Xbox-Powered Medical Simulations & Medical Devices Interfaces

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ABSTRACT

When the computing power of Xbox is connected to real medical instruments, medical training simulations of high risk, low frequency procedures can be conducted in the field. These procedures offer unique challenges for medics and physicians because they must be performed quickly and cleanly to avoid the risk of injury and potential fatality to the patient. Yet, they happen with such low frequency that only a low cost, commercial, simulation platform is cost-effective for on-site training of these procedures.

This need for a commercial simulation platform is especially acute for minimally invasive procedures such as endoscopic intubation owing to the complexities of the endoscopes used and the severity of the consequences of misuse. Virtual reality simulators allow practice on a virtual patient before performing actual surgery. The user "performs surgery" on the virtual organs by manipulating the tools, which may also be displayed on the screen as the user moves them. Using the Xbox, significant haptic information can be generated, closely simulating what is available to the practitioner in actual practice. Organs are replicated in a realistic virtual environment, recreated by inputting data from computerized tomography (CT) and magnetic resonance imaging (MRI) from scans of the patient.

ABOUT THE AUTHORS

James Xu is the Director of Software House at the Simulation and Training Environment Laboratory (SiTEL), a part of the $3.8 billion not-for-profit MedStar Health healthcare system. He is responsible for setting the directions to bring effective and immersive training and learning solutions to medical and healthcare industries. Prior to taking his post at SiTEL, James Xu supported ADL Initiative by focusing on applying emerging technologies, such as gaming, simulation, Virtual Worlds, Web 2.0, mobile and other learning technologies, in the space of learning, education and training. Before joining ADL, he spent over 15 years in the software industry and served as Chief System Architect, VP of Software Development and CTO. During the past several years, Mr. Xu has been concentrating on developing enterprise systems using Service Oriented Architecture (SOA) and other Web 2.0 technologies. James Xu is currently a professor at DeVry University teaching Game and Simulation Programming. He holds a Master of Science degree in Mechanical Engineering, and is pursuing Ph.D. in Modeling & Simulation.

Yuri Millo, MD is responsible for the overall vision of Simulation and Training Environment Laboratory (SiTEL)'s innovations, solutions and consulting. In 2003, Dr. Millo led the founding team that launched SiTEL's first product, a learning management system for healthcare. Today, SiTEL's learning management system is used by tens of thousands of people from healthcare, emergency services, armed forces, government and education. Using innovative approaches as a way to enhance provider competency, reduce medical errors, improve safety, and reduce health care costs, Dr. Millo established SiTEL's Serious Games team to develop video games to train health care and emergency preparedness professionals in a variety of capacities. Dr. Millo served in the Israeli Air Force as Rescue Team Commander, completed medical school at Caregi Faculty of Medicine, Florence, Italy and trained in general and vascular surgery in Tel Aviv and plastic surgery in Jerusalem, Israel. He completed a fellowship in pediatric plastic surgery in Vancouver, BC, Canada. Dr. Millo travels internationally to volunteer with Operation Smile, a children's medical charity that treats childhood facial deformities. He is also member of the American College of Surgeons, Advanced Initiatives in Medical Simulation, the Society for Simulation in Healthcare, and the MedStar Institute for Innovation of MedStar Health.

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THE NEED

In the healthcare industry, a patient's safety and outcome is almost always the key measure of the quality of the industry. Although one major determining factor of a patient's safety and outcome is the skill and judgment of the surgeon, historically, the focus on patient safety in the operating room has been on the supportive functions involving devices, medications, staffing, and administrative procedures, but rarely on the surgeon's technique and performance (Fried, & Satava, 2005).

While a surgeon's cognitive knowledge base, problem-finding abilities and decision-making processing are evaluated and measured with objective testing during residency, technical skills, which are at the core of the profession, are traditionally assessed subjectively. Since competence and safety are of paramount importance, being able to measure a surgeon's technical skills objectively becomes a critical factor (Fried, & Satava, 2004).

Through the advancement of computer technologies, a number of medical simulation devices are being developed to teach and train surgical procedures, provide objective evaluations of the surgeon's technical abilities and enable detection and analysis of surgical errors and near miss incidents in a predefined and controlled environment without risk to patients.

