

Development of a Tele-Surgical Training Robot and Simulator

Al-Zahrawi is a training robot and simulator for minimal invasive surgery (MIS) or laparoscopic surgery that is being developed at the NUST School of Electrical Engineering and Computer Science in collaboration with Holy Family Hospital, Pakistan. This ICTR&D funded project is primarily focused towards developing a cost effective solution for training surgeons for conventional and robotically assisted MIS procedures. This document presents a brief overview of MIS and the usage of surgical robots in this recently introduced surgical technique. The main focus of the paper is on the design of the Al-Zahrawi system.

Minimal Invasive Surgery (MIS) and ICT

Laparoscopy or Minimally Invasive Surgery (MIS) is a surgical procedure in which a laparoscope (a thin lighted tube) and other surgical instruments are inserted into the human body through small incisions rather than a relatively larger incision commonly used in the traditional open surgeries. The internal operating field may then be visualized on a video monitor connected to the scope. MIS has become quite popular these days as it facilitates quick patient recovery and less chance of post-operative infections. However, these added benefits come at the cost of a more challenging and difficult task for surgeons since they have to migrate to this new surgical procedure while leaving behind their traditional open surgical skills, which they have been practicing since centuries.

Performing minimal invasive surgery requires special skills like expert hand eye coordination, precise movement of laparoscopic instruments within a confined space and the ability to successfully perform surgery without damaging any of the organs. These special psychomotor skills cannot be acquired without hands on practice. However, practicing this new surgical technique on human patients directly is extremely unethical and can have dire consequences. Computer simulators have played an important role in the training of personnel for skills that would be difficult to acquire otherwise and thus can be utilized to assist surgeons for acquiring the MIS experience prior to practice in the operation theatre. Various MIS simulators, such as LapSim, LapMentor and ProMIS, have been developed but their licenses are very costly and thus they are not affordable by most of the medical schools and teaching hospitals of developing nations like Pakistan. This fact has resulted in a very limited usage of MIS in Pakistan and other countries have similar constraints. In order to overcome this issue, the main focus of the Al-Zahrawi training system was to develop a low cost simulator based on open source software tools and libraries while leveraging upon the relatively cheap HR cost here than compared to the one in the western world. Besides the simulator, we also developed a hand manipulator that resembles the shape of a commonly used MIS instrument and is utilized to drive our simulator.

Recently, robotic assistance has been found to be very useful in MIS due to their extra degrees of freedom and high precision compared to a human hand. Currently the most commonly used MIS robot is the da Vinci Surgical Robot, which costs about Pk. Rs. 160 million. Again, due to this hefty cost, it is not affordable by most of the medical schools and training centers in a developing country like Pakistan. To overcome this limitation, we have developed a cost-effective MIS robot, dedicated towards surgeon training purposes. The cost effectiveness is achieved due to the local design and manufacturing and the fact that the robot would not require a rigorous testing phase (which usually takes 70-80% of the engineering design time and cost) since it is only developed for training purposes.

We have named our MIS robot and simulator Al Zahrawi after one of the greatest medieval Arab surgeons Abu al-Qasim Khalaf ibn al-Abbas Al-Zahrawi (936–1013), who has also been referred to as the father of modern surgery by some. In the rest of the document, we describe some salient design features of our proposed simulator and training robot. The document also shares the commercialization potential of our project along with some details about the awards and laurels that the project has won so far and the main team members of this National ICTR&D funded project.

Al-Zahrawi Virtual Reality Simulator

The Al-Zahrawi simulator is primarily composed of three main modules: Mechanical Interface, Controller Circuit and Software Application. The Mechanical Interface module is required for the user to interact with the simulator. The Controller Circuit module is responsible for the communication between the Mechanical Interface and the computer. The Software Application module consists of the GUI and runs the simulation scene based on the selection from a list of scenes.

