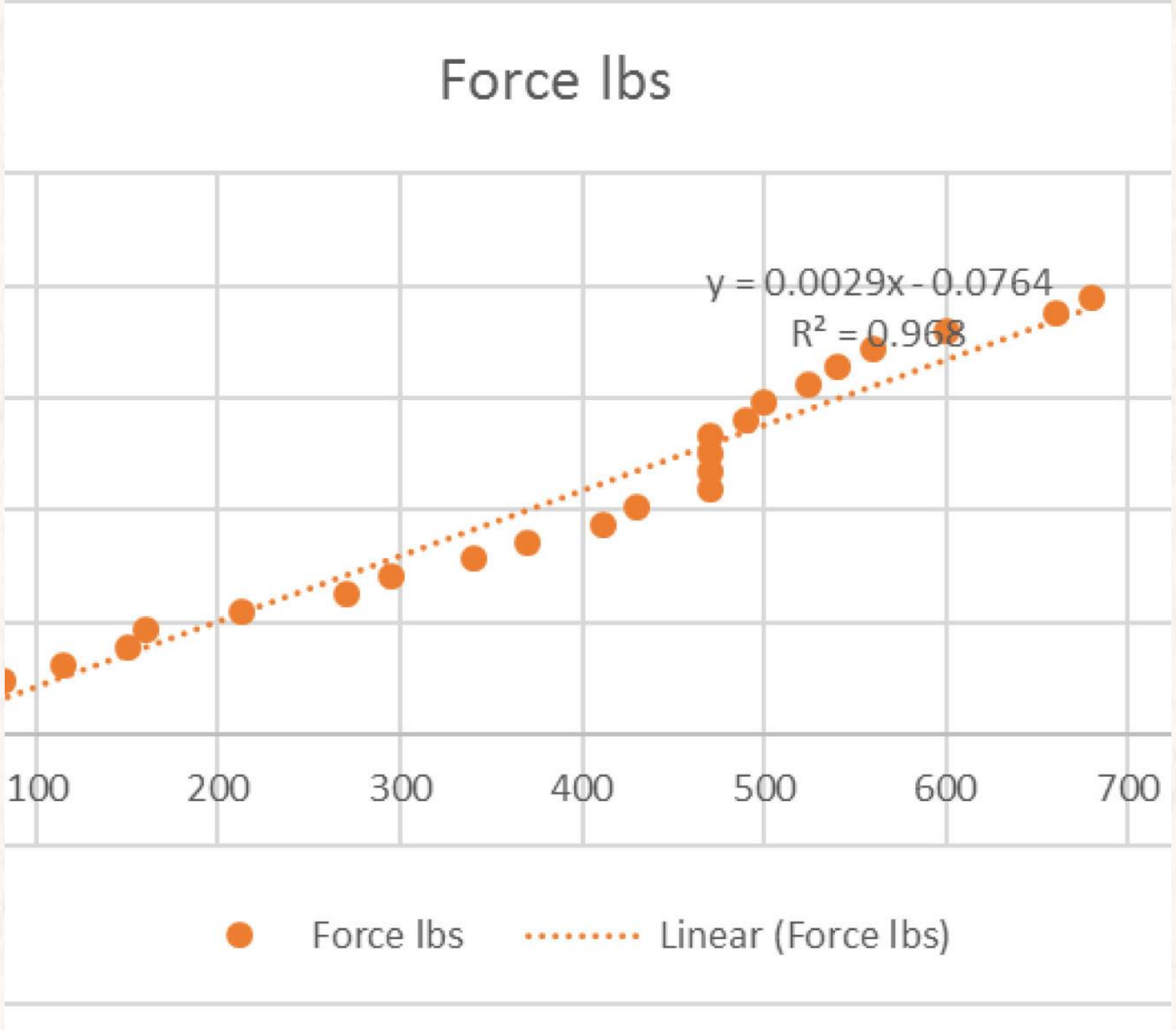


Force and Time Measurements

- The force applied by the jaws of the grasping tool shouldn’t exceed 2.2 lbs due to potential tissue damage
- Up to 100N range capacitive force sensors are flush-mounted to the handle of the grasping tool
- A calibration function has been developed to translate the measured force to the one applied by the jaws
- After the start of the test force and elapsed time values are sent to the MS PC about every 30ms

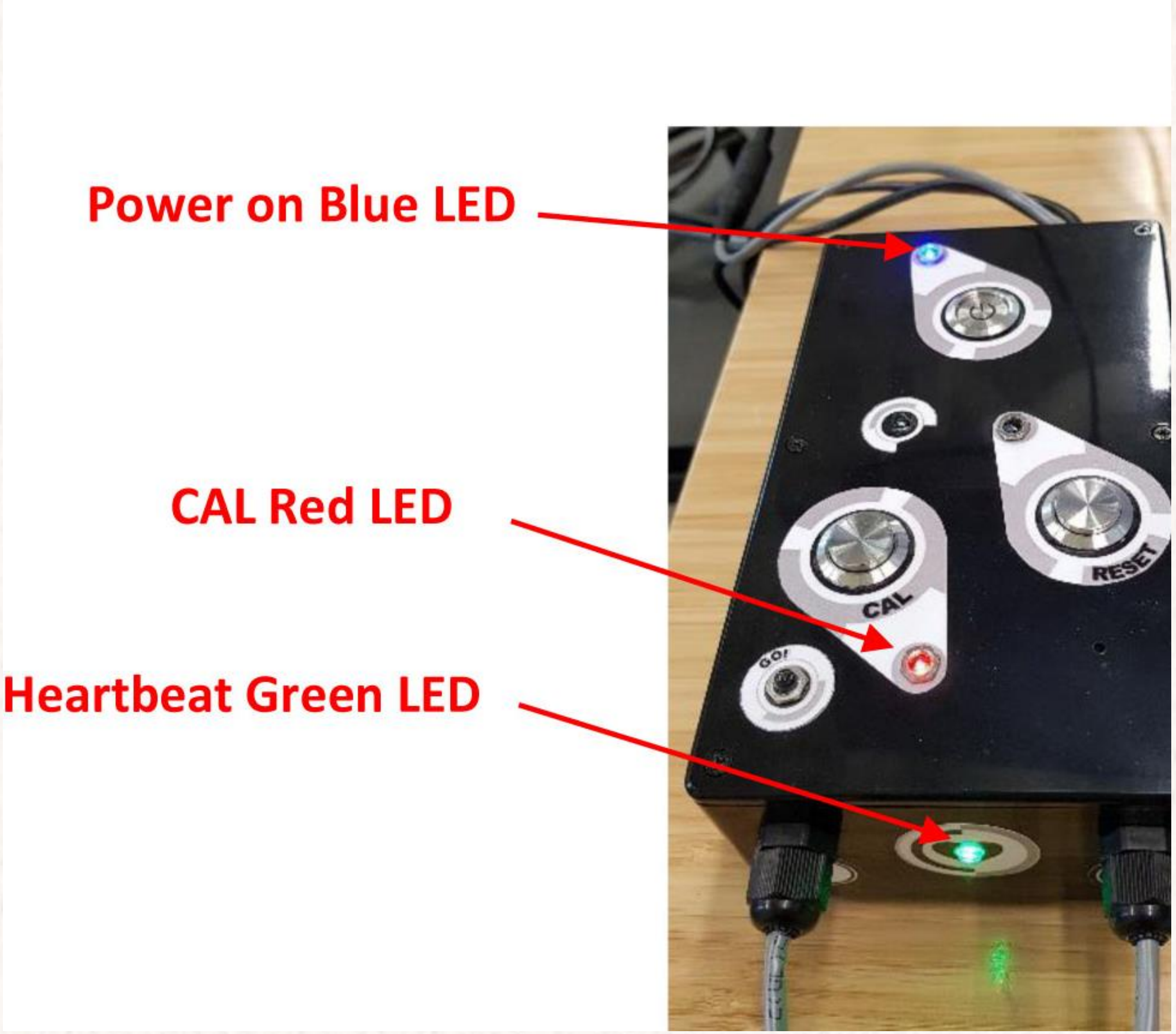
Force Measurements Cont'd

- The graph shows the linearized force values applied by the jaws versus the raw measured data
- On the horizontal axis the output values of the ADC module on the sensor interface board are given



