VR Surgical Simulators and Virtual Humans

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Boston Dynamics has developed a variety of virtual reality applications. The focus is primarily in two areas: training systems that use interactive haptics and real-time human simulation. This paper touches briefly on work we have done in these two areas.

Training Systems using Interactive Haptics with Physics-Based Simulation

BDI has developed training simulators that use physics-based simulation, real-time 3D graphics, and interactive haptics. The BDI Surgical Anastomosis Simulator allows users to practice end-to-end anastomosis, the task of suturing tube-like organs together. Anasomosis is a common procedure in human surgery. Holding real surgical tools in the hands, the user grasps and sutures the vessels using standard curved needle technique. The user can feel the tissues through force feedback at the same time they see the procedure through real-time 3D computer graphics. This confluence of the senses makes interaction natural and effective. A key feature of BDI's simulators is their ability to measure and quantify the performance of the user.

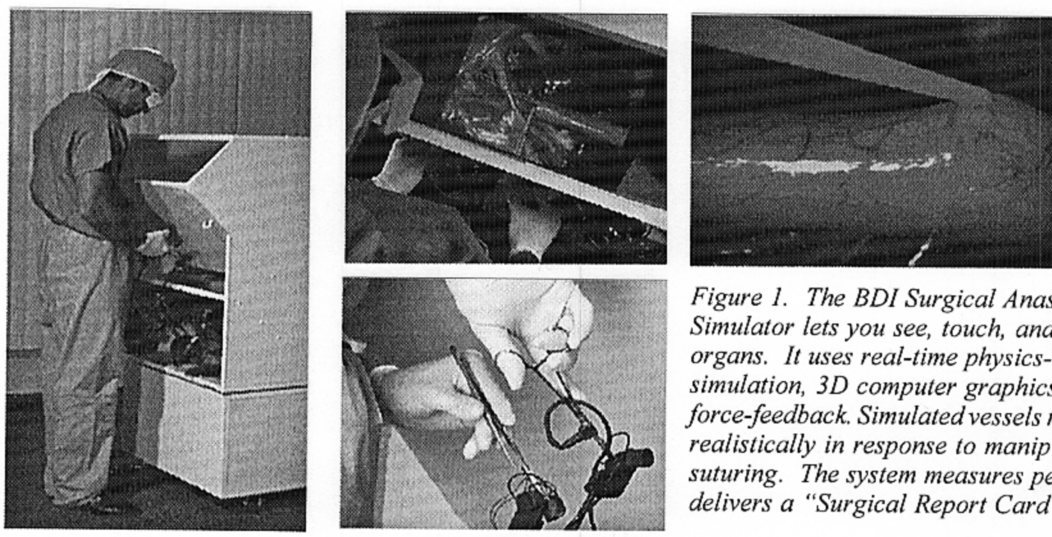


Figure 1. The BDI Surgical Anastomosis Simulator lets you see, touch, and feel simulated organs. It uses real-time physics-based simulation, 3D computer graphics and interactive force-feedback. Simulated vessels move realistically in response to manipulation and suturing. The system measures performance and delivers a "Surgical Report Card"

Surgical Simulation: New Technology for Medical Education

Surgical simulation is an interactive, computer based technique for learning, practicing, and evaluating surgical procedures. The patient's body and vital signs exist only in the computer. The surgeon sees and hears the patient using 3D computer generated graphics and sound, and touches the patient using *force-feedback* devices. A force-feedback device allows the surgeon to reach into the patient with instrumented surgical tools to touch, feel and manipulate simulated organs. Physics-based computer simulations of the bones, joints, tissues and organs allow them to behave realistically in response to touch.

Surgical simulation improves medical education by providing a means to control and standardize the training regimen and evaluation criteria. Trainees learn by doing. They are presented with lessons that are commensurate with their skill level. They learn to adapt given procedures to a range of anatomical variations and surgical conditions. Trainees are able to repeat procedures until they master them without fear of harm to a patient or the cost of an operating room.

Surgical simulation makes it possible to objectively evaluate surgical skills. Access to detailed position, velocity, and force information makes it possible to measure tool accuracy, tissue damage, and surgical technique. Trainees are able to review their performance and compare it to that of experts. By using "gold standards" derived from the performances of expert surgeons, simulators amplify the teaching capacity of experts beyond the one-on-one apprenticeship that has been the standard. By insuring that trainees are prepared to make the best possible use of valuable time in the operating room, surgical simulation enhances traditional training techniques to improve the quality and reduce the cost of surgical education.