The fiber-optic intubation simulation project discussed in this paper is designed to train healthcare professionals to perform the fiber-optic intubation procedure accurately and avoid abrasive errors in a specified time-period. Such minimally invasive, emergency procedure is performed to protect a patient's airway and provide a means of mechanical ventilation when the patient has serious difficulty breathing normally. An endoscope (see Figure 1) is used to deploy a tube in the trachea of the patient to aid breathing.

Figure 1. Endoscope

More recently, it has become common to perform the procedure with a fiber optic endoscope or bronchoscope which is inserted to visualize the internal airway as the endotracheal tube is passed through the mouth, larynx, and vocal cords, into the trachea. This procedure must be performed quickly and cleanly to avoid the risk of injury and potential fatality to the patient.

Inexperienced surgeons make a number of common errors when performing the tracheal intubation procedure that can lead to patient distress, injury and even fatality. The most common errors include (Baheti, Millo, & Desai, 2010):

- Grazing the walls of the airway. Such mistake can lead to excessive bleeding and can even prove fatal. During the actual procedure, the effect of grazing is often overlooked by novices.
- Intubation of the esophagus. This is another common error because the esophagus is often more easily accessible than the vocal cords.
- Damaging the vocal cords through repeated contact while trying to navigate the scope through. Contacts made anywhere in the vicinity of the vocal cords section, such as epiglottis, esophagus or the vocal cords itself, can cause excessive coughing and gagging which makes the intubation even more difficult as the vocal cords open and close more quickly. Trying to force the scope though may result in damaging the vocal cords

or other sections. It could also be fatal if the patient is not intubated fast enough.

There is a clear and apparent need to properly train medical professionals to efficiently and cleanly perform all surgical procedures to minimize the risk of injury and death. This need is especially acute for minimally invasive procedures such as endoscopic intubation due to complexities of the endoscopes used and the severity of the consequences of mistakes. Traditionally, training for such procedures is conducted in a clinical healthcare environment involving patients, which poses increased and unnecessary risks to the patients involved. To minimize or to avoid these risks, efforts have been made to develop medical simulators seeking to reproduce, as realistically as possible, the look and feel of the human body so that medical professionals can improve their cognitive knowledge and psychomotor skills without risk to patients while at the same time, both cognitive knowledge and technical competency can be assessed objectively.

THE VISION

Although simulation training has been a core technology for aviation safety, new virtual reality (VR) simulations are an innovative approach to surgical training, one which will revolutionize education, training and assessment in the healthcare field. Applying the technology and methods that have proven effective in aircraft pilot training may significantly improve surgical procedure training. The primary goal of this project is to develop a fiber-optic intubation simulation for education and training that is easily accessible and can be widely adopted.

There are several commercially available virtual surgery simulators available for training endoscopic procedures. Often, their utilization rate is low and here are some of the reasons:

- High cost. Most of the commercially available medical simulators could cost tens of thousands dollars and often hundreds of thousands of dollars. Such a high cost brings many negative impacts:
    - Purchases of devices with such a big price tag require a long approval process.
    - Even approved, high cost limits the quantity to a minimum which limits the accessibility.
    - High cost also lowers usage to prevent breakage and maintenance cost.
- Not built for education and training. Often, these simulators are built on cutting-edge technologies with their focuses on functions. But in order to take full advantage of these functions, one has to develop a whole new set of curricula specifically for the simulator. That requires a tremendous amount of resource, specific knowledge, support and manpower.
- Lack of wide acceptance from physicians and faculty. Beside their own learning experiences (mostly without a simulator and therefore with no opportunities to recognize the value that simulations can offer), each physician may have developed his/her own way of approaching a particular medical procedure based upon his/her years of experiences. The physician may feel that simulators cannot serve the needs of training because of lacking the ability of simulating his/her particular approach.

With the primary focus set on serving the purposes of learning and training, the vision of this project is to change the way simulations are designed and developed. Instead of developing a functional simulator before figuring out how it can be utilized in education and training, this project tries to define educational objectives first so a simulation can be developed to aid the education and training to achieve exactly those objectives. This concept is critical in achieving some of the primary goals.

Reducing Cost

In order for a simulation to be widely adopted, it has to be widely available throughout an organization and among potential learners. A lower unit cost will certainly help, by reducing the pressure on making purchasing decisions, making more simulators available and increasing the confidence that they can be used without the worry of high maintenance costs. The defined educational objectives are used to set the scope of the project, which also impacts the cost. Knowing the objectives also helps in choosing simulation platforms that have a large effect on the cost. For this project, in addition to the popular personal computer platform, the Xbox is chosen as a platform for its low price point, availability and connectivity (see Figure 2).