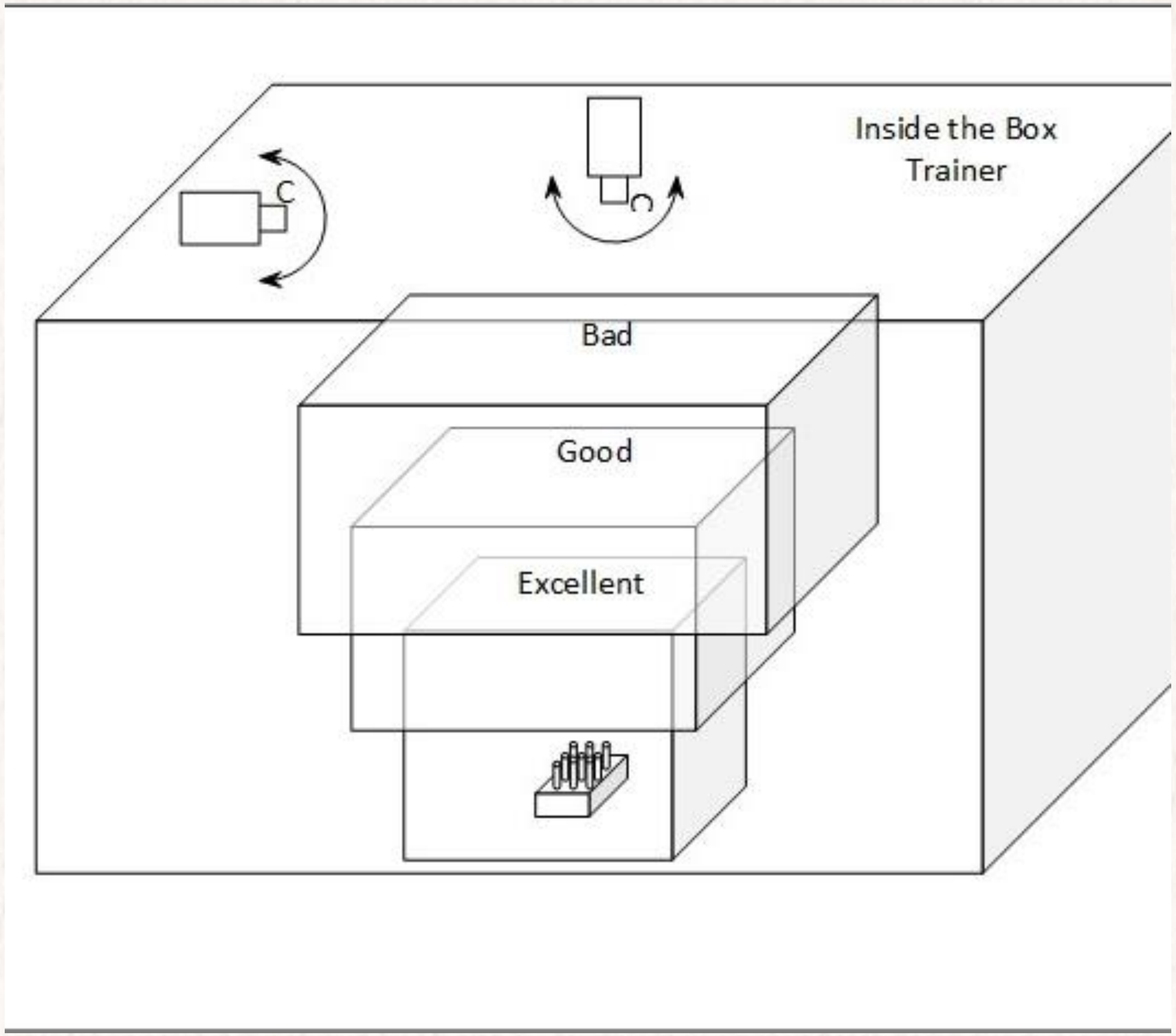
Microcontroller System

- It is based upon the Cortex M4 STM32F429I uC chip
- The force sensor interface boards are connected through the I2C protocol
- There is a built in force calibration function
- Heartbeat LED indicates that the Microcontroller System is ready to operate
- It is connected to the MS PC through the UART/USB protocol
- It is interfaced to the Test Start/Stop push button

