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SURGICAL STIMULATORS history and perspectives

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ABSTRACT

A surgery simulator is computer technology developed to simulate surgical procedures for the purpose of training medical professionals, without the need of a patient, cadaver, or animal. The concept goes back to the 1980s with video games, but only in the 1990s with three-dimensional graphics and the 2000s with the use of motion sensors for realistic movements (motion control) has the technology been able to simulate the real situation. The most common type of surgery taught through this method is laparoscopic surgery, although it has also been used to do a trial run before other kinds of procedures. Cataract surgery and other ophthalmic procedures are also widely taught using surgical simulators.

Keywords: simulators in education, professional retraining

Virtual surgery as a means to simulate procedures and train surgeons grew out of the video game industry. Video games for entertainment have been one of the largest industries in the world for some time [9]. However, as early as the 1980s, companies such as Atari began working on ideas of how to use these video environments for training people in different tasks and different professions. Younger trainees in the medical field showed greater eye–hand coordination and quick-thinking abilities over those who had never played. Although graphics were extremely limited, Atari began developing several types of simulators related to health care [9]. This type of training met with strong scepticism until studies in the mid-1980s began to show that the concept had promise [9, 50].

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Many surgical procedure names can be broken into parts to indicate the meaning. For example, in gastrectomy, "ectomy" is a suffix meaning the removal of a part of the body. "Gastro-" means stomach. Thus, gastrectomy refers to the surgical removal of the stomach (or sections thereof). "Otomy" means cutting into a part of the body; a gastrotomy would be cutting into, but not necessarily removing, the stomach. And "pharyngo" means pharynx, "laryngo" means larynx, "esophag" means esophagus. Thus, "pharyngolaryngoesophagectomy" refers to the surgical removal of the three.

The field of minimally invasive surgery has spawned another set of words, such as arthroscopic or laparoscopic surgery. These take the same form as above; an arthroscope is a device which allows the inside of the joint to be seen.

Iapyx removing an arrowhead from the thigh of Aeneas using a forceps (Virgil Aeneid XII.383-440) Roman fresco from the Casa di Sirico in Pompeii. National Archaeological Museum, Naples

3D computer graphics, sometimes called CGI, 3D-CGI or three-dimensional computer graphics are graphics that use a three-dimensional representation of geometric data (often Cartesian) that is stored in the computer for the purposes of performing calculations and rendering digital images, usually 2D images but sometimes 3D images. The resulting images may be stored for viewing later (possibly as an animation) or displayed in real-time.

Virtual surgical simulator CAE NeuroVR

3D computer graphics, contrary to what the name suggests, are most often displayed on two-dimensional displays. Unlike 3D film and similar techniques, the result is two-dimensional, without visual depth. More often, 3D graphics are being displayed on 3D displays, like in virtual reality systems.

VirtaMed surgery simulation platform

D graphics stand in contrast to 2D computer graphics which typically use completely different methods and formats for creation and rendering.

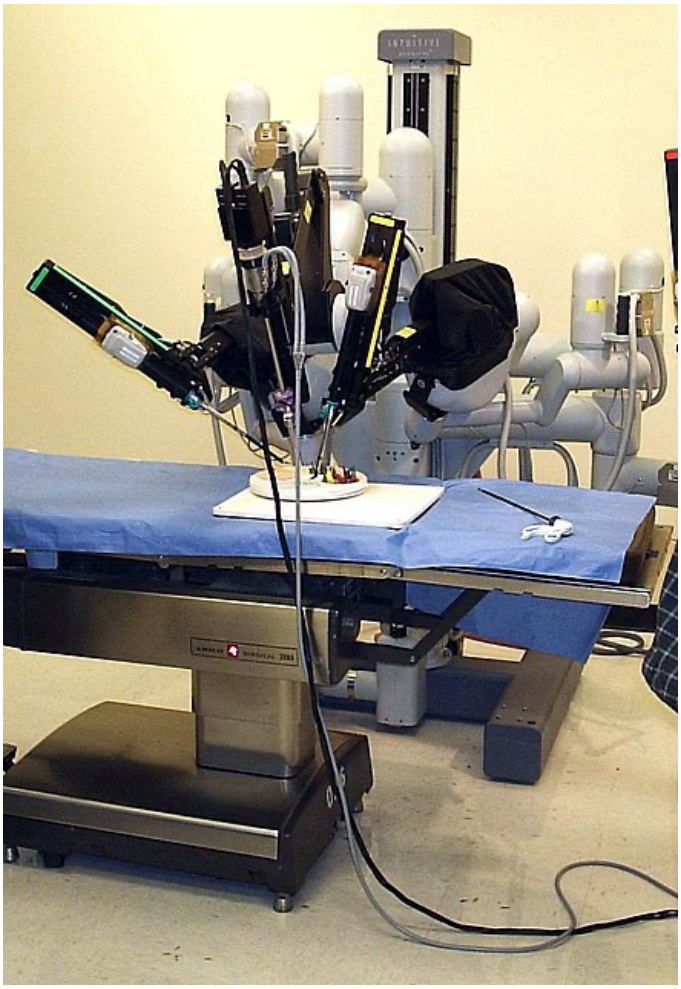
3D computer graphics rely on many of the same algorithms as 2D computer vector graphics in the wire-frame model and 2D computer raster graphics in the final ren-