Figure 2. Fiber-Optic Intubation Simulation on an Xbox

Serving Both Cognitive Learning and Skill Training

This fiber-optic intubation simulation project is designed to be able to serve both cognitive learning and technical skill training according to objectives defined.

For cognitive learning, the goal is to minimize the impact of learning the interface and device controls so that learners can concentrate on acquiring the necessary medical knowledge, such as airway anatomy. Learning the interface and control is not the objective, acquiring medical knowledge is. Operating a control should be as transparent as possible in cognitive learning.

According to a Pew study of American adults and video games (Pew Internet & American Life Project, 2008), 81 percent of adults aged 18 to 29 years played games. Since the Xbox is one of the most popular gaming platforms and its controller is familiar to most game players, it becomes a valid choice as the simulation platform for this project to reduce the impact of learning how to use the control.

For psychomotor skill training, a simulator is developed to replace the Xbox controller so learners can be trained and assessed according to defined objectives. In additional to tracking the insertion depth and rotation of the scope, a more realistic haptic feedback, especially the feeling of the scope grazing the airway walls, is generated to give learners a surgical sense of touch. This is an important skill that surgical professionals must possess in order to explore, diagnose and operate effectively.

Increasing Accessibility

Currently, most medical simulations are accessible only in labs, due to the requirement for expensive simulators. The ability to separate device controls in this project provides great flexibilities on how simulations can be delivered according to objectives. Since Xbox game consoles are widely available in many families and homes, simulations that support cognitive learning can be delivered and assessed through Xbox Live. This dramatically increases the accessibility of medical simulations. Furthermore, the same simulation can be run on both Xbox and PC, increasing the accessibility even more.

Supporting Competency Based Assessment

Being able to teach and objectively assess both a surgeon's cognitive knowledge base and technical skills in a series of simulations is just one part of this project. The ultimate goal is to integrate simulations into the education and training procedures so learning outcomes can be assessed in a more meaningful way.

THE APPROACH

The approach taken by the fiber-optic intubation simulation project team was to center our efforts on serving the needs of education and training. Therefore, the design and the architecture of the system had to be flexible enough to accommodate different objectives in different educational and training content at different levels.

The conceptual design of the Fiber-Optic Intubation Simulation project consists of four core components (see Figure 3).

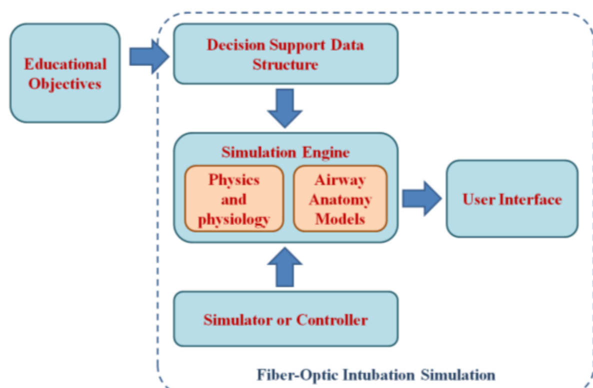

Figure 3. Fiber-Optic Intubation Simulation Conceptual Design

Decision Support Data Structure

The Decision Support Data Structure component contains a collection of data elements that represent decision points in a simulation procedure. These data elements are derived from the educational objectives. They are used to guide a simulation procedure according to defined objectives and to assess the outcomes of the procedure to determine if all objectives are achieved.

This component is implemented separately from the simulation algorisms in the Simulation Engine. Therefore, when educational objectives change, data elements in this component can be changed without any need to change and rebuild the entire simulation system. This design provides the ability to deliver different simulation procedures according to educational needs.

Simulator/Controller

The simulation system can use one of the two input devices – an Xbox controller or the simulator with haptic feedback.

When educational objectives are set for delivering cognitive learning, such as teaching airway anatomy, and the endoscope operating procedures are not a key piece of the content, an Xbox controller can be used. With the wide acceptance of the Xbox game console platform, there are two advantages of using an Xbox controller:

- It shortens or eliminates the learning curve for using the input device. Learners who own an Xbox already feel comfortable with the controller, so they can focus on learning the content. The controller becomes transparent.
- Learners with an Xbox can access and conduct simulation procedures anywhere as long as they have access to an Xbox.

When educational objectives are set for delivering technical skill training, such as training in the operating procedures of an endoscope, the simulator (see Figure 4) can be used as the input device.