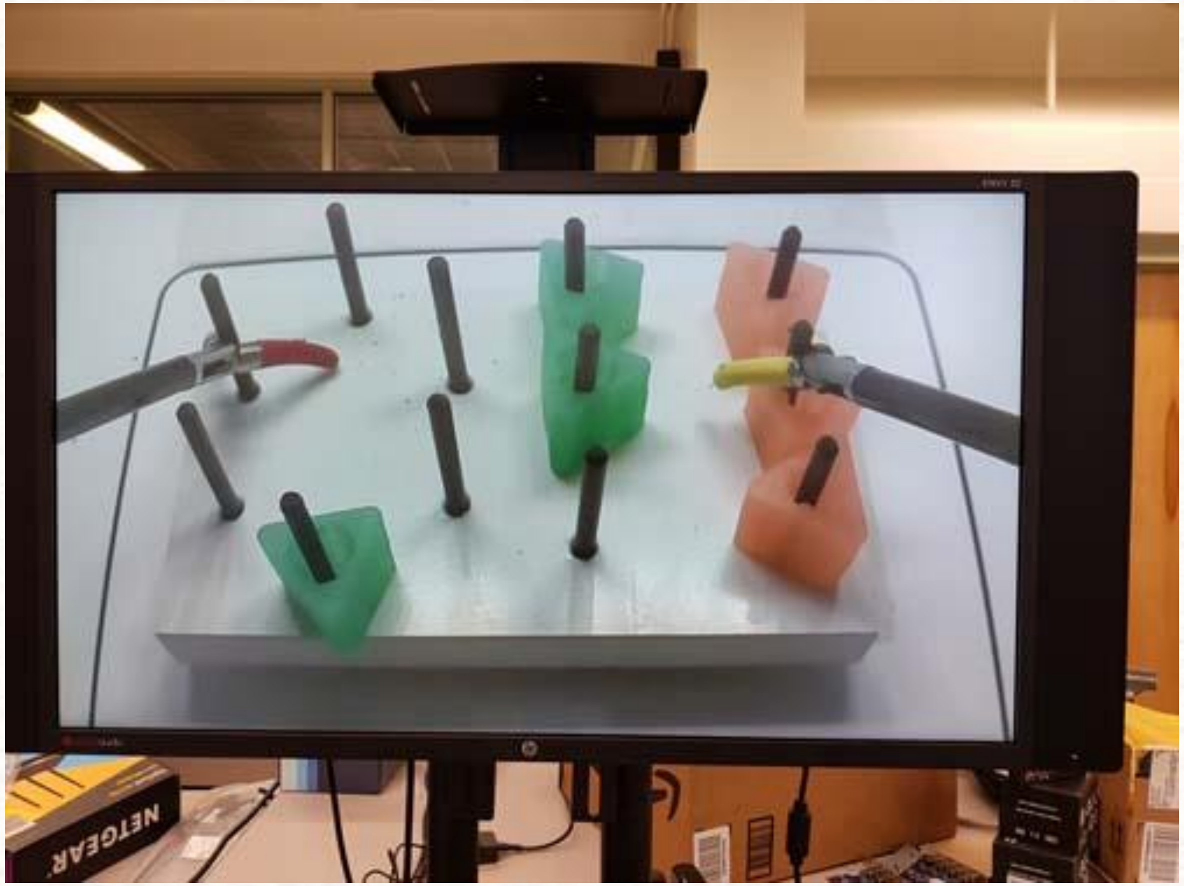


Tool Tip Tracking

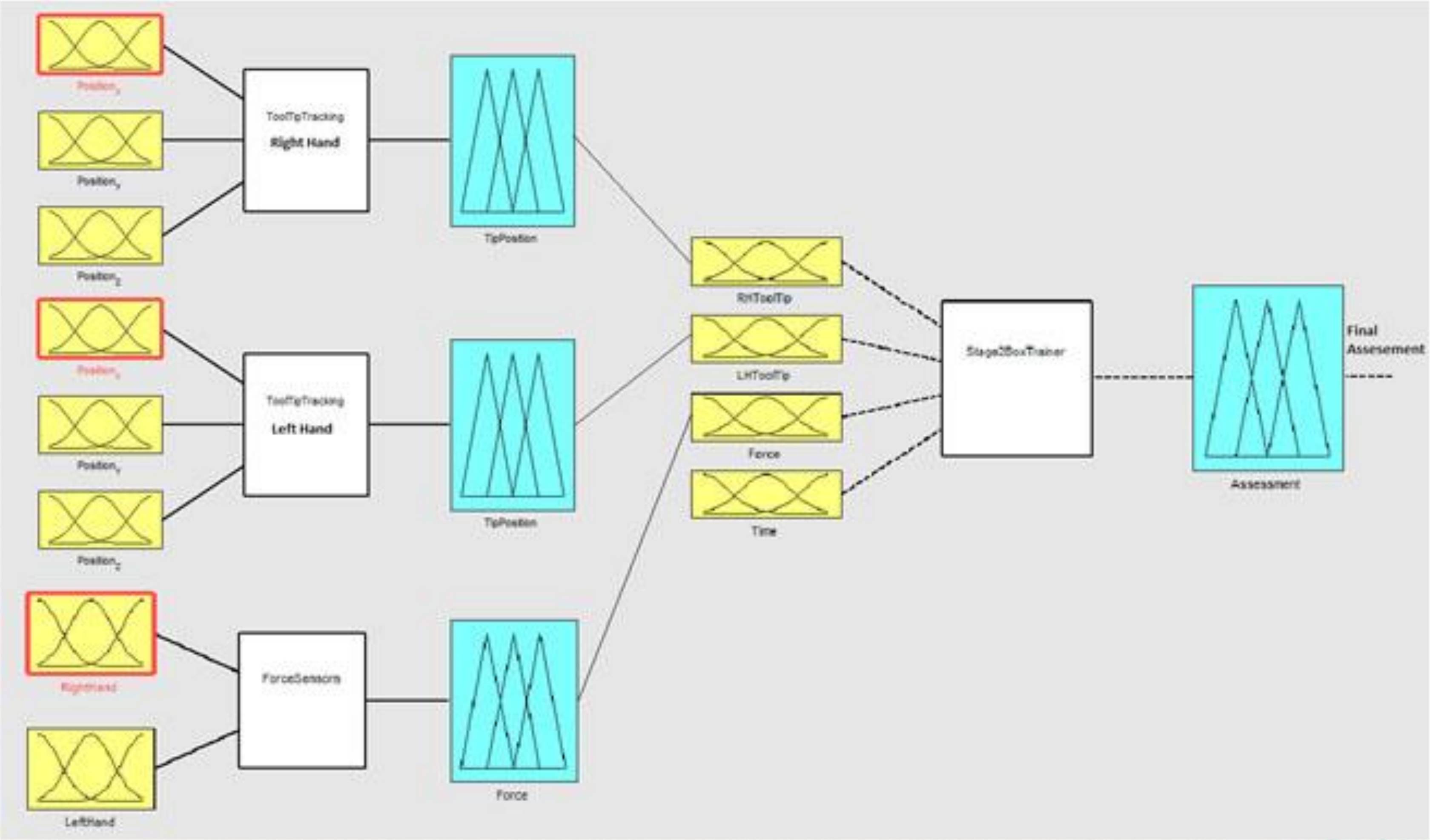
- In laparoscopic surgery the tool tip movements, while executing a particular task, should be confined into a 3D space of limited size
- If the tool tips moved too much beyond the target space they might cause unintended damage to internal organs in close proximity
- Two 5MP HDMI webcams with USB interface are used
- Tracking was accomplished by color identification
- Two streams at the rate of 30 frames/sec with 1028x720 pixels per frame



Tool Trip Tracking Cont'd



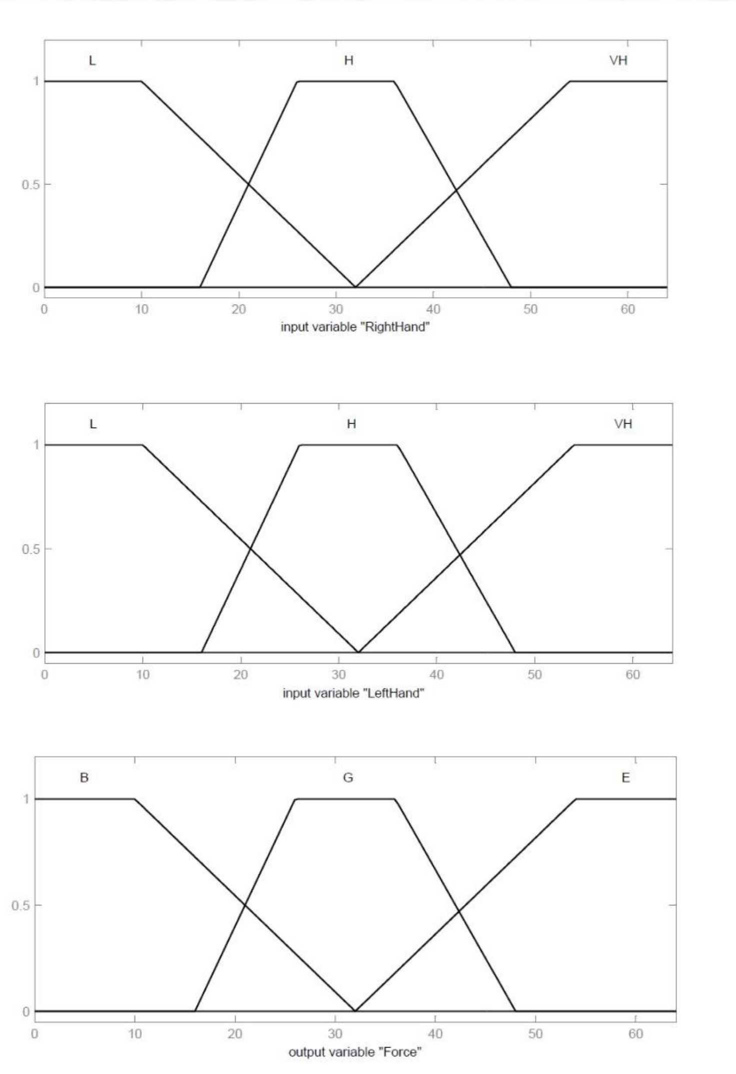
Fuzzy Logic Performance Assessment System Block Diagram



Fuzzy Logic Performance Assessment System Cont'd

- In the first layer, the fuzzified right-hand and left-hand tool tip movements as well as the fuzzified forces applied by the right-hand and left-hand grasping tools are entered into their respective fuzzy knowledge bases
- A Mamdani-type inference system along with the Center of Gravity defuzzification algorithm are implemented to process these fuzzy inputs
- The defuzzified outputs are then fuzzified again as inputs for the final assessment system in the second layer. They are joined by the fuzzified time measurement input values.
- These functionally decoupled fuzzy knowledge bases allow independent fine-tuning of the performance of the key components of the assessment system

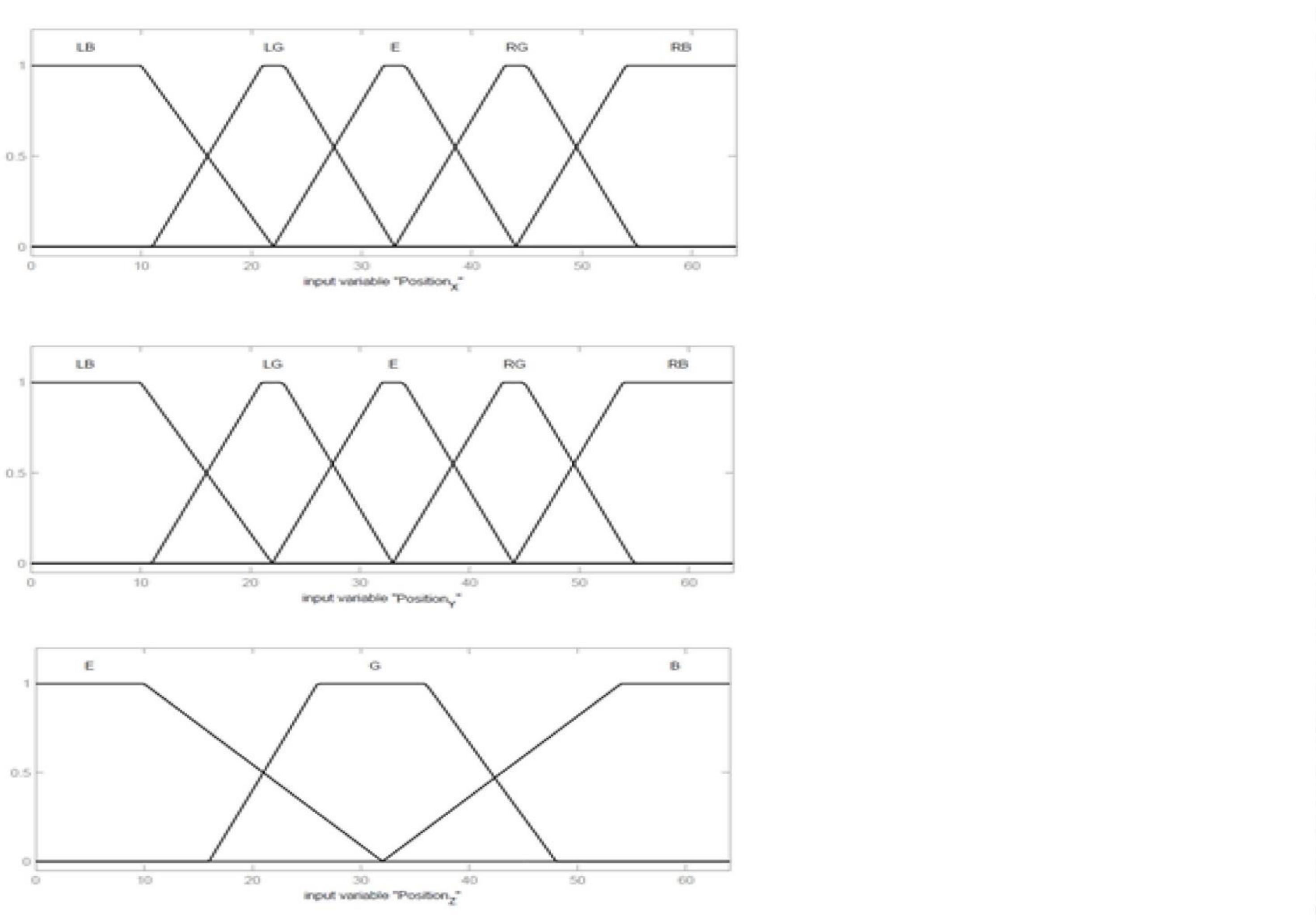
Fuzzy Sets for Grasping Force Measurements



