A Virtual Environment for Simulated Rat Dissection: A Case Study of Visualization for Astronaut Training

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Abstract Animal dissection for the scientific examination of organ subsystems is a delicate procedure. Performing this procedure under the complex environment of microgravity presents additional challenges because of the limited training opportunities available that can recreate the altered gravity environment. Traditional astronaut crew training often occurs several months in advance of experimentation, provides limited realism, and involves complicated logistics. We have developed an interactive virtual environment that can simulate several common tasks performed during animal dissection. In this paper, we describe the imaging modality used to reconstruct the rat, provide an overview of the simulation environment and briefly discuss some of the techniques used to manipulate the virtual rat.

1. INTRODUCTION

The International Space Station will be expanding its research capabilities over a number of years to support a wide variety of scientific and technological experiments. The biological experiments performed within this facility will investigate the effects of near weightlessness on successive generations of organisms of various complexities. The effects of microgravity on mammalian systems are of particular interest in order to derive the potential changes facing long-duration human spaceflight for exploration-class missions. To understand these changes, collection of tissue while in microgravity is needed in order to capture these effects before the biological modifications that would occur during re-entry to a 1g environment. Both on-orbit and subsequent terrestrial evaluation will require the tissues that are collected to be of the highest quality in order to increase the scientific return from each mission [1].

Some of the constraints on the amount of Life Sciences training crewmembers receive are the access to high fidelity physical mockups (which can simulate only the physical, not gravitational, environment within an experiment module), and by the limited time the crewmembers are given with the Life Science crew trainers. In addition, there exists at least a 6-month delay between training completion and performance of the experiment, which will impact the success of the research.

Within a *virtual* environment however, many scenarios can be presented to the user and allow for training in any remote environment both before launch and during flight. Scenarios, such as changes to the original protocol, emergency procedures and experimental countermeasures, can be simulated in such an environment. Moreover, specific animal characteristics such as species, strain, gender, age and pathologies can be varied and presented within the simulation without requiring the actual specimen. An evaluation mode can also be added to the simulation so that the user can review their performance within the training system and track their progress during the space mission. A virtual environment can also help crew trainers plan scientific protocols and investigate the time and resources that will be required during the difficult process of retrieving bio-specimens in the unusual environment of space.

The principal concept of this project has been to create a flexible, multi-user, remote-capable system in order to provide Science Payloads Operations with an advanced way to train crew on performing life science experiments in space. This paper describes the technologies required to create a virtual environment for the simulation of a rat dissection procedure incorporating simulated weightlessness and discuss the issues that arise when trying to provide an interactive semi-immersive, haptic interface to the user.

2. METHODS

The training system consists of an anatomically accurate computer model of the rat; a simulation engine capable of providing soft-tissue modeling, rigid body dynamics, collision detection and response, and haptic force calculation; and a number of user interface and display devices to interact with the user.

Acquisition and Segmentation

In order to achieve narrow beam collimations to increase the spatial resolution of detail along the slice

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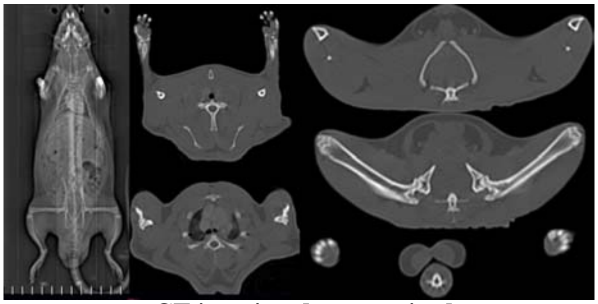
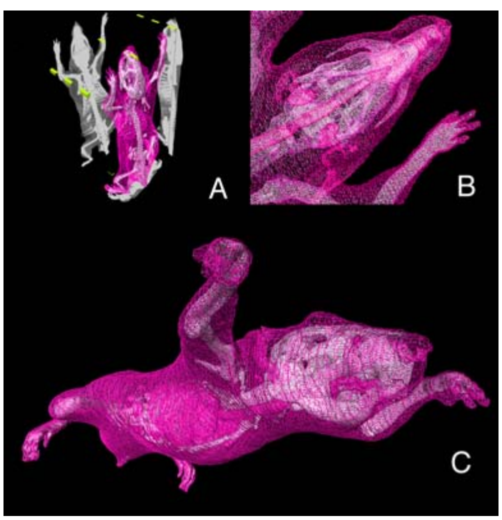
axis, the multi-detector computed tomography (MDCT) technique was performed using a Siemens SOMATOM Plus 4 Volume Zoom (Erlangen, Germany). A 218g 44-day old male Norway rat (rattus norvegicus) was chosen for the animal model. Data were acquired under 'in vivo' conditions in a fully anesthetized animal, without the introduction of Ionidated intravenous contrast media.