dered display. In computer graphics software, 2D applications may use 3D techniques to achieve effects such as lighting, and similarly, 3D may use some 2D rendering techniques.

A 1980s era head-mounted display and wired gloves at the NASA Ames Research Center

The objects in 3D computer graphics are often referred to as 3D models. Unlike the rendered image, a model's data is contained within a graphical data file. A 3D model is a mathematical representation of any three-dimensional object; a model is not technically a graphic until it is displayed. A model can be displayed visually as a two-dimensional image through a process called 3D rendering, or it can be used in non-graphical computer simulations and calculations. With 3D printing, models are rendered into an actual 3D physical representation of themselves, with some limitations as to how accurately the physical model can match the virtual model [42].

However, the graphic and interactive limitations of video games hindered their development and usefulness until the 1990s, when companies such as Nintendo and Sony began to produce three-dimensional polygon graphics to produce the concept of "virtual reality." This improved more with the introduction of Wii systems which allowed more realistic manipulation of virtual reality through motion sensors. Studies at this time showed that the new interaction method improved coordination and space perception. The advances also allowed the technology to move from "game" to "simulator" [9]. DaVinci Surgical System programmed its first simulator for laparoscopic surgery in 2005, and its accuracy and design made it quickly accepted by surgeons [5]. While most of this technology has been used for general surgical training, it has also been used to plan specific surgeries as well. The first virtual surgery (where actual surgery followed the virtual practice) was performed on 17 August 2009 when Dr. David Clarke in Halifax, Nova Scotia removed a brain tumour 24 hours after removing a simulated tumour [6]. By 2010, numerous hospitals had some kind of simulation technology available for medical professionals, especially for the training of laparoscopic procedures [9].



Da Vinci Surgical System

The use of this kind of simulation technology continues to be important, especially with younger generations of medical students. These students have grown up with both entertainment video games and serious games, those developed for educational purposes, making the use of simulators both more acceptable and effective [7].

These students have been shown to benefit from this kind of training more readily, especially in the areas of laparoscopic procedures and suturing [8].

Surgeon Simulator

Surgery simulators are generally used to train medical students and surgeons in specific types of procedures without the use of animals or cadavers before working with live patients. They are best suited for two types of skills needed for surgery, eye–hand coordination and the ability to perform three-dimensional actions using a two-dimensional screen as a guide. Eye–hand coordination is improved because the simulation can give both visual feedbacks, by way of a screen, as well as tactile feedback that simulates the manipulation of organs and tissue [1]. Eye–hand coordination (also known as hand–eye coordination) is the coordinated control of eye movement with hand movement and the processing of visual input to guide reaching and grasping along with the use of proprioception of the hands to guide the eyes. Eye–hand coordination has been studied in activities as diverse as the movement of solid objects such as wooden blocks, archery, sporting performance, music reading, computer gaming, copy-typing, and even tea-making. It is part of the mechanisms of performing everyday tasks; in its absence, most people would be unable to carry out even the simplest of actions such as picking up a book from a table.

This kind of virtual reality is most often used in the training of surgeons in laparoscopic procedures, as in reality it is not possible to see the operation being performed. The simulator uses a computer screen displaying a three-dimensional graphic of the organs being operated on. Various surgical tools or gloves are connected to motion sensors and haptic or tactile feedback mechanisms where the user can physically feel the difference in simulated tissue and organs. The user can "perform surgery" upon the virtual organs by manipulating the tools, which are also displayed on the screen as the user moves them, and the tools also provide force-feedback and collision detection to indicate to the user when they are pushing on or moving some organs or tissue. By inputting data from computerized tomography (CT) and magnetic resonance imaging (MRI) scans the patient can be replicated in the virtual environment. The simulations can also provide more intensive training activity with the introduction of rare pathological cases and complications [1].

