

MERGING AUGMENTED REALITY AND ANATOMICALLY CORRECT 3D MODELS IN THE DEVELOPMENT OF A TRAINING TOOL FOR ENDOTRACHEAL INTUBATION

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Abstract: Augmented reality is often used for medical training systems in which the user visualizes 3D information superimposed on the real world. In this context, we introduce a augmented reality tool to train the medical practitioner hand-eye coordination in performing critical procedures such as endotracheal intubation.

INTRODUCTION

The development of a training tool for endotracheal intubation (ETI) using a 3D augmented reality environment is aimed at medical students, residents, physician assistants, pre-hospital care personnel, nurse-anesthetists, experienced physicians and any medical personnel who need to perform this common but critical procedure in a safe and rapid sequence.

Training a wide range of clinicians in safely securing the airway during cardiopulmonary resuscitation (CPR) and ensuring immediate ventilation and/or oxygenation is critical for a number of reasons. First, ETI, which consists of inserting a endotracheal tube through the mouth into the trachea and then sealing the trachea so that all air passes through the tube, is often a lifesaving procedure. Second, the need for ETI can occur in many places, in and out of the hospital. Perhaps the most important reason for training clinicians in ETI, however, is the inherent difficulty associated with the procedure.

In the case of severe trauma patients, emergency airway management is classified as a cause of pre-hospital death trauma by the American Heart Association [1]. A study by Orlando Regional Healthcare showed that out of 108 ETI patients who arrived at the Orlando Regional Medical Center emergency room from May 1 to Dec. 31, 1997, 27 had tubes that were placed mistakenly in either the esophagus or the voice box. Of the 27 patients with misplaced tubes, 13 died in the emergency room [2]. Moreover, in a 16 hospital study conducted by the National Emergency Airway Registry between August 1997 and October 1998, out of 2392 recorded ETIs, 309 complications were reported, with 132 of these difficulties resulting from intubation techniques [3]. Many anesthesiologists believe that the most common reason for failure of intubation is the inability to visualize the vocal cords. In fact, failed intubation is one of the leading causes of anesthesia-related morbidity and mortality [4]. Thus, there is international concern for the need for extensive training of

paramedics for pre-hospital emergency situations both in Europe and in the United States [5].

Current teaching methods lack flexibility in more than one sense. The most widely used model is a plastic or latex mannequin commonly used to teach Advanced Life Support (ACLS) techniques, including airway management. The neck and oropharynx are usually difficult to manipulate without inadvertently "breaking" the model's teeth or "dislocating" the cervical spine, because of the awkward hand motions required, even of an expert.

A relatively recent development is the Human Patient Simulator (HPS), a mannequin-based simulator. The HPS is similar to the existing ACLS models, but the neck and airway are often more flexible and lifelike, and can be made to deform and relax to simulate real scenarios. The HPS can simulate heart and lung sounds, produce urine, twitch its fingers, and provide palpable pulses and realistic chest movement. The simulator is interactive, but requires real-time programming and feedback from an instructor [6].

Thus, we propose an interactive tool for training that does not involve programming or instructor feedback. Instead, by using augmented reality (AR) visualization, an immediate visual assessment can be made as to whether an intubation procedure was correctly performed. The HPS will be at the base of the development of the training tool, where we use computer-generated anatomical models extracted from either the Visible Human dataset or patient specific data.

We shall now summarize current developments in augmented reality for endotracheal intubation conducted at the University of Central Florida, and the creation and assessment of anatomical models conducted at Columbia University.

AUGMENTED REALITY

In an effort to improve airway management training, an AR system (illustrated in Fig. 1) is being developed. The system will allow paramedics to practice their skills and provide them with visual feedback they could not otherwise obtain. Utilizing a HPS from Medical Education Technologies, Inc. (METI) combined with 3D visualization of the airway anatomy and the endotracheal tube, paramedics will be able to obtain a visual and tactile sense of proper ETI.

The AR system integrates a head-mounted projective display (HMPD) [7] with a Linux-based PC to visualize internal airway anatomy optically superimposed on a HPS.



Fig.1 Illustration of a training tool for training medics on endotracheal intubation, by Steve Johnson-ODALab.

With the exception of the HMPD, the airway visualization is realized using commercially available hardware components. The computer used for computations and stereoscopic rendering has a 1GHz AMD Thunderbird CPU running Red Hat Linux 7.0. The graphics card used is a dual-head, Asus GeForce2MX. The locations of the user, the HPS, and the endotracheal tube are tracked using a Polaris hybrid optical tracker. The tracking data obtained is updated at 20 Hz. Finally, the amount of bending in the endotracheal tube is tracked with a fiber optic curvature measurement device from Measurand Corporation.

HMPDs are a novel type of head-mounted displays. They differ from conventional head-mounted displays in that the images are formed using projection optics. Similar to a LCD projector, a HMPD projects computer-generated images into the environment. However, a HMPD uses a retro-reflective screen instead of a diffusing projection screen. In a HMPD, the image from the LCD is projected to a beam splitter, directed by the beam splitter toward the retro-reflective screen, reflected back by the retro-reflective screen, and passes through the beam splitter to the eye of the user. A discussion of engineering and



Fig. 2 The HMPD system.

perceptual issues can be found in [8]. A picture of the HMPD system used for AR visualization can be seen in Fig. 2.

The HMPD has a diagonal, binocular field of view of 52 degrees, and retro-reflective material is placed on the neck and chest of the HPS, as shown in Fig. 3, to see the computer models. The HMPD displays images at a resolution of 640x480 and the models are rendered at a distance of 1m from the user. The advantages of using a HMPD are the light weight

optics (8g per eye) and the high quality images obtained from projection optics as opposed to eyepiece optics employed in a projection optics as opposed to eyepiece optics employed in a conventional head-mounted display [9].

The very first laryngoscope was invented in 1855 by Manuel Garcia, a Parisian singing master who wanted to see his own vocal cords. Several years later in 1893, after other inventions, the cuffed endotracheal tube was proposed by Eisenmenger, and the first practical tube produced in 1928, was accepted into common use in the 1930s. These are essentially



Fig. 3 Endotracheal tube with curvature measurement device and intubation tool.

the same tools we use today [10]. Intubation on the mannequin is shown in Fig. 3. The location of the HPS, the trainee, and the endotracheal tube are tracked during the visualization. With respect to the airway, the HPS is anatomically correct. If the graphics models are also anatomically correct, as discussed in the next section, the trainee wears the HMPD and is able to see the internal airway anatomy accurately superimposed on the HPS. A monocular view behind the HMPD of work in progress is shown in Fig. 4. In a near future implementation, the trainee



Fig. 4 In a first implementation of the methods, an approximate model of the trachea and the lungs were employed to demonstrate the optical superimposition.

will also see the endotracheal tube, and feel normal bodily functions while practicing an intubation.

ANATOMICALLY CORRECT MODELS

The training tool will make use of generic models from the Visible Human Dataset [11] to represent the anatomical structures that play a key role in the endotracheal intubation. 3D visualizations of hand-segmented trachea and the mandible, from the Visible Human data, are shown in Fig. 5. In addition,