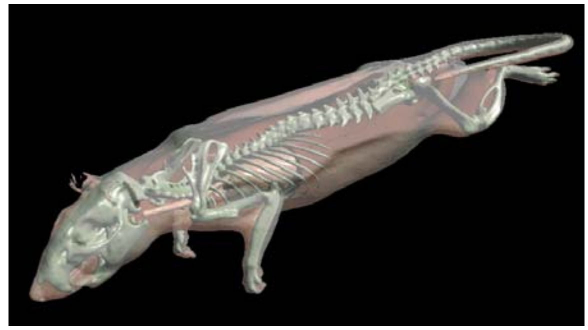
CT imaging data acquired

The animal was scanned in the supine position and embedded in foam material to prevent motion during imaging. 240 axial slices were obtained with the following parameters: slice collimation 2x0.5mm, slice width 0.5mm, rotation time 0.8s, field of view 11x11cm, 512x512 matrix, 120.0 kV and 150.0 mA. The segmentation was performed using Amira 2.0 (Template Graphics Software Inc., San Diego, CA). An automatic thresholding function, along with manual region selection functions, provided reasonable segmentation for both skeletal and soft organ systems.



Segmentation of skin, bones, and internal organs (A), close-up of mesh around skull (B), entire mesh (C)

Once the interesting organs in the 3D-image volume were segmented, we generated a corresponding polygonal surface model by extracting isosurfaces using a generalized marching cubes method. The resulting mesh of the skin, internal organs and bones consisted of over 6 million triangles. This mesh was then reduced with a quadratic slimming method, resulting in a mesh of under 100,000 polygons, which was more amenable to interactive simulations. The figure above demonstrates the segmentation and mesh generation process.



Rendering of entire rat model

Soft-tissue deformation

The reconstructed anatomy of the rat is represented as deformable objects within a physically- based modeling simulation system [2]. In order to provide real-time, haptic-compatible update rates of truly arbitrary deformations, a simplified mass-spring system was employed. Although some researchers have described advances in the use of finite element models to model localized soft-tissue deformations [3], this simulation not only requires coupling regions with varying stiffness but also performs interactive mesh manipulation via cutting [4].

We have developed a real-time, soft-tissue modeling engine with integrated collision detection and resolution that interfaces to a number of haptic and non-haptic input/output devices. This system, named *spring,* models an object as a collection of point masses connected by linear springs in a 3D mesh structure. The behavior of each tissue is modeled by modulating these stiffness coefficients and additional springs are placed between adjacent internal organs in order to propagate the effects of grasping connected components. Bones are modeled as rigid objects that are used primarily for constraining the deformable geometry in space.

Solution of the deformation equations is performed using a localized semi-static solver (a simplification of the traditional Euler method that ignores inertial and damping forces), which provides a significant increase in performance. In order to speed up the simulation further, we have chosen to solve the deformation equations asynchronously, using a multithreaded implementation on a multi-processor Sun Microsystems (Menlo Park, CA) E3500 (8x400 MHz UltraSparc) workstation. The simulation system is written in C++ using the OpenGL, GLUT, and GLUI libraries for visualization and user interface. Cross-platform and multithreading capabilities are provided via the POSIX libraries.

Interaction

Several virtual tools for grasping, cutting and probing were developed. The figure below demonstrates six frames of the simulation. Frame A shows a cardiac puncture to extract blood from inside the heart. Frame B demonstrates the creation of an incision along the midline of the abdomen. Frame C demonstrates the resulting soft-tissue deformation of the skin due to turgor forces, exposing the underlying anatomy. Frame D illustrates extraction of the heart. Frame E depicts the cutting of the trachea to facilitate the removal of the lungs, which is completed in Frame F.

User interaction: Cardiac puncture (A), creating an incision (B), skin deformation (C), removal of the heart (D), releasing the lungs (E), removal of the lungs (F).

Non-haptic Devices

In order to allow the user to interact with the environment using actual dissection tools, an Ascension Technologies (Burlington, VT) Flock-of-Birds electromagnetic tracker is attached to real surgical forceps, scalpels and scissors. By mapping the actual three-dimensional position and orientation of the tools to their counterpart in the virtual space, the user can easily interact with the tissue of the virtual rat.