Fuzzy If Then Rules for Grasping Force Assessment

RH and LH	L	H	VH
L	E	G	B
H	G	G	B
VH	B	B	B

Fuzzy Sets for Tool Tip Movements (X, Y and Z) Assessment



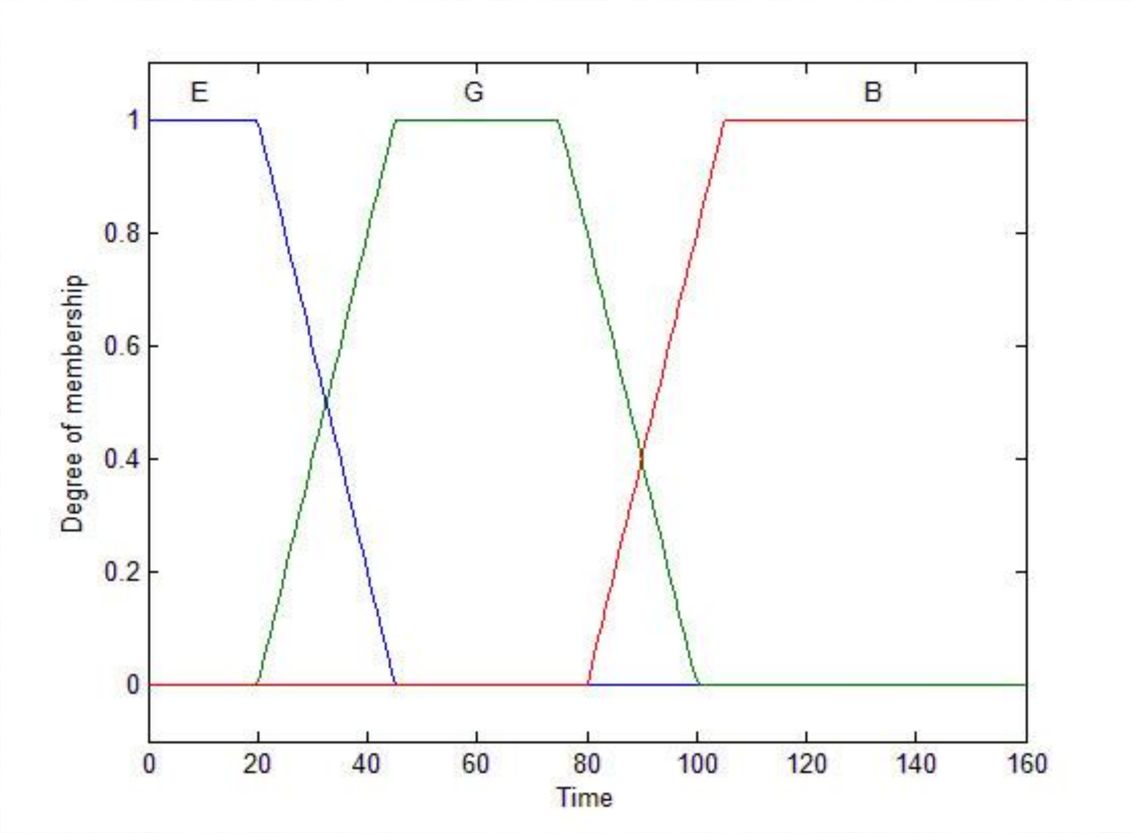
FAM Matrices for Tool Tip Tracking Assessment

Z	X	LB	LG	E	RG	RB
E	Y					
LB		B	B	G	B	B
LG		B	G	E	G	B
E		G	E	E	E	G
RG		B	G	E	G	B
RB		B	B	G	B	B

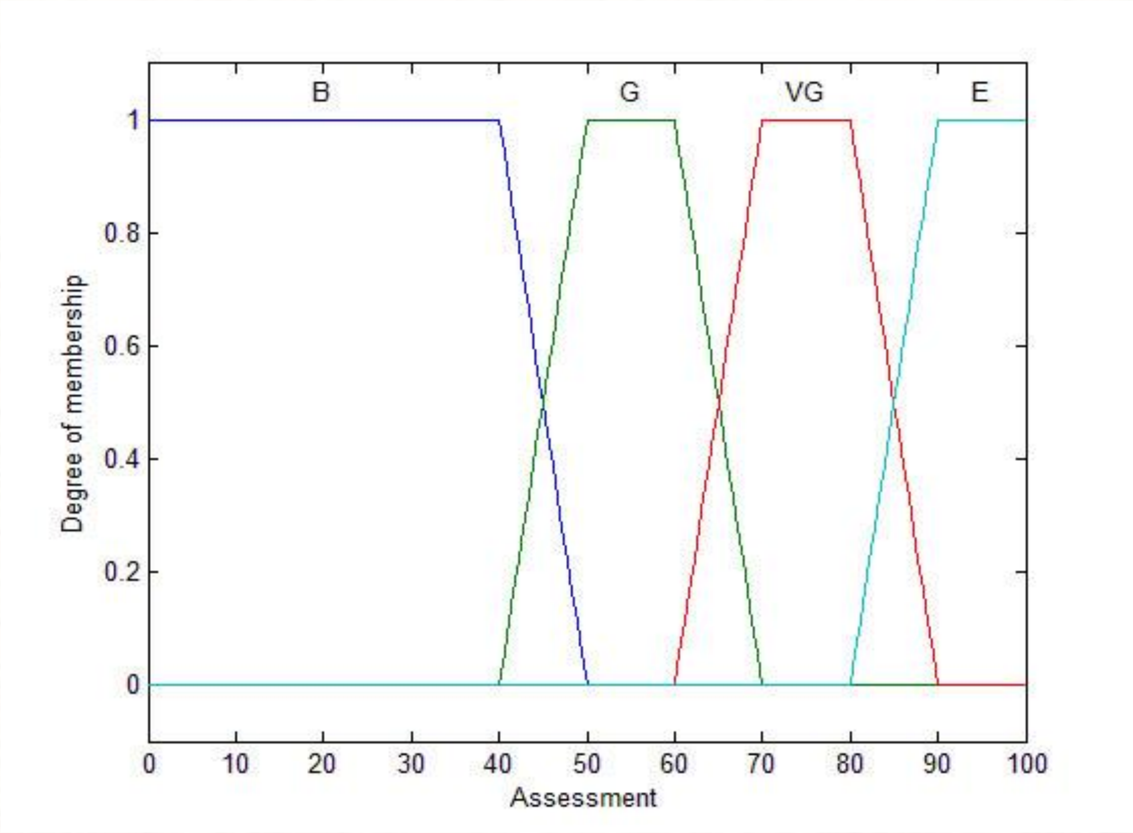
Z	X	LB	LG	E	RG	RB
G	Y					
LB		B	B	B	B	B
LG		B	G	G	G	B
E		B	G	E	G	B
RG		B	G	G	G	B
RB		B	B	B	B	B