However, the use of these simulators has its limitations. While significant gains have been seen with their use in novices, their effectiveness diminishes as the procedure is repeated with students reaching a plateau. For more experienced surgeons, the use of these simulators has had very limited use [2].

A simulator for training surgeons that combines virtual reality and tactile feedback. With the help of special robotic manipulators, it simulates the real sensations of using several medical instruments on different types of tissues.

Haptic technology (also kinaesthetic communication or 3D touch) is technology that can create an experience of touch by applying forces, vibrations, or motions to the user. These technologies can be used to create virtual objects in a computer simulation, to control virtual objects, and to enhance remote control of machines and devices (telerobotics). Haptic devices may incorporate tactile sensors that measure forces exerted by the user on the interface. The word haptic, from the Greek: means "tactile, pertaining to the sense of touch". Simple haptic devices are common in the form of game controllers, joysticks, and steering wheels.

Haptic technology facilitates investigation of how the human sense of touch works by allowing the creation of controlled haptic virtual objects. Most researchers distinguish three sensory systems related to sense of touch in humans: cutaneous, kinaesthetic and haptic. All percep-

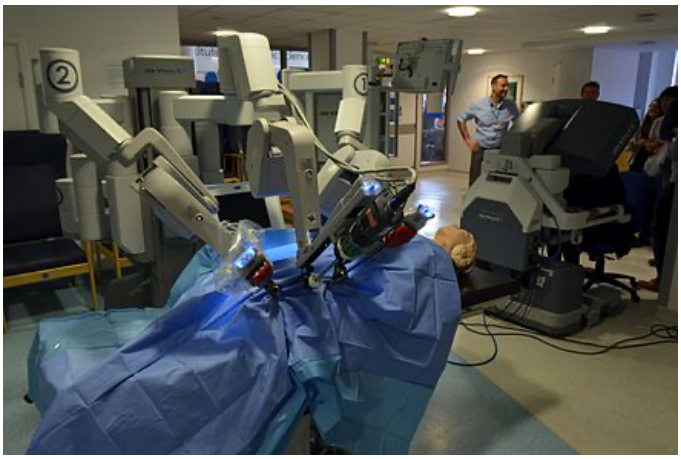
tions mediated by cutaneous and kinaesthetic sensibility are referred to as tactual perception. The sense of touch may be classified as passive and active, and the term "haptic" is often associated with active touch to communicate or recognize objects.

On physiology, the somatosensory system is the network of neural structures in the brain and body that produce the perception of touch (haptic perception), as well as temperature (thermoception), body position (proprioception), and pain. It is a subset of the sensory nervous system, which also represents visual, auditory, olfactory, and gustatory stimuli. Somatosensation begins when mechano- and thermosensitive structures in the skin or internal organs sense physical stimuli such as pressure on the skin (see mechanotransduction, nociception). Activation of these structures, or receptors, leads to activation of peripheral sensory neurons that convey signals to the spinal cord as patterns of action potentials. Sensory information is then processed locally in the spinal cord to drive reflexes and is also conveyed to the brain for conscious perception of touch and proprioception. Note, somatosensory information from the face and head enters the brain through peripheral sensory neurons in the cranial nerves, such as the trigeminal nerve.

The neural pathways that go to the brain are structured such that information about the location of the physical stimulus is preserved. In this way, neighboring neurons in the somatosensory cerebral cortex in the brain represent nearby locations on the skin or in the body, creating a map, also called a cortical homunculus.

The most widely used simulator for laparoscopic surgery today is the da Vinci Surgery Simulator. It is the newest way to practice these procedures that involve the surgeon in the surgery and control of the device. The simulator is a tutorial that prepares a surgeon for real surgery at the da Vinci Surgical System. It contains real-time images, identical controls of the original device and potential problems that may occur during a real surgery [9].

The Da Vinci Surgical System is a robotic surgical system that uses a minimally invasive surgical approach. The system is manufactured by the company Intuitive Surgical. The system is used for prostatectomies, and increasingly for cardiac valve repair, and for renal and gynecologic surgical procedures. The Da Vinci System consists of a surgeon's console that is typically in the same room as the patient, and a patient-side cart with three to four interactive robotic arms (depending on the model) controlled from the console. The arms hold objects, and can act as scalpels, scissors, bovies, or graspers. The final arm controls the 3D cameras. The surgeon uses the controls of the console to manoeuvre the patient-side cart's robotic arms. The system always requires a human operator.