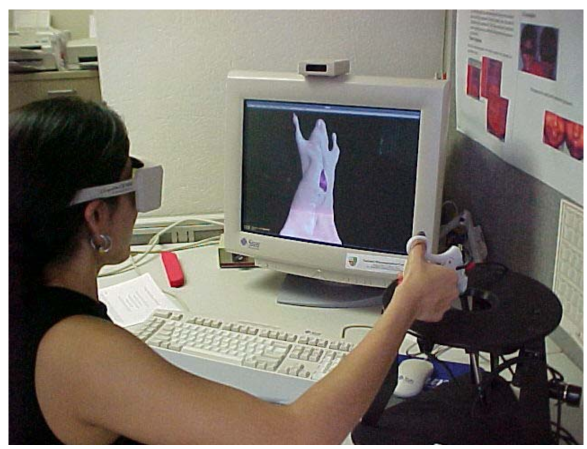
Haptic Devices

Probing the virtual rat can be used to extend the grasping or cutting procedures by adding force-feedback in order to give an impression of the compliance of each tissue. The haptic interface is achieved by using devices such as a SensAble Technologies (Woburn, MA) PHANTOM or an Immersion (San Jose, CA) 3GM or Laparoscopic Impulse Engine. The haptic device is connected to an embedded processor (Intel Pentium-based dedicated PC) and communicates via 100Mbps Ethernet to the Sun server running the simulation. In this way, the update of the haptic device is decoupled from the simulator in order to support high-speed (10,000Hz) haptic interpolation, despite potentially lower simulation speeds.

Display Devices

Desktop Displays

Stereoscopic viewing of the system is achieved by using StereoGraphics (San Ramon, CA) CrystalEyes stereo glasses and a workstation monitor as shown below.



Interactive session with the dissection simulator.

Head-Mounted Displays

We can also view the simulation using a Sony PLM-S700 Glasstron head mounted display (HMD) with an attached electromagnetic tracking device. While HMDs have traditionally offered lower resolution than CRT-based displays, the use of a tracked head-mounted display provides the benefit of superimposing the image of the rat at the same location as the origin of the haptics space and can increase the level of realism within the simulation.

3. RESULTS

We have developed a prototype environment for simulating tasks that are performed in animal dissection. By integrating components for imaging, segmentation, mesh generation and reduction, we can import a very high-quality geometry into a system that models objects with different physical properties. This system provides for interaction with both non-force-feedback and haptic devices and for display with a stereo workstation monitor or tracked head-mounted display. The next phase of this project will focus on increasing the visual and haptic realism presented to the user.

Future directions

Highly realistic visualization of the rat anatomy is essential in providing a meaningful learning experience. To address this issue, we will incorporate additional organ systems as well as investigate the benefits of photorealistic effects such as texture environment mapping. In addition, modeling complex components such as connective tissue and fur are anticipated. Fluid modeling, in order to simulate blood, irrigating water, etc., is of particular interest due to the changed dynamics that these fluids undergo in microgravity and will be incorporated in the near future.

In addition, we are acquiring supplementary datasets, providing models of rats with various anatomical and pathological conditions. We are also combining CT and various Magnetic Resonance Imaging (MRI) modalities for greater soft-tissue differentiation.

Extending visual realism will require research into the nature of organ movement. More exploration needs to be done in order to determine the proper method for capturing the dynamics of tissue motion. Currently we are connecting organs and bones to one another by using simplified virtual muscles and ligaments. However, the exact placement and behavior of these virtual structures requires further research.

In order to provide an effective learning environment, additional operational realism may be also be necessary. This realism could be provided by using multi-model interaction, incorporating additional auditory or visual cues, or by employing novel haptic interfaces. One obvious need is to provide an interface that allows the user to manipulate the rat with two hands facilitating the dissection procedure. An interface incorporating the CyberGlove (Immersion Corp) hand-based input devices is currently underway to address this need.

As features are added to the system, it is also important to evaluate the effectiveness of the environment as a learning tool. While other researchers have characterized the benefit of various systems for the performance of complex tasks [5], this system could benefit from similar user studies which are currently in the planning stages.

4. CONCLUSION

We have developed a virtual reality system for simulating animal dissection whose goal is to facilitate the learning process both before launch and during space flight. This system can be used to simulate diverse procedures on a variety of specimens in a novel physical environment and can reduce the need to transport personnel and equipment to specific training locations.