Z	X	LB	LG	E	RG	RB
B	Y					
LB		B	B	B	B	B
LG		B	B	B	B	B
E		B	B	G	B	B
RG		B	B	B	B	B
RB		B	B	B	B	B

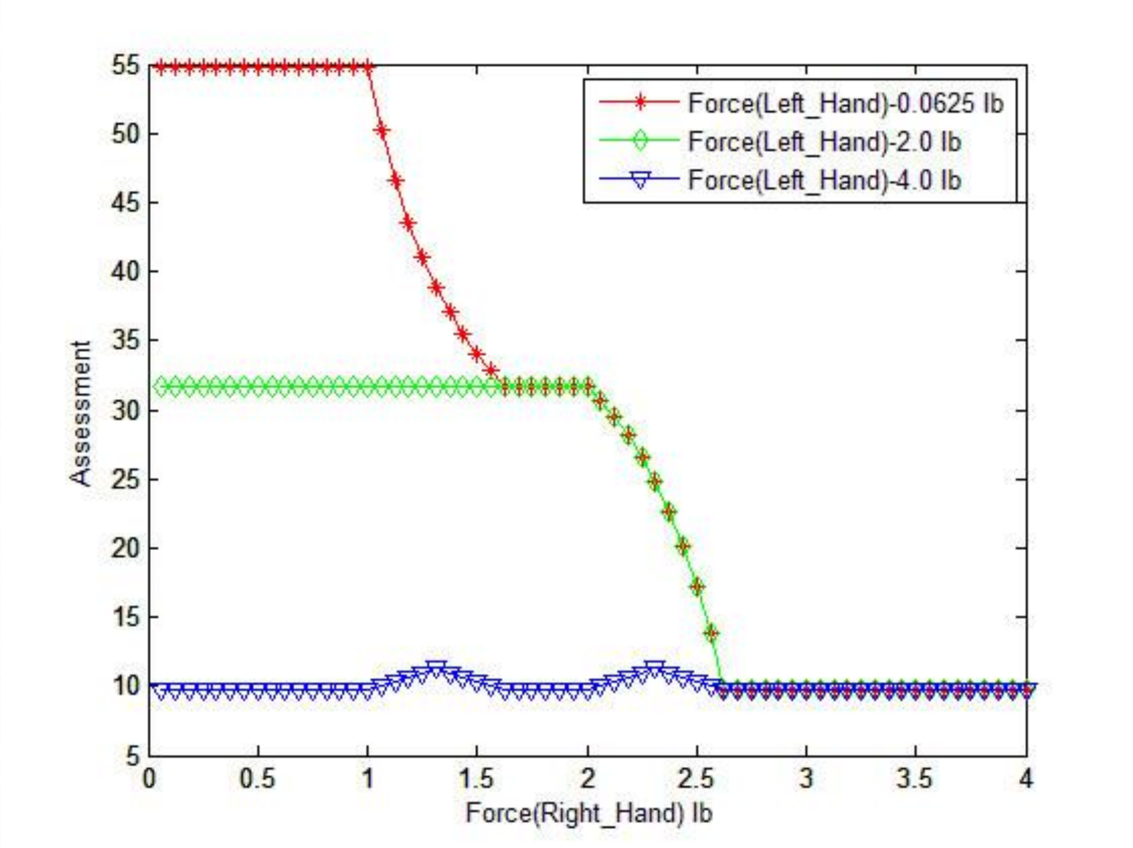
Membership Functions for Time Taken



Membership Functions for the Final Assessment

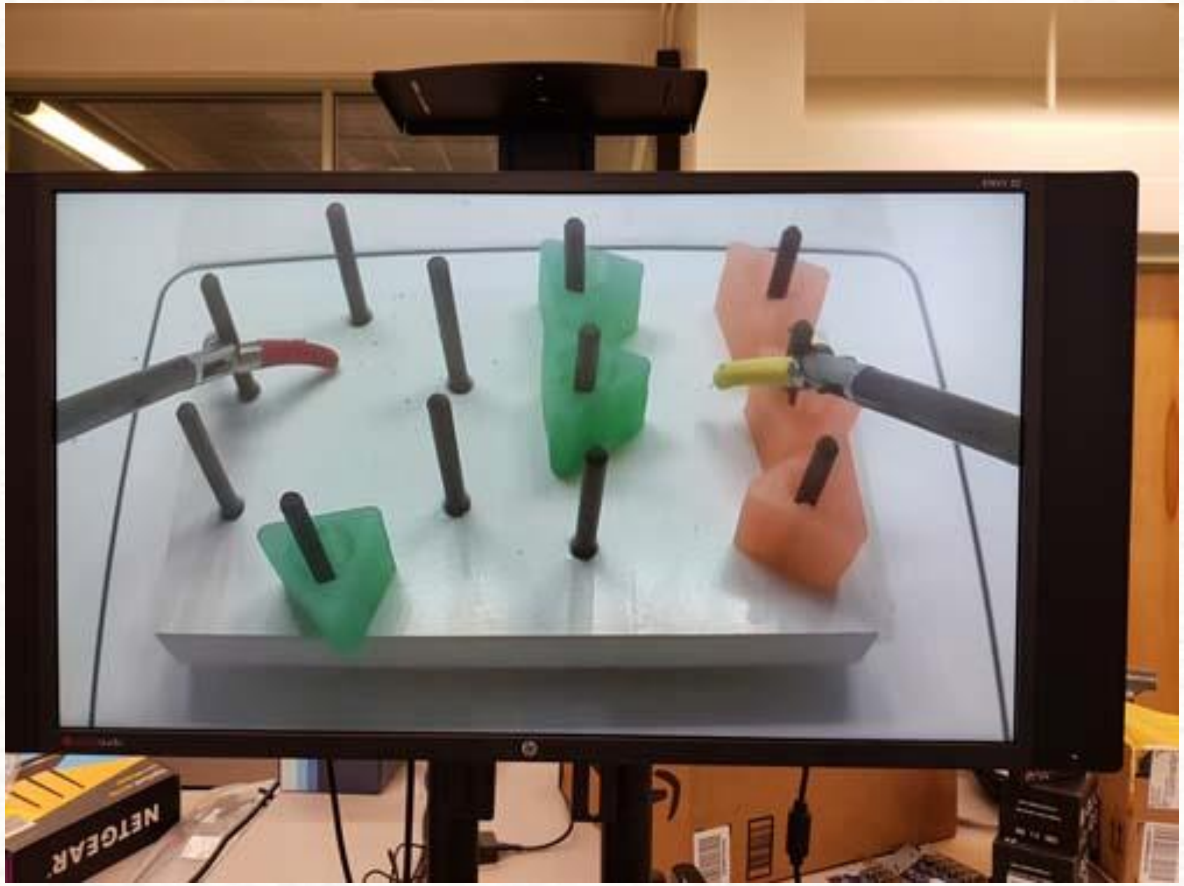


Simulated Assessment of Forces Applied by Grasping Tools