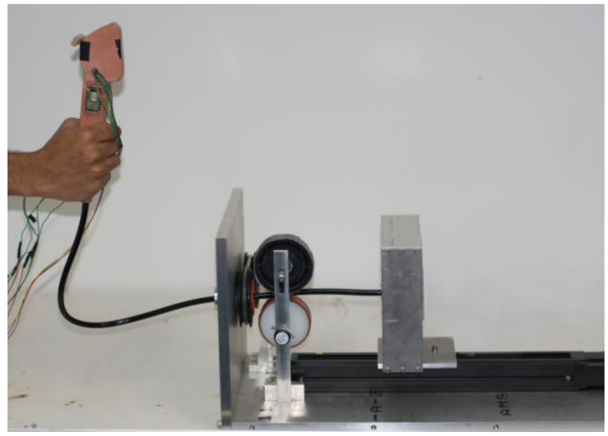

Figure 4. Simulator

The endoscope simulator prototype provides three main capabilities. It tracks the depth of insertion and the rotation of the scope, measures the bend of the tip, and provides haptic feedback. The simulator is fitted with a sleeve of magnets at the tip, a magnetometer inside the handle and a digital encoder at the top. The magnetometer measures the rotation of the scope; the digital encoder measures the bending angle of the tip of the scope; and solenoids are arranged between two square sections to provide feedback. The grazing of the endoscope against the inner walls of the airway is simulated by changing the velocity of rails and the magnetic field in the inner rectangle surrounded by the solenoids. The speed of rails and current in the solenoids are varied based on the intensity of the grazing. Thus, the solenoids are actuated in pairs, groups or individually with varying current strength, thereby producing varying force feedback to simulate the effect of the scope grazing the airway.

Between the Xbox controller and the simulator, the system can satisfy a wide range of educational and training needs.

User Interface

Simply put, the User Interface (see Figure 5) provides

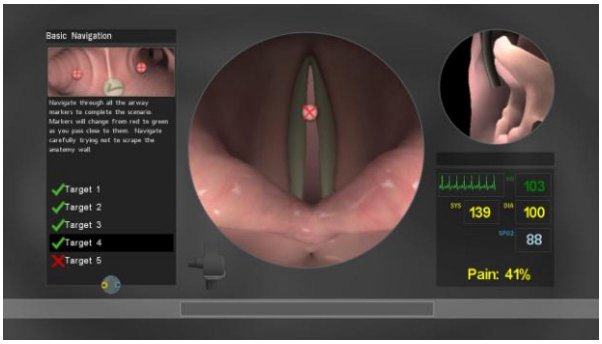

Figure 5. User Interface

a high fidelity rendering of the airway and the visual tracking of the scope. Based on the design of the content being delivered, key points are marked to give guidance to learners or used for assessments.

The display screen is divided into four parts:

- The objectives window (left portion)
- The actual procedure window (center portion)
- The vital stats monitor window (lower right portion)
- The side view of the insertion (upper right portion)

The objectives window displays information about the task to be performed. The procedure window displays the actual simulation - the view as seen from the camera at the tip of the endoscope. The vital stats monitor shows the heart rate, the blood pressure, and the SPO2 levels. These levels vary based on the performance of the user. They change when the patient condition changes during the procedure.

Simulation Engine

The Simulation Engine contains all the logic and intelligence of the simulations. It can be conceptually divided into two components, the “Airway Anatomy Models” component and the “Physics and Physiology” component.

The “Airway Anatomy Models” component contains a set of three dimensional digital models of the airway (see Figure 6). These models are not only realistic

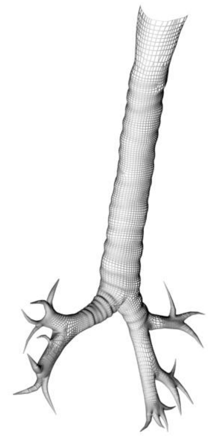

Figure 6. Airway Model (partial)

and accurate, they also contain properties that can respond to various situations during a simulation procedure such as coughing and breathing. When the scope grazes or pushes the airway wall, the model can appear to be deformed or bruised. Additionally, obstructions can be generated within the model if the educational content calls for it.

The “Physics and Physiology” component contains the main logic of the simulation that ties everything together. The code base is developed on Microsoft’s XNA framework so the same code base can be run on both an Xbox and on a personal computer.