5. ACKNOWLEDGEMENTS

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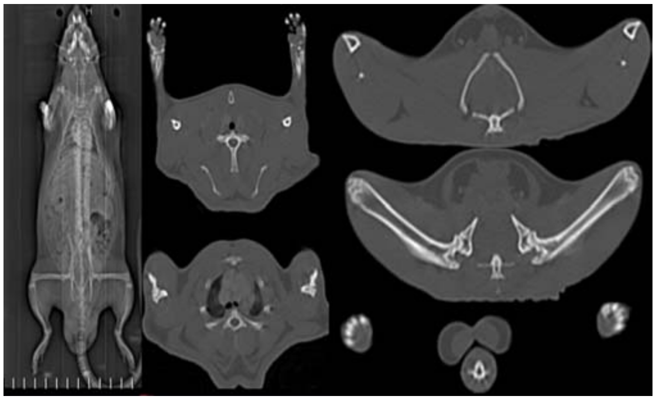
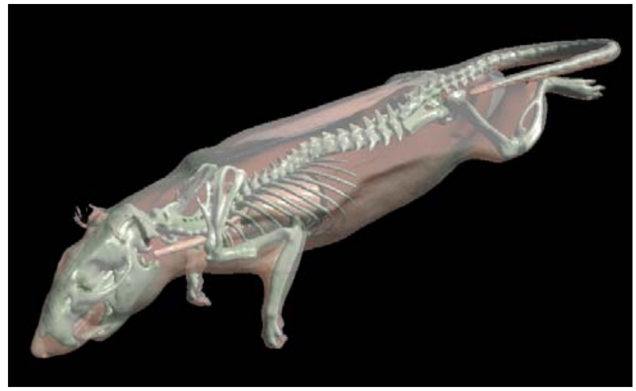
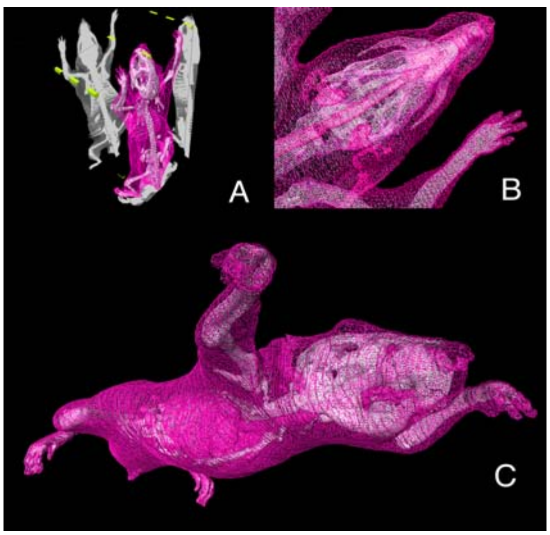


CT imaging data acquired



Rendering of entire rat model



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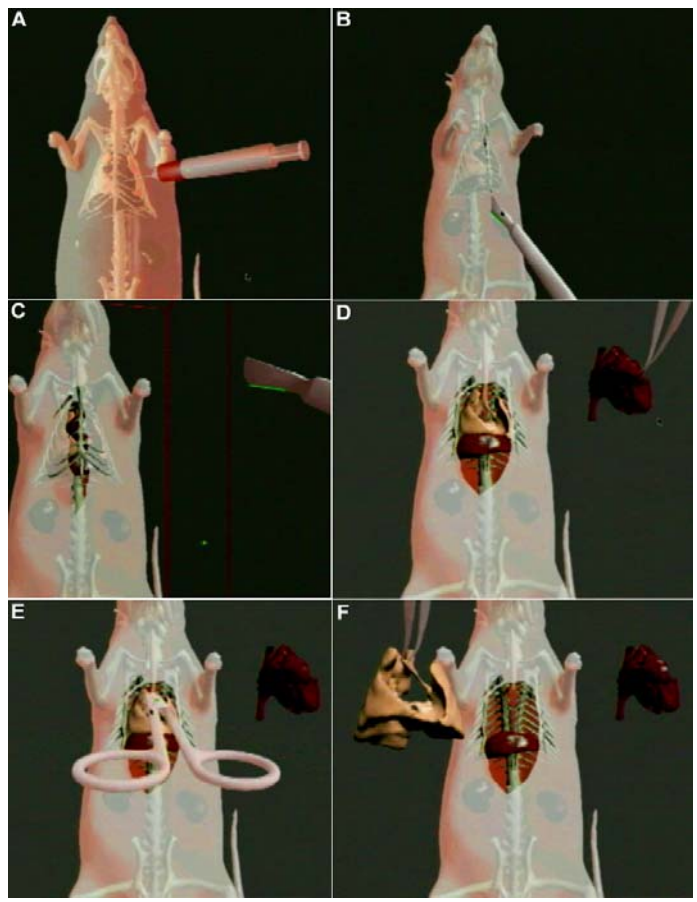

User interaction: Cardiac puncture (A), creating an incision (B), skin deformation (C), removal of the heart (D), releasing the lungs (E), removal of the lungs (F).

Interactive session with the dissection simulator