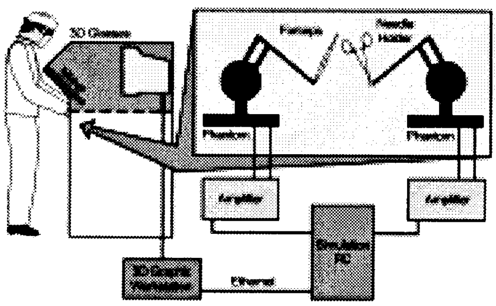


Figure 2. Hardware Diagram for the BDI Surgical Anastomosis Simulator. The simulator is an integrated system that uses standard computers for simulation, 3D graphics, and force feedback devices.

The simulator is an integrated system that allows users to practice end-to-end anastomosis, a common surgical procedure. The user holds real surgical tools, which are connected to force-feedback devices. Holding an instrumented needle holder in one hand and forceps in the other, the user can grasp and stabilize a tube using the forceps while puncturing the tube with a needle held in the jaws of the needle holder. The user sutures the vessels using standard curved needle technique. The forces of interaction between the tools and the simulated vessels are displayed to the user through the force-feedback devices, while the visual images of the interaction are displayed through 3D computer graphics.

A key feature of the simulator is its ability to measure surgical skill. The simulator measures damage to the tissues, curved needle suturing technique, time, accuracy, and several other parameters. In a preliminary test we have compared the performance of experienced vascular surgeons and medical students on a simulated surgical task. We found that the surgeons performed significantly better than the medical students.

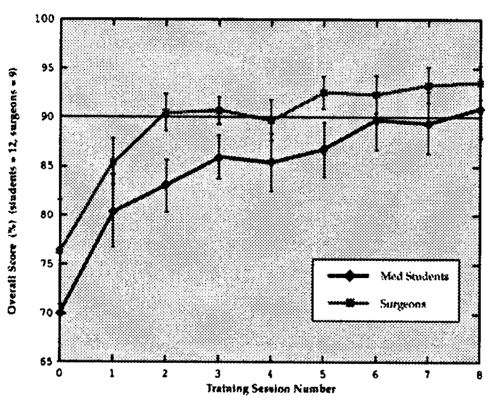
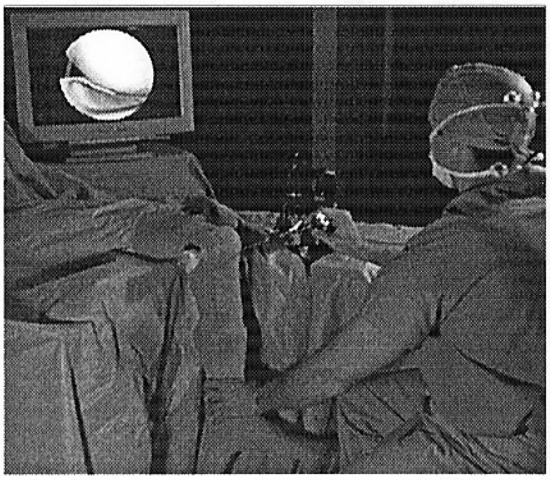


Figure 3. The overall scores of experienced surgeons exceeded those of medical trainees on the skill assessment test.

Knee Arthroscopy Simulator

Working with the American Board of Orthopaedic Surgeons, Boston Dynamics developed the BDI Knee Arthrosocpy Simulator, a virtual reality simulator for teaching arthroscopy of the knee. The simulator is an integrated training system that uses an arthroscopy mounted on a force feedback device, 3D computer graphics, a mechanized lower leg, and physics-based simulation of interactions between the arthroscope and tissues of the knee joint. The system will be used for training and accreditation within arthroscopy.



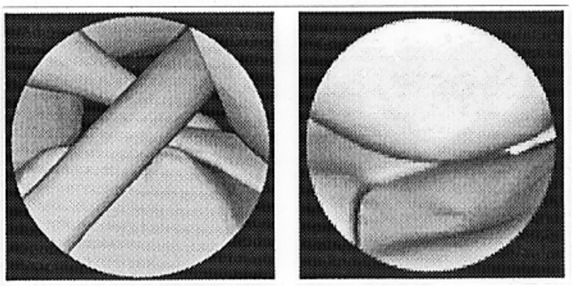


Figure 4. BDI Knee Arthroscopy Simulator. It was developed in conjunction with the American Board of Orthopaedic Surgeons. The trainee manipulates the arthroscope and the leg mechanism, while viewing simulated images from within the virtual knee.