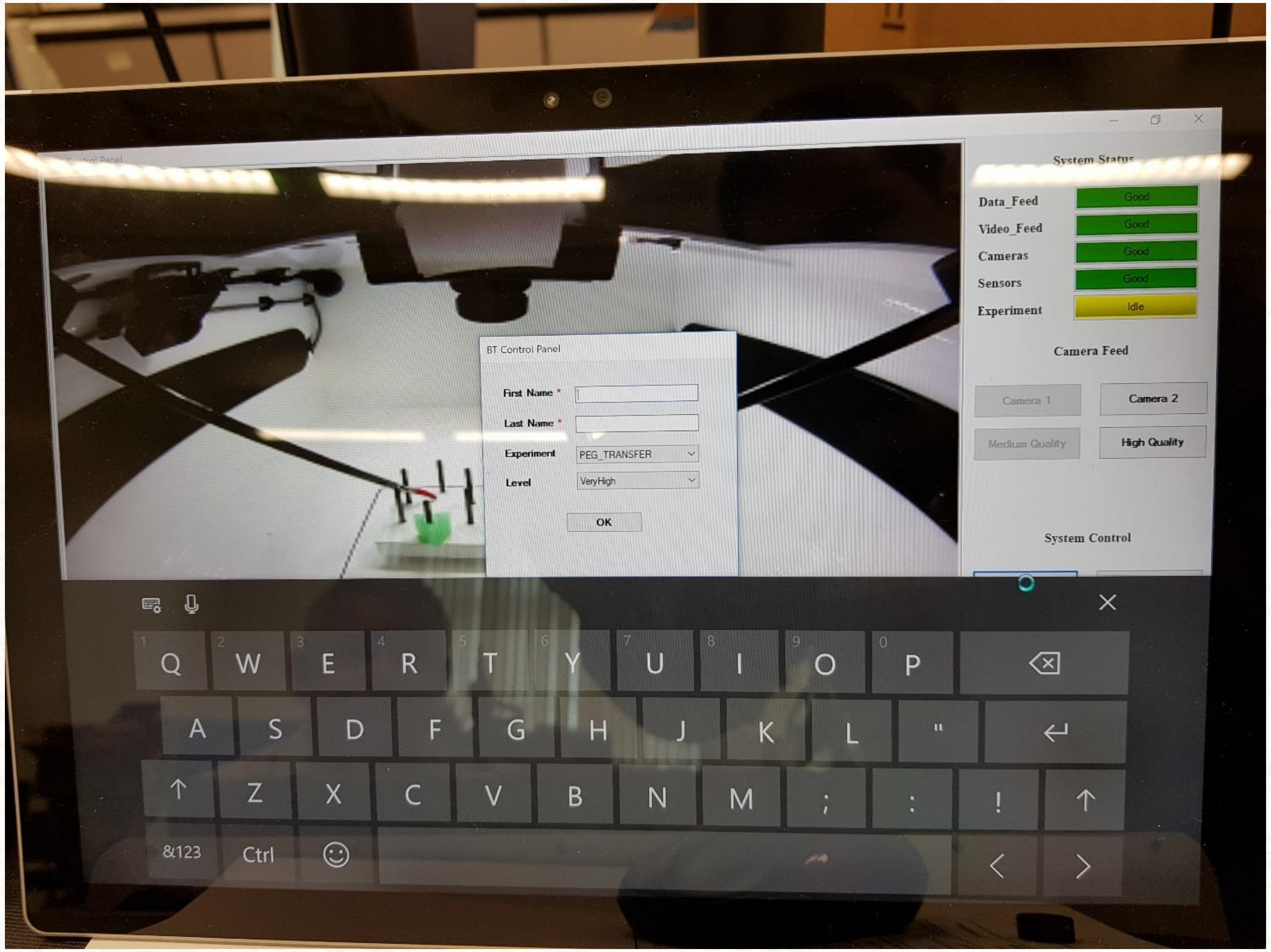


Intelligent Box-Trainer System

Illustrations of Using the Intelligent Box-Trainer System



Illustrations Cont'd



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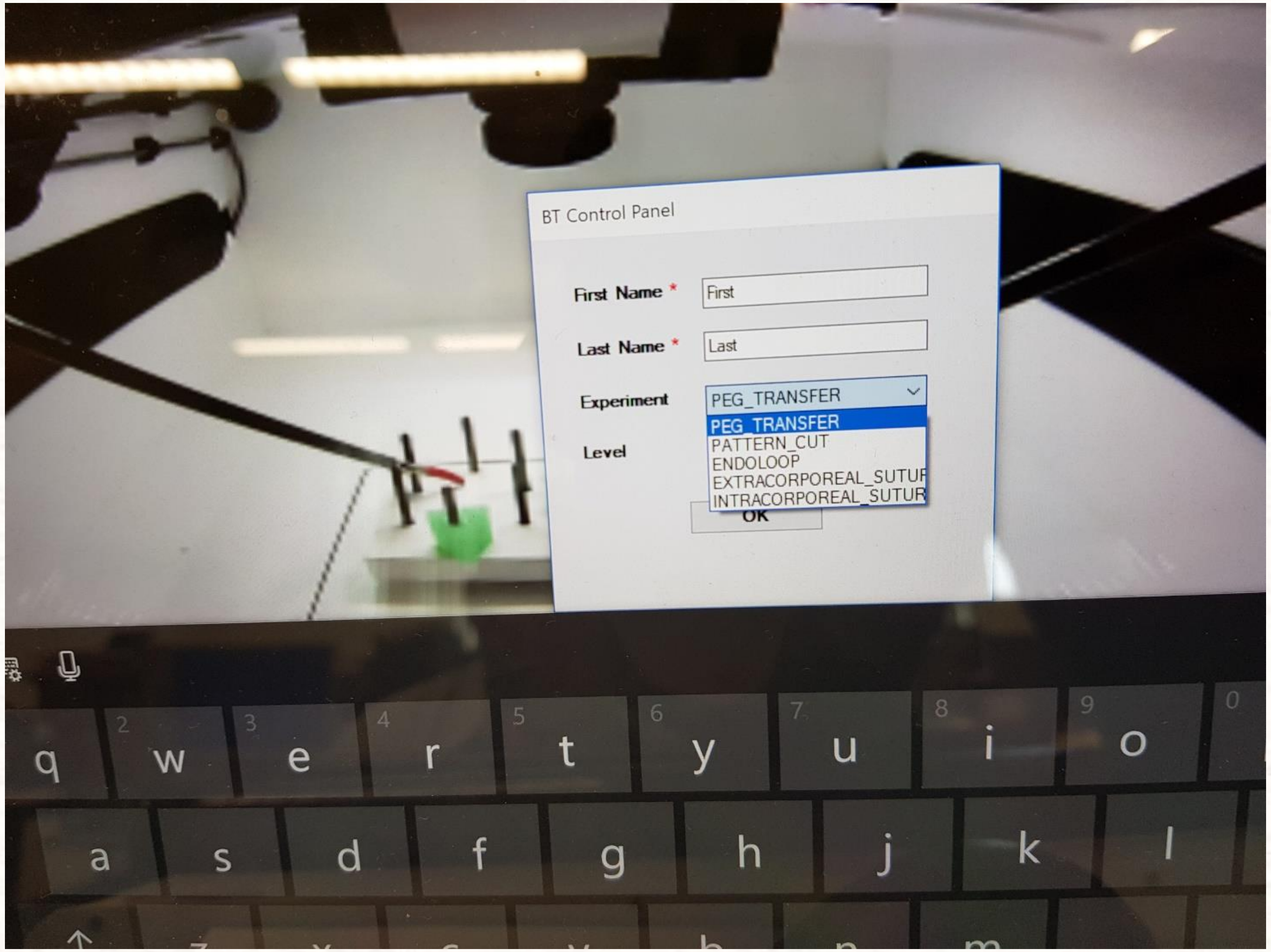

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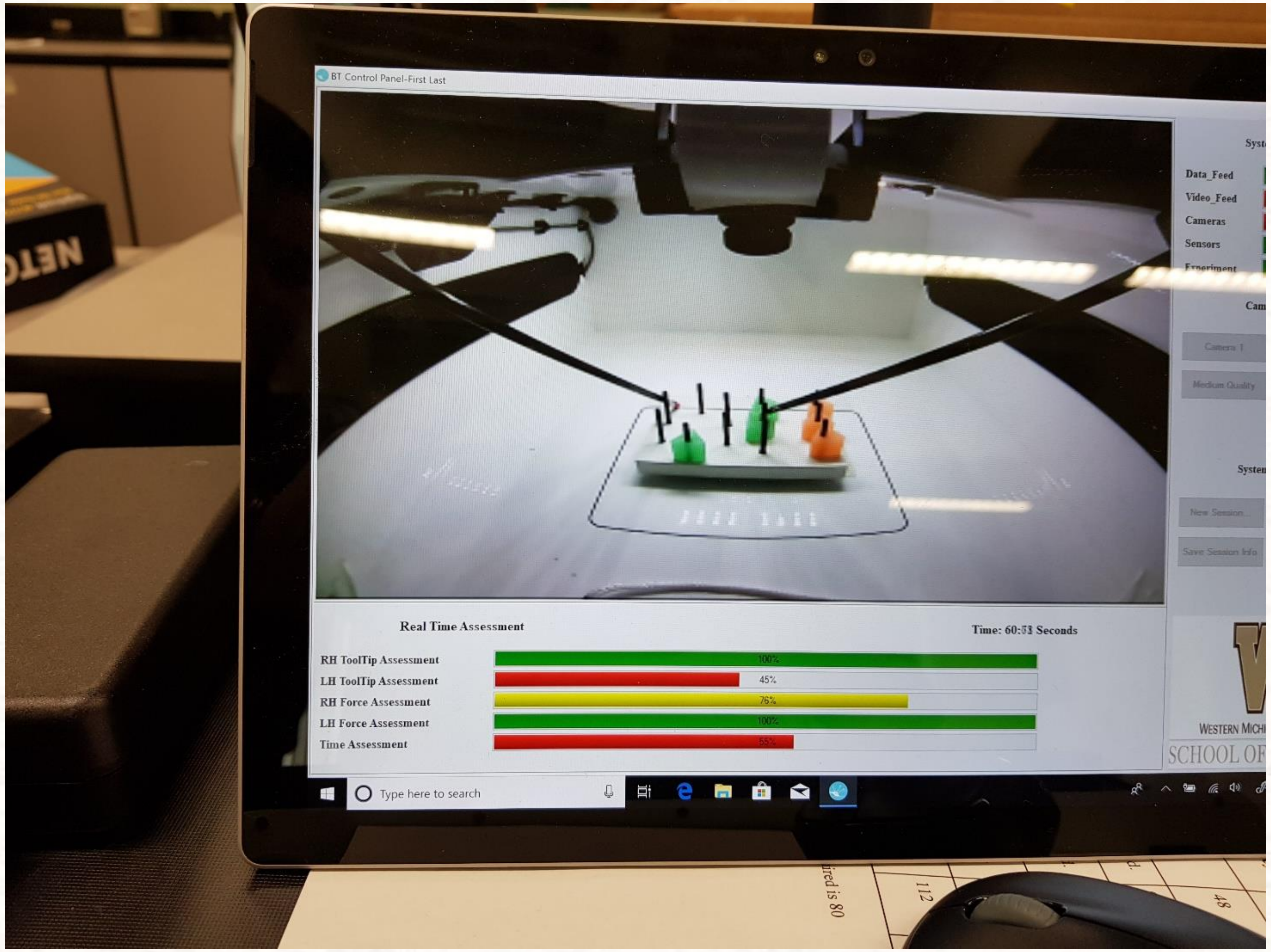