The physics model, implemented using the JigLibX physics engine, processes the inputs passed from the input device, whether it is an Xbox controller or a simulator, and controls the dynamics of the system. The JigLibX physics engine provides accurate physical responses as the endoscope interacts with the walls of the airway, the vocal-cords, and the trachea.

Both the endoscope and the anatomical geometry (airway, vocal-cords or trachea, etc.) of the virtual airway are similarly modeled in the physics engine. Collisions between the virtual scope and the virtual airway are continuously tested during the simulation. Once collision is detected by the physics engine, the movement of the virtual scope is restricted or stopped in the virtual airway. This is communicated to the simulator to provide haptic feedback. At the same time, based on the severity of the collision, the physiology logic calculates the reaction of the virtual patient and changes the information displayed in the user interface accordingly.

The simulation works as an educational and training tool for navigating the airway, as well as for learning the different aspects of the procedure. During a simulation procedure, the "Physics and Physiology" component constantly accesses the data elements in the Decision Support Data Structure to guide the learner or to assess the outcome or the learner based on the design of the educational objectives. The displayed image replicates all the movements of the endoscope, namely insertion, rotation, and the bending at the tip. The "Physics and Physiology" component integrates the graphics interface with the input device to complete the simulation.

The Fiber-Optic Intubation Simulation is integrated with SiTEL's learning management system so learning outcomes, whether from a course in the learning management system or from a simulation on an Xbox, can be evaluated in one place. This provides a more objective assessment of a learner's competency which could include the level of cognitive knowledge base, problem-analysis and decision-making abilities and technical skills.

THE NEXT STEP

Although it functions well and performs as designed, we feel that the current prototype of the simulator can be improved or even redesigned. Research and design work is already underway to develop a new prototype of the simulator that will further reduce its cost, weight and complexity. Our ultimate goal is have the simulator available to every learner so he/she can conduct training and practice and improve core skills anywhere without having to come to the lab. Our goal is to put simulators and simulations in use, not just on display.

Even with positive feedback, a validation and verification process should be conducted to ensure that simulation, including the simulator itself, is designed and developed based on requirements, and that it serves the needs of its intended audience.

Scenarios need to be created to conduct studies to determine the effectiveness of the simulation. Currently, three scenarios are under development:

- Scenario 1 – Basic Navigation
  - Description: Learn to navigate the airway with either the controller or the scope simulator. Familiarize with controls and airway anatomy.
  - Goal: Hit successive targets presented to the learner. All such targets must be hit before the scenario is completed.
- Scenario 2 – Anatomy
  - Description: Navigate to random targets.
  - Goal: Reach all targets in the airway before the scenario is completed.
- Scenario 3 – Intubation
  - Description: Deploy the tube at the correct position in the airway. In practice mode, the correct position is indicated by arrows within the trachea.
  - Goal: Intubation is performed in the correct location.

Complications could occur during the procedure. Learners must pay attention to vital signs and administer medications and follow procedures.

THE CONCLUSION

Studies show that medical simulators are an effective means of improving practitioner performance without the need for an actual patient. In particular, virtual reality simulators allow practice on a virtual patient before performing actual surgery. Virtual surgery uses a computer screen displaying a graphic of the organs being operated on. The user can "perform surgery" upon the virtual organs by manipulating the tools, which may also be displayed on the screen as the user moves them. It would be greatly advantageous to provide a system and method for simulating a medical procedure that provides more comprehensive haptic feedback. This would include, for example, procedures used for an endoscopic tracheal intubation, which would then provide two types of force feedback:

- When the endoscope grazes against any section of the airway, vocal cords or trachea and
- When contact is made with any section of the airway, vocal cords or trachea such that no further insertion is possible.

This has been a challenging project. It is not only challenging technically to develop one of the first medical simulations on the Xbox platform, but also challenging to ensure the medical accuracy and to provide an engaging and realistic experience. The project involved surgeons serving as our subject matter experts and researchers as key contributors on our innovations. We believe that its potentials far outweigh all the challenges we have faced to date. Through the many discussions with medical professionals (ranging from medical students to experienced surgeons), all feedback to date has been very positive. Hands-on experiences and tests performed by our subject matter experts indicate that this project, while still in development, delivers the experiences required for training and serves the needs of the educational objectives defined. With its characteristic, acceptance and capabilities, the Xbox can serve as a simulation platform to deliver simulations both in a lab and remotely at home.

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