The Mechanical Interface of the Al-Zahrawi simulator, depicted in Figure 1, is a mechanical manipulator that is designed to mimic the actual laparoscopic tool in structure and functionality. A laparoscopic instrument is usually a 5-DoF mechanical structure. The point of entry into the body inhibits the free movement of the instrument and acts as a pivot around which the tip of the instrument moves. This leaves the surgeon with five possible movements: pitch, yaw, roll, depth and open/close of gripper. These identified motions along with the workspace requirements formed the basis for designing the Mechanical Interface for the Al-Zahrawi simulator.

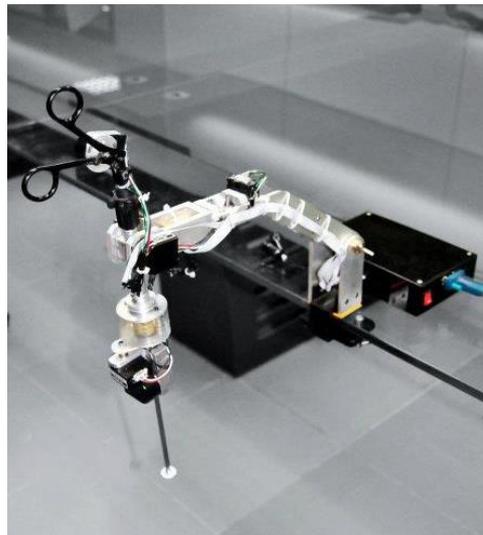


Figure 1: Hand Manipulator of Al-Zahrawi Simulator allows surgeons to perform similar actions performed in Minimally Invasive Surgery

The Controller Circuit module of the Al-Zahrawi simulator system uses encoders, installed on the joints of the Mechanical Interface, to gauge the mechanical movements. These movements are then recorded by a microcontroller and transferred to the computer via a duplex communication protocol on the USB interface.

The Software Application module receives the data corresponding to the mechanical movements and translates it into motions of the simulated instrument. Besides that, it also presents the user with a graphical interface to interact with. This GUI includes options like selecting exercises, using web resources and viewing past performance. A local database runs at the backend to maintain users records.

However, the main function of this module is to run real-time simulations for training the users. These simulations use SOFA as the physics engine, which constitutes the core of this entire module. The main exercises provided by the Al-Zahrawi simulator, depicted in Figure 2, train surgeons for camera navigation, hand-eye coordination, lifting, grasping, fine dissection, precision and speed, which are essential components of traditional MIS.