Da Vinci patient-side component (left) and surgeon console (right)

A surgeon console at the treatment centre of Addenbrooke's Hospital

While the use of robotic surgery has become an item in the advertisement of medical services, there is a lack of studies that indicate long-term results are superior to results following laparoscopic surgery [8]. Critics of robotic surgery assert that it is difficult for users to learn [3]. The Da Vinci system uses proprietary software, which cannot be modified by physicians, thereby limiting the freedom to modify the operating system [4]. The system has a cost of $2 million which places it beyond the reach of many institutions [9].

The manufacturer of the system, Intuitive Surgical, has been criticized for short-cutting FDA approval by a

process known as premarket notification, and instead of entering the market through the 510(k) process. The company has also been accused of providing inadequate training and encouraging healthcare providers to reduce the number of supervised procedures required before a doctor is allowed to use the system without supervision [10].

There have also been claims of patient injuries caused by stray electrical currents released from inappropriate parts of the surgical tips used by the system. Intuitive Surgical counter this argument by saying the same type of stray currents can occur in non-robotic laparoscopic procedures [11]. A study published in the Journal of the American Medical Association found that side effects and blood loss in robotically performed hysterectomies are no better than those performed by traditional surgery, despite the significantly greater cost of the system [12, 13]. As of 2013, the FDA was investigating problems with the Da Vinci robot, including deaths during surgeries that used the device; a number of related lawsuits were also underway [14].

It was used in an estimated 200,000 surgeries in 2012, most commonly for hysterectomies and prostate removals [4]. The system is called "Da Vinci" in part because Leonardo da Vinci's study of human anatomy eventually led to the design of the first known robot in history [5].

The ZEUS Robotic Surgical System (ZRSS) was a medical robot designed to assist in surgery, originally produced by the American robotics company Computer Motion. Its predecessor, AESOP, was cleared by the Food and Drug Administration in 1994 to assist surgeons in minimally invasive surgery. The ZRSS itself was cleared by the FDA seven years later, in 2001. ZEUS had three robotic arms, which were remotely controlled by the surgeon. The first arm, AESOP (Automated Endoscopic System for Optimal Positioning), was a voice-activated endoscope, allowing the surgeon to see inside the patient's body. The other two robotic arms mimicked the surgeon's movements to make precise incisions and extractions. ZEUS was discontinued in 2003, following the merger of Computer Motion with its rival Intuitive Surgical; the merged company instead developed the Da Vinci Surgical System.

The ZEUS was designed for minimally invasive microsurgery procedures, such as beating heart surgery and endoscopic coronary artery bypass grafting (E-CABGTM). The system was also used to initiate more complex procedures, like a mitral valve surgery IDE study. The ZEUS' robotic arms not only mimic the surgeon's hand movements but also scale down the movement, allowing the surgeon to easily make precise and small cuts.

The arms also correct for tremors in a surgeon's hands, which are normal even without fatigue, though a highly trained surgeon will be able to lessen the negative effects. However, some surgeries can last for hours, in which case the surgeon's arms will get tired, and the resulting tremors from fatigue can make the surgeon create false cuts, which can be devastating during a delicate operation. To handle this, the ZEUS is designed to track and nullify these tremors while still responding to the movements/commands of the surgeon's hands.

During the surgery, the surgeon sits at the ZEUS console to control the arms. This can also lessen fatigue because the surgeon is sitting down during the long operation rather than leaning over the patient.

The ZEUS is also able to perform remote surgery. Because the surgeon is simply controlling the robotic arms, the surgeon can sit at a ZEUS console remote from where the surgery is actually taking place, and still be able to perform the surgery.

In a study of another program, the Minimally Invasive Surgical Trainer-Virtual Reality (MIST-VR), participants were tested 10 consecutive times within a 1-month period. Assessment of laparoscopic skills included time, errors, and economy of hand movement, measured by the simulator [2].

One of the more popular games/simulators has been Trauma Center, a game based around solving puzzles and problems that might occur during surgery. The objective of the game is to attend to patients that have sustained accidents, broken bones, internal bleeding and trauma, as well as respond to various diagnoses and perform various surgical procedures. The objective of the game is to make the user think faster and increase their ability to solve problems at the surgical table. Surgeons and health experts say that the game is perfect to accelerate the time of decision-making at the surgical desk because it is a game based on placing pressure on the user by giving the user a time limit [1, 7].

The EyeSi is a virtual reality simulator for intraocular surgery training [10]. The HelpMeSee Eye Surgery simulator is another virtual reality simulator with real-time haptic feedback, that is used to train trainees for Manual Small Incision Cataract Surgery [11].

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