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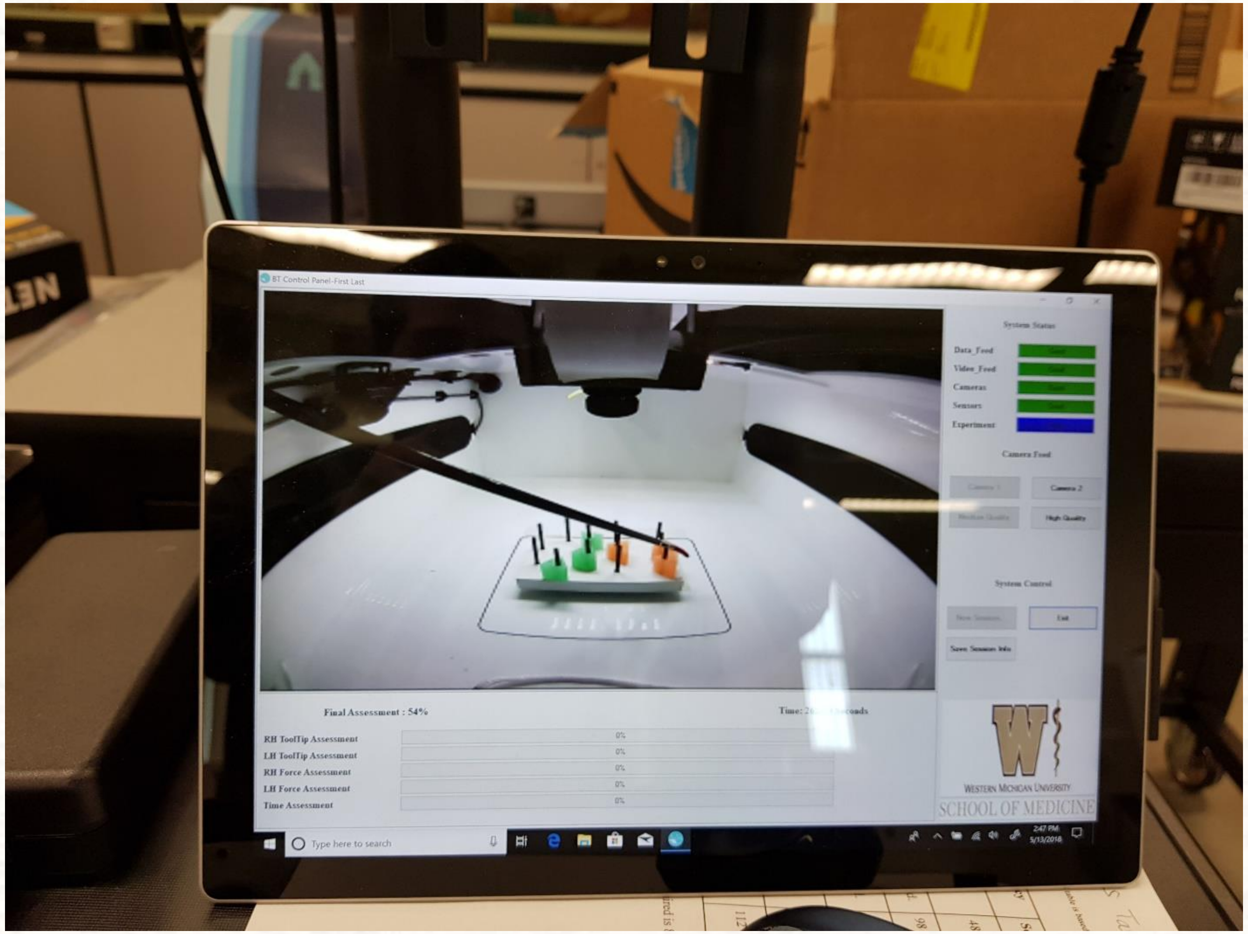

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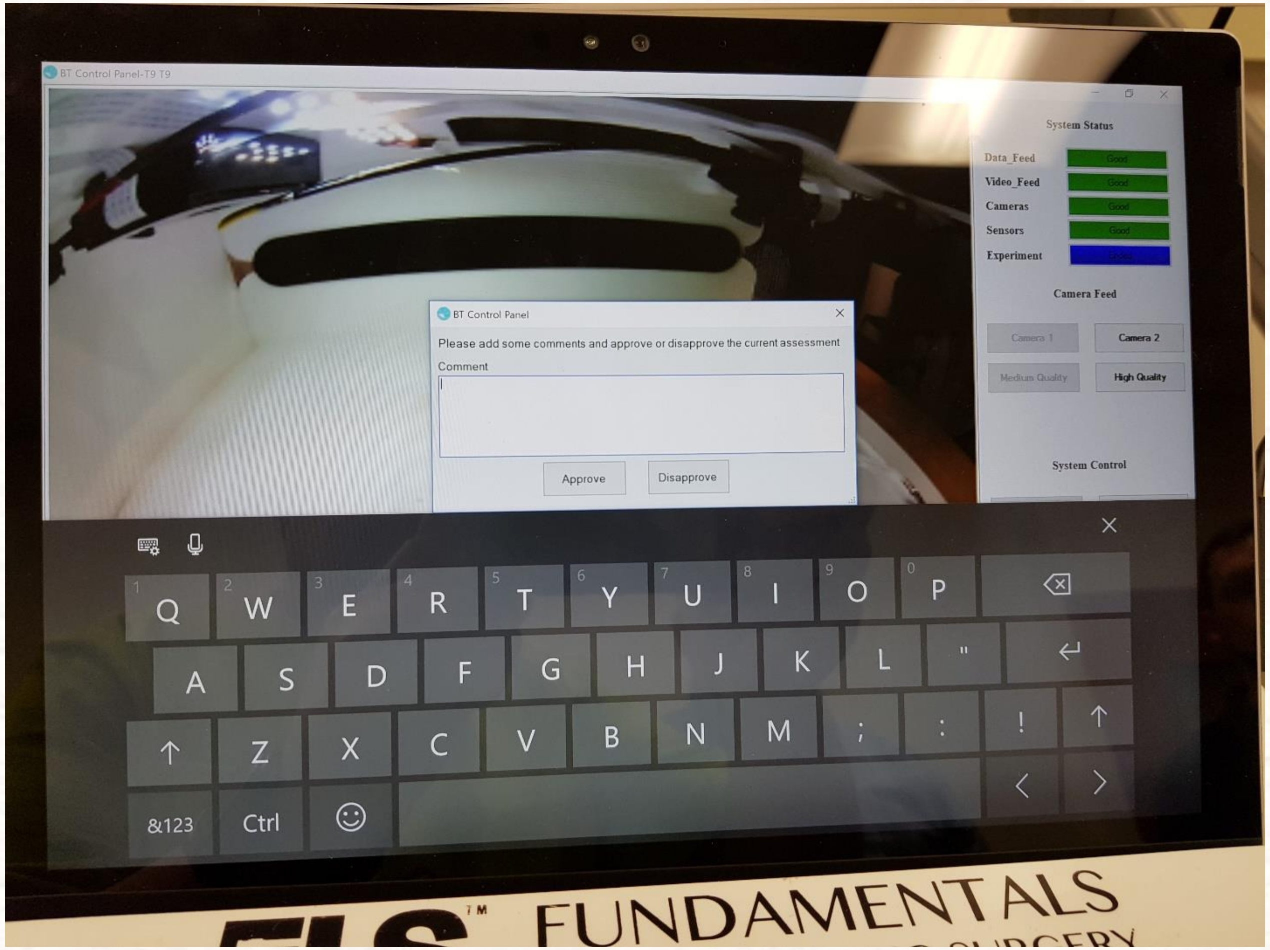