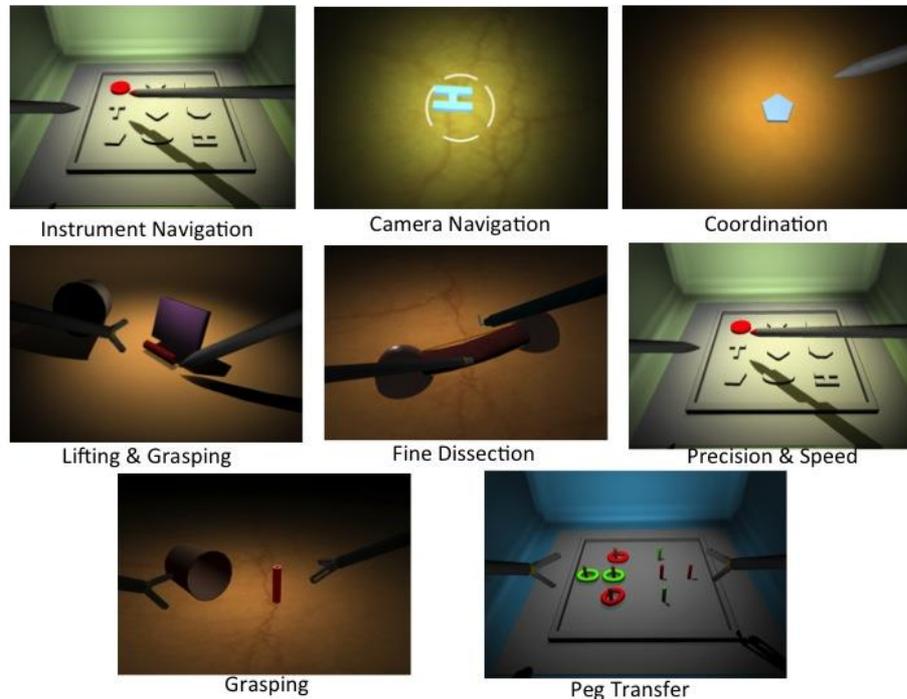


Figure 2: Simulator Exercises available in the Al-Zahrawi Simulator

Al-Zahrawi Robotic Trainer

The Al Zahrawi MIS robotic system is based on a Master-Slave topology in which the surgeon sits at the master console and operates the robotic manipulator from a distance. The Al-Zahrawi tele-surgical system consists of a custom- designed Master Manipulator (MM) and a slave manipulator (SM) with an interchangeable instrument module (IM). The two unique characteristics of this newly developed Al- Zahrawi robotic systems are: The IM is completely sterilizable and has no electronic components or motors. The IM has the unique independent foresep jaw movements, which increases the dexterity of the tool tip, without the use of a wrist mechanism, making its construction much simpler.

The main functionality of the Master Controller, depicted in Figure 3, is to facilitate the surgeon to operate on a remote patient. It comprises of two Master Manipulators (MMs), a display monitor, foot pedals and the Master Control and Sensing Module (MCSM). The MMs allow the surgeon to directly control the remotely installed robotic arms for conducting the surgery. The monitor provides an interactive interface with an embedded real-time video feedback from the endoscopic camera and other information regarding the patient and the system. The incorporated clutch foot pedal allows the surgeon to switch between the endoscope control and the forceps control modes. The Indexing foot pedal is used to align the MM with SM. The MCSM contains all the necessary electronics with a prime task of acquiring surgeon's hand movements and sending it to the slave console, which in turn drives the slave manipulators.

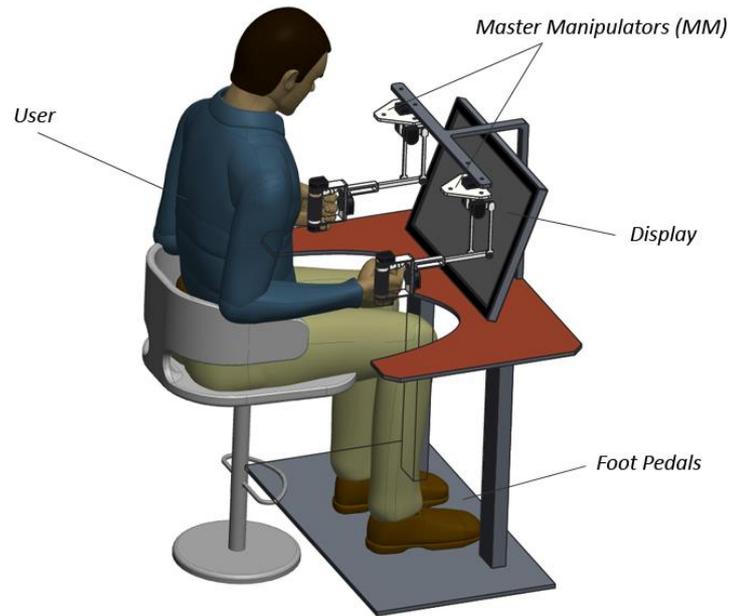


Figure 3: Master Console of the Al-Zahrawi Training Robot

The basic function of the MM, depicted in Figure 4, is to track the movements made by the surgeon's hand and transfer this data to the SM. The MM employs mechanical mechanisms with optical encoders to achieve this.