Virtual Aircraft Maintenance

The Joint Strike Fighter Program, Naval Air Warfare Center and Boston Dynamics demonstrated virtual reality technology applied to aircraft maintenance training. The trainer uses virtual reality to simulate the aircraft. Force feedback gives the user a sense of touch, while computer graphics gives the senses of sight and sound. The user sees, touches, and manipulates the virtual aircraft during the training process. The behavior of the mechanisms are driven by physics-based simulation, so they behave like real bojects when touched.

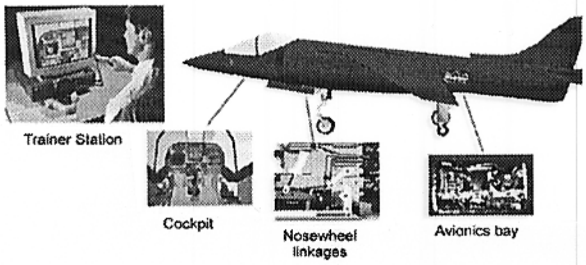


Figure 5. The Virtual Aircraft Maintenance System simulated two real-world maintenance tasks that are routinely performed on the AV8B aircraft.

The system allows a user to perform the essential elements of two real-world maintenance tasks that are normally performedon AV8B vertical take-off and landing aircraft. One task is diagnosis of failed Radar Warning Receiver System Built-In Test (RWR BIT). The second maintenance task is adjustment of the Vernier/Non-Linear Nosewheel Steering Linkage. The Virtual Aircraft Maintenance simulator used physics-based simulation, real-time 3D graphics, and interactive haptics to simulate these training tasks. The system was delivered to the Naval Air WarfareCenter, Training System Division in 1996.

Human Simulation

Boston Dynamics has developed human simulations for a variety of applications and products. Some of the simulations use techniques from robotics with physics-based simulation and control to study the fundamentals of human behavior. Others human simulations are light-weight visual simulations that are useful for training and entertainment. This section touches briefly on our work in this area.

DI-Guy Family of Characters for VR and Visual Simulation

DI-Guy is software for adding lifelike human characters to real time simulated environments. Boston Dynamics developed *DI-Guy* to add realistic soldiers to DIS simulations. *DI-Guy* now includes a wide range of non-military characters, with new characters being added all the time. Each character produces natural life-like behavior, even when switching from one activity to another. *DI-Guy* is already being used in projects by the US Army, Navy, Air Force, and Marines, and for a variety of commercial applications worldwide.

Figure 6. DI-Guy Family of interactive human characters. They are a COTS product designed for a variety of industrial, military, and commercial applications.

The Digital Biomechanics Laboratory

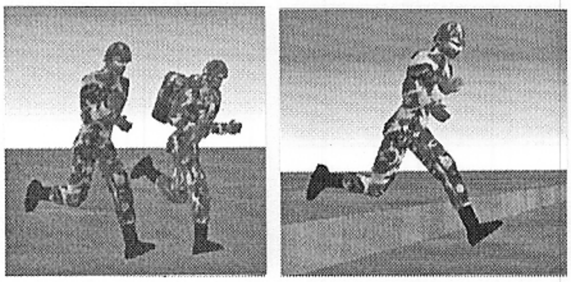


Figure 7. Digital Biomechanics Laboratory feasibility studies. Runners on the left simulate running with and without backpack to examine loading and locomotion control. Runner on the right steps down a 50 cm step.

The US Army has contracted Boston Dynamics to develop the *Digital Biomechanics Laboratory*, an advanced human simulation system that will simulate humans performing useful tasks and using equipment under novel conditions. It will allow users to perform experiments that are too difficult, costly, or dangerous to perform on live people. The Digital Biomechanics Laboratory will be used to evaluate the effectiveness of clothing, footwear, equipment and movement strategies. The goal is to shorten product development, evaluation, and acquisition cycles. A key feature of the Digital Biomechanics Laboratory that goes beyond existing ergonomics models is the ability to allow testing in the context of performing realistic human tasks.