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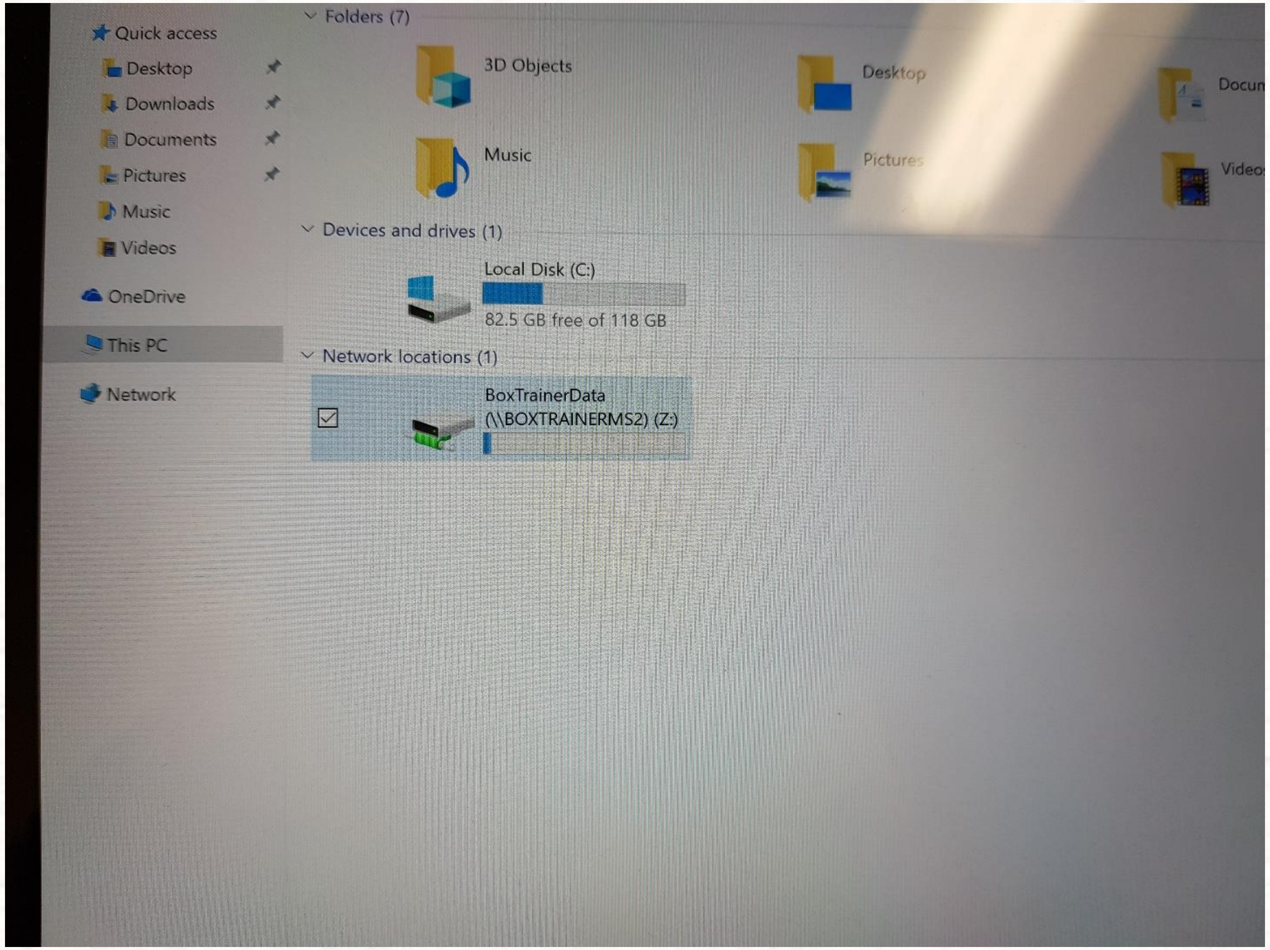


Conclusions and Future Research

- Two prototypes of the Intelligent Box-Trainer System have been delivered to the Medical School
- With the proposed system, the assessment of the performance of residents taking the FLS tests is decided using measured data as well as the opinion of expert surgical faculty in a quantifiable, objective and consistent manner
- The system provides recorded visual and measured data feedback for the residents which will help them to improve their laparoscopic skills
- The FLS Tests certification documents only specify crisp Pass/Fail criteria. There is a need for residents and practicing laparoscopic surgeons to assess their performance regarding various specified skill levels. This will require a lot of tests and collaboration with expert surgeons to develop and later fine-tune the respective knowledge bases.
- Currently, we are focusing on the pattern cutting and the three suturing-related tests

Planned Cyber -Physical System for Intelligent Robotic Surgery Laboratory

Research Questions/Objectives

- Can best robotic surgery practices as identified in (1) be used to develop automated, or partially automated robotic surgery procedures using computational intelligence methods (in particular, controllers using fuzzy automata) which are deemed very valuable by expert surgeons?
- In case of tele-robotic surgery applications, what kind of safe, automated robotic surgery procedures can be developed when the internet connection between the master station operated by a surgeon and the remote slave station with the actual patient is lost for a considerable period of time?

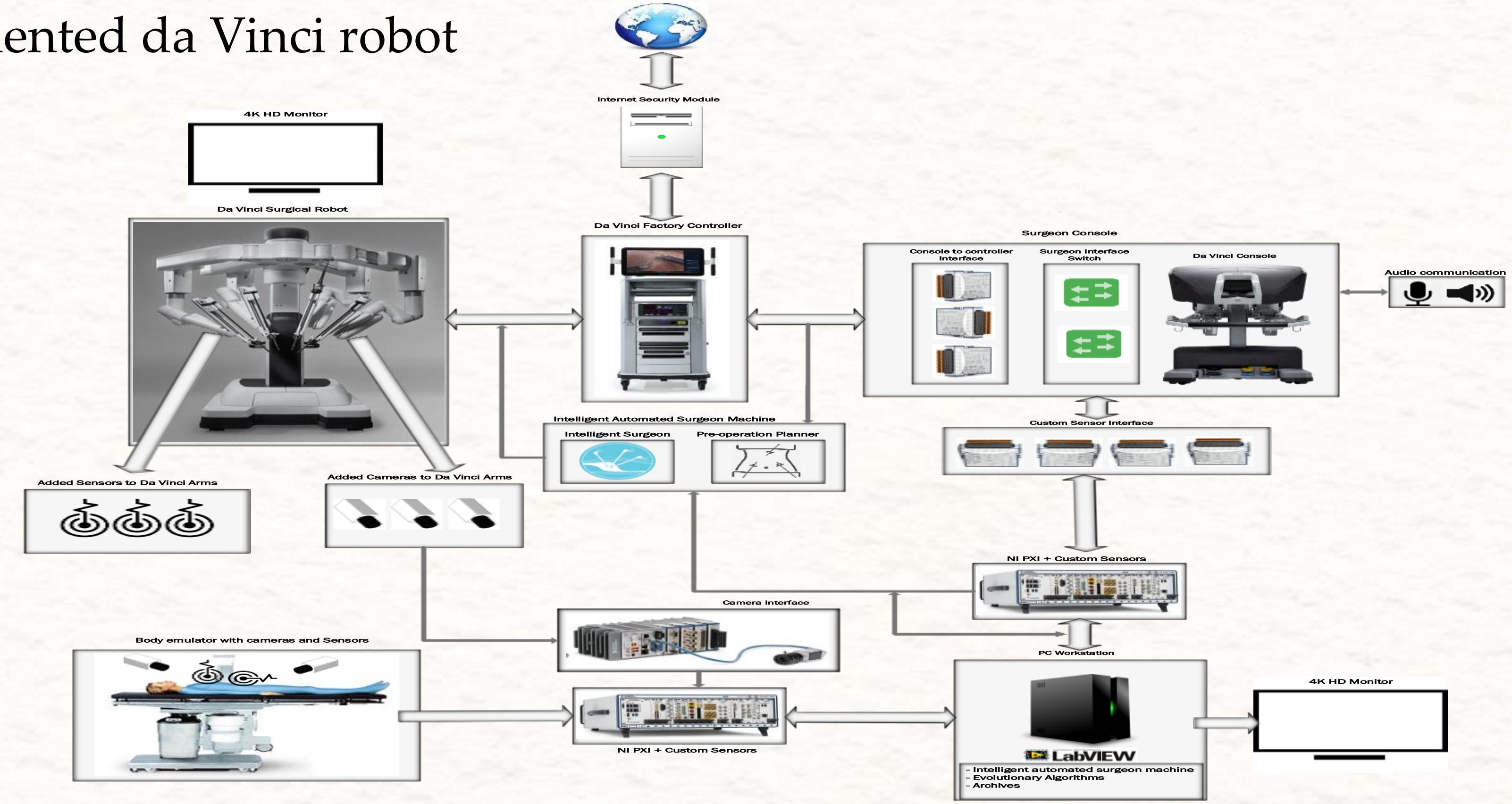
Planned Cyber -Physical System for Intelligent Robotic Surgery Laboratory (Cont'd)

Research Questions/Objectives

- How can sensory data and recorded video fused with computational intelligence methods (in particular, fuzzy logic) to capture domain knowledge of expert robotic surgeons be used to develop an objective, intelligent assessment support system for skills required in robotic surgery?
- Comparatively, what are the advantages of a hardware-in-the-loop cyber-physical system (a da Vinci robot operating on 3D printed phantom objects and augmented with sensor arrays and additional HD video cameras) over current 3D virtual reality simulators with respect to skill development and skill assessment?

Intelligent Robotic Surgery Laboratory Block Diagram

Instrumented da Vinci robot



Thank You!

Any Questions?