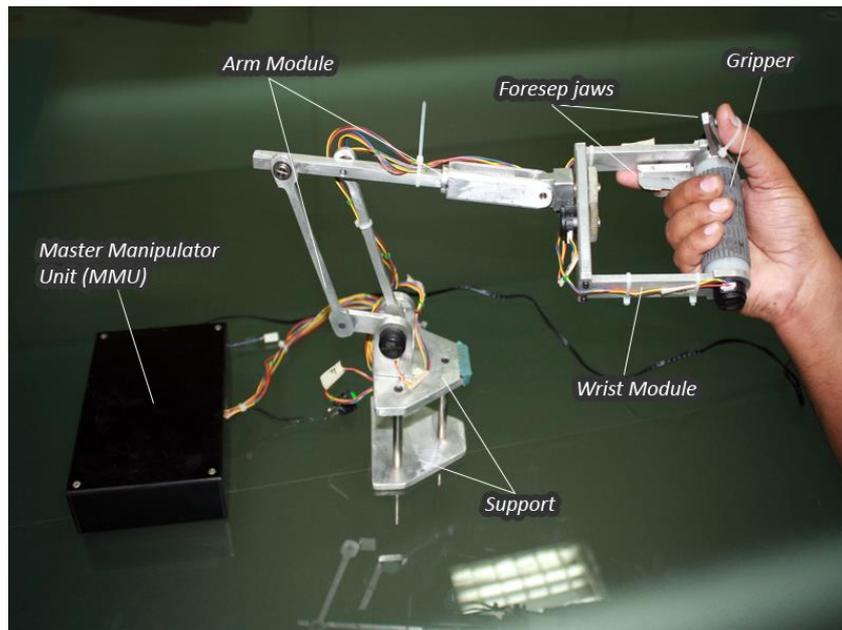


Figure 4: Master Manipulator of the Al-Zahrawi Training Robot

The Slave Console (SC), shown in Figure 5, is located besides the patient and away from the surgeon. The most important components of the SC include the robotic manipulators and the instrument module.

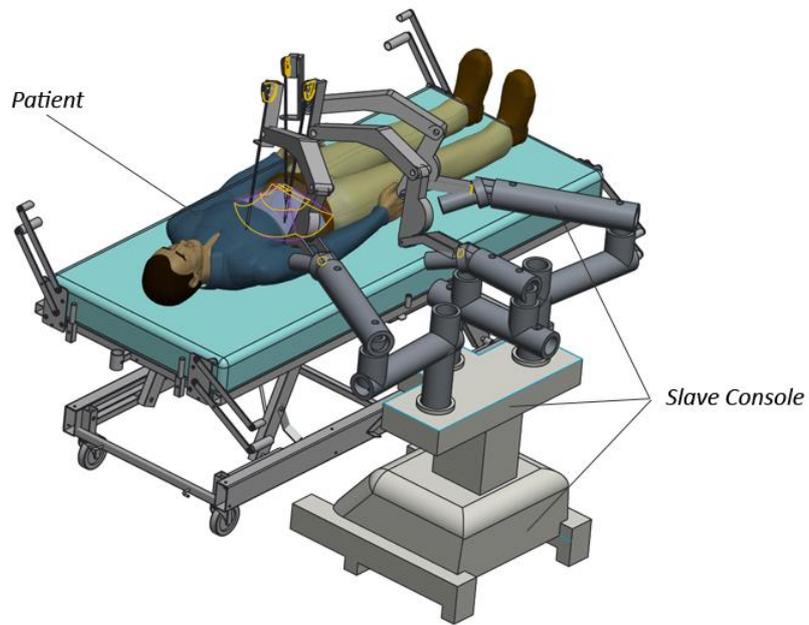


Figure 5: Slave Console of the Al-Zahrawi Training Robot

The robotic manipulator, depicted in Figure 6, is based on the modified double parallelogram mechanism and is able to rotate and translate the end-effector about a fixed point in space. This fixed point must be coincident with the incision point, which is a pre-requisite for MIS.