SuperBowl XXXII: See Defense from the Quarterback's View

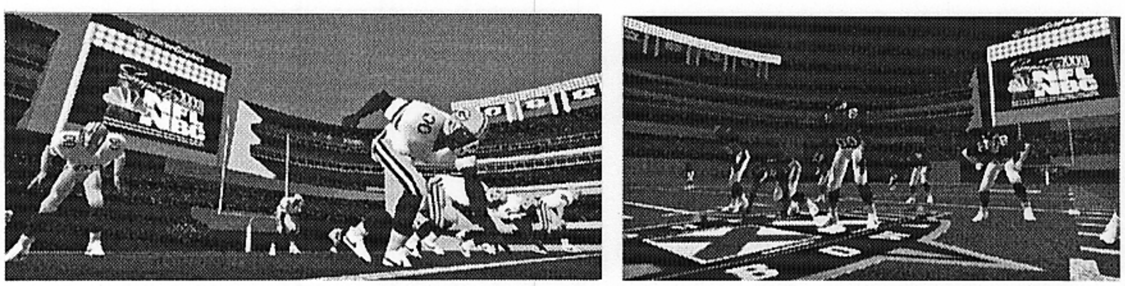


Figure 8. An image taken from the quarterback's point of view. The system was designed to give the broadcast viewer an idea of what the quarterback sees when the defense takes positions at the line of scrimmage. Images courtesy of NBC Sports, Silicon Graphics, MultiGen and Boston Dynamics.

Ever wonder what the Superbowl quarterback sees just before the snap? How does he read the defense's intentions and call the play? Boston Dynamics worked with NBC Sports, Silicon Graphics, and MultiGen to let TV viewers find out. The NBC SuperBowl XXXII broadcast crew queued up the *DI-Guy* simulation twice during the game, but it never got to air.

Urban Combat Simulation for DARPA and SRI International

In a project for DARPA and SRI International, Boston Dynamics simulated urban combat scenarios. The scenes in figure 3 show a four-man fireteam entering a building and eliminating one enemy threat. Urban Combat, an important application area for *DI-Guy,* involves clearing buildings, hostage rescue, drug interdiction, civil disturbance, site security, and the like. In Urban Combat people work at close quarters in and around buildings. Boston Dynamics is building tools for interactively modeling groups of people working at close quarters in MOUT scenarios. In addition to urban combat, they will be used for driving simulators, architectural walkthroughs, and retail planning.

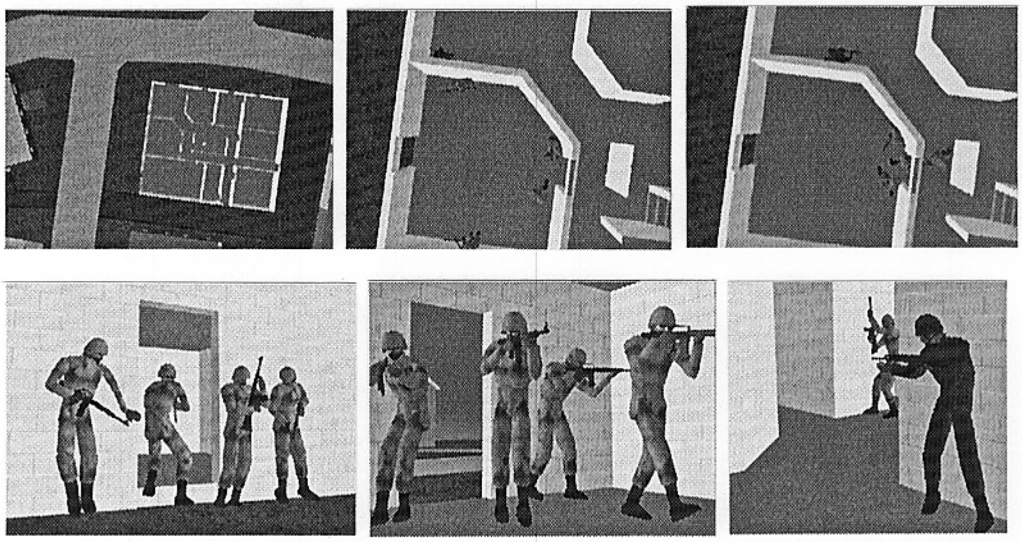


Figure 9. Screen shots taken from a simulated room clearing operation using DI-Guy. The project was done for DARPA and SRI International.

Chem/Bio Characters for CBDCOM

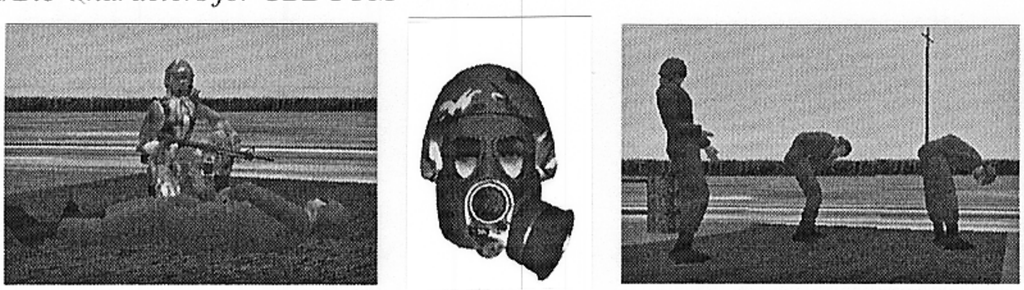


Figure 10. CB-Guy provides equipment and behavior for simulating chem/bio procedures and situations. Photograph of soldier wearing MOPP gear and character wearing one of several gas masks.

Working with OptiMetrics Inc and the Chemical Biological Defense Command we are simulating use of MOPP gear in various battle scenarios. The MOPP gear includes four types of gas mask, hoods, gloves and other protective equipment. We created characters called *CB-Guy*, that can use the special equipment and that exhibit behavior suitable for chem/bio simulations. The behavior portrays various levels of exposure, ranging from mild itching, watery eyes and fatigue, to loss of coordination, vomiting, and various forms of incapacitation. In the future, *CB-Guy* will be driven by battlefield simulation and analysis software.

Human Simulation for Reebok

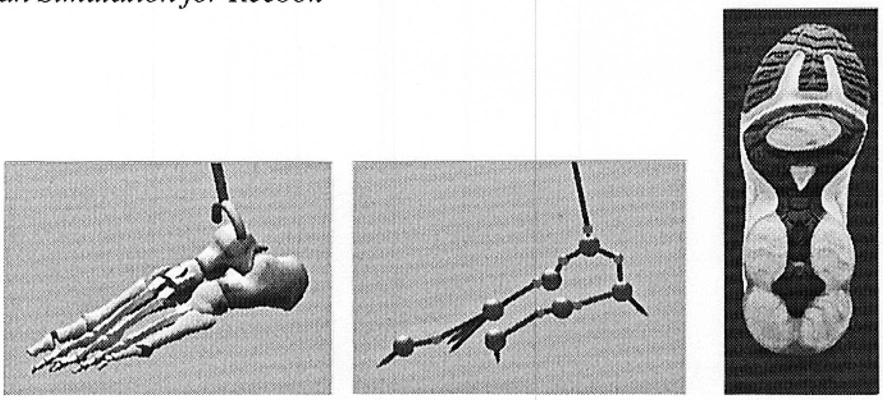


Figure 11. DMX shoe and foot models used in simulation-based design of shoe mechanism.

We developed a physics-based human simulation to better understand how the human foot works, and to learn about interactions between the foot and the body of a person engaged in athletic activity. Reebok uses this simulation in its biomechanics laboratory, and for trade shows and television commercials.

Laboratory Robots

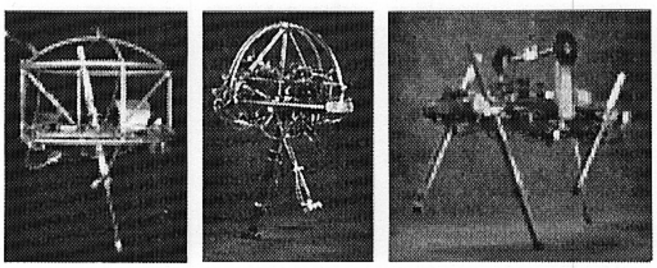


Figure 12. Dynamic robots that run, balances, and does somersaults. They have one, two, and four legs. They were built as part of a series of laboratory experiments at the CMU and MIT Leg Laboratory. The experiments were designed to study the principles of balance in legged locomotion.

In previous work at MIT and CMU, members of the Boston Dynamics team created a family of one, two, and four legged robots that actively balanced themselves while running. These robots could run in place, run along simple paths, run up and down a simple flight of stairs, run fast (13 mph), jump over obstacles, and perform simple gymnastic maneuvers. The purpose of the research was to learn more about the fundamental principles of balance and dynamic control in legged locomotion.

For more information about the work reported in this paper, please see the Boston Dynamics website at www.bdi.com.