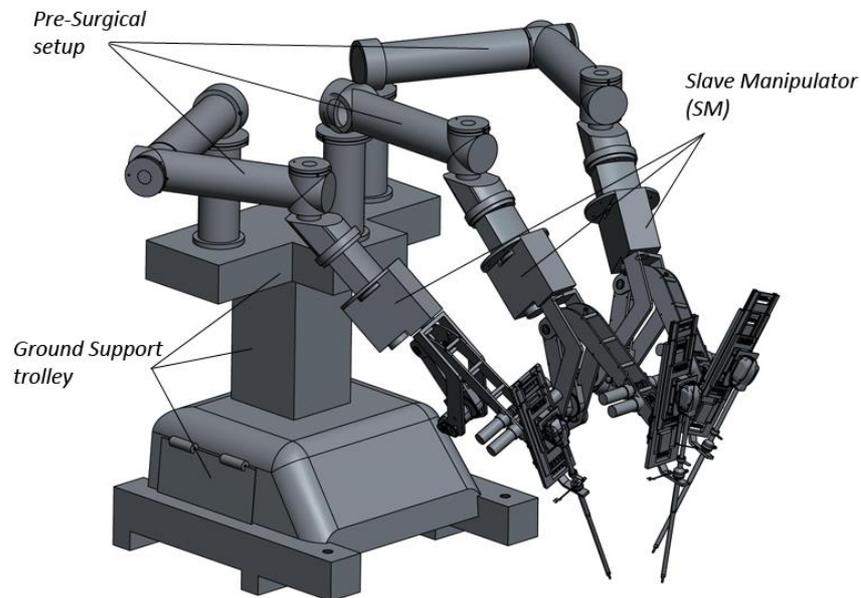


Figure 6: Robotic Manipulator of the Al-Zahrawi Training Robot

The robotic manipulator has a modular design with an interchangeable Instrument Module (IM). Usually during MIS the surgeon uses different surgical tools, e.g., Grasper, Clip Applicator, Curved Scissors, Needle Holder etc. Keeping this in mind, an interchangeable instrument module, shown in Figure 7, has been designed with a quick release mechanism for the Al-Zahrawi system. Many surgical robotics, such as

SOFIE and RAVEN, lacks this functionality. The IM is fully sterilizable since it does not contain any electronic equipment and motors. The motors are placed in the slave manipulator and actuation is transferred to the IM by utilizing cables and pulleys.

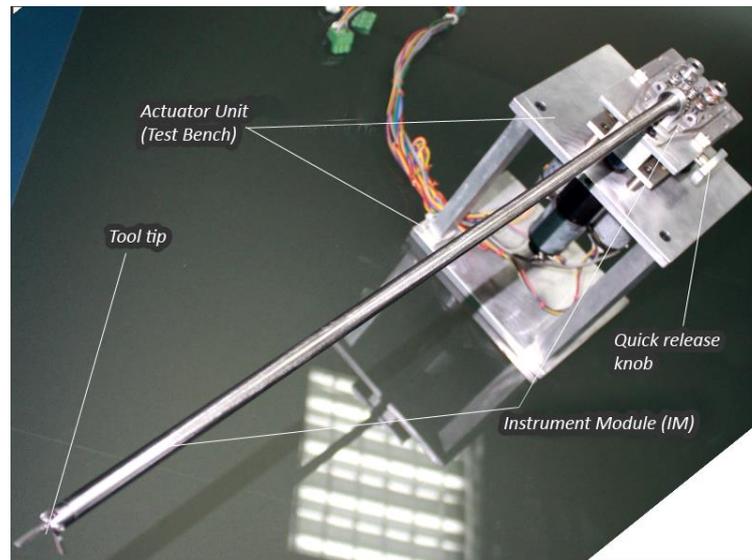


Figure 7: Instrument Module of the Al-Zahrawi Training Robot

Commercialization Potential

Al-Zahrawi system provides both sort of surgical trainers for Minimally Invasive Surgery (MIS), i.e., conventional & robotics assisted. Both conventional and robotic MIS, are being adopted worldwide at a rapid pace of 28%, with the prime advantages of reduced trauma, faster recovery & lesser blood loss.

The uniqueness of the Al-Zahrawi Simulator lies in its smart evaluation feature, which does not require an expert surgeon's assistance to evaluate a trainee. Our simulator trainer is ten times less expensive than our competitors in the market. There is no direct competitor of the Al-Zahrawi Robotic Trainer in the global market but alternative products include dv-Trainer by MIMIC technologies. Al-Zahrawi's edge over dv-trainer is its offering of training over a physical robotic system whereas dv-trainer provides only virtual training.

We define our market as "surgeons" and customers as "hospitals". 234 million surgical procedures are performed annually, forming \$135 billion market. High income economies – target market segment – are 74% of the total surgical procedures market. Our current holding is in Pakistan and some of our notable potential customers include Holy Family Hospital, Rawalpindi; Qatar Hospital, Karachi; and Pakistan Institute of Medical Sciences, Islamabad.

Awards and Honors

The Al-Zahrawi system has won various awards from both the technical development and business communities. Some of the notable ones are listed below:

National Platform:

1. Winner at 2nd Place @ TiE International Business Plan Competition, Islamabad Chapter (Jan, 2013) Prize Money PKR 200,000/-



2. Winner @ IBA – INVENT Entrepreneurial Challenge, Karachi (Aug, 2013)
Prize Money PKR 175,000/-



3. Winner at 2nd Place @ MIT Enterprise Forum, Islamabad (Nov, 2013) Prize Money – Trip to Silicon Valley



4. Finalist @ Preston Entrepreneurial Challenge, Islamabad (Apr, 2013)
5. Finalist @ P@SHA Launch Pad, Islamabad (Jun, 2013)

International Platform:

1. Finalist @ GIST – Tech I Connect at 4th Global Entrepreneurial Summit, Kuala Lumpur, Malaysia (Oct, 2013)



2. Finalist @ TiE International Business Plan Competition, Hong Kong Chapter (Jan, 2014) Finals to be held on 22-Jan-2014

Team

The multidisciplinary nature of this project requires skills from various domains, such as Electrical, Software and Mechanical Engineering and Surgery. Our team is composed of 20+ professionals with expertise on scientific visualization, graphics, formal methods, robotics and surgery. Brief profiles of some of the key team members of our project are as follows:

Dr. Osman Hasan, the PI of the project, holds a PhD in Electrical Engineering and has an over 15 years of experience in the area of robotics and embedded system design. Besides the overall project management, he personally overlooks the development of the Al-Zahrawi robotic trainer.

Dr. Asif Zafar – Vice President of Society of Surgeons Pakistan and a professor of surgery in the Holy Family Hospital, Rawalpindi – is leading the surgical team in the project, for testing/validation purposes.

Shamyl Bin Mansoor, the simulation consultant, holds a Masters degree in Electrical Engineering & Computer Science from Seoul National University. His area of expertise includes physical modeling and simulations. He is managing the development of the Al-Zahrawi Simulator.

Syed Y. Hassan is working as Project Coordinator in the project. Hassan holds a Master degree in Finance, in addition to his MBA, with a working experience of approx 10 years. He deals with the financial & management issues in particular, in the project. In addition to this, he is playing key role in the commercialization of project. Only during last year, he won four business idea competitions for this project.

Zohaib Amjad (Team Lead – Software) being Erasmus Mundus scholar holds a double Master's degree in ICT from KIT, Germany and Politecnico di Torino, Italy. Zohaib took the challenge to develop the simulator in an open source physics engine SOFA, and achieved it in due course of time.

Asad Hameed (Team Lead – Mechatronics) did his Master's from EME College in electrical engineering and control system. Project has benefitted with Asad's experience in terms of smart controls. One of the novel ideas that he developed is the safety control of robotic arms in emergency situation.

Nabeel Kamal, is Mechanical Design Engineer. Nabeel played a challenging role in designing the robotic arms. Achieving a remote centre of motion for robotic arms was a challenging task and he made it possible. He holds a master's degree in mechanical engineering from NUST College of EME.

Bushra Sadia, was initially hired on the research associate position, but soon she proved her flair and was promoted to Software Engineer. She is playing her part in developing advanced exercises for the simulator. She is a post graduate engineer from NUST-SEECS.

Mariyam Shakoor (Software Engineer) graduated from NUST-SEECS in 2010. She mainly worked on developing the basic exercises of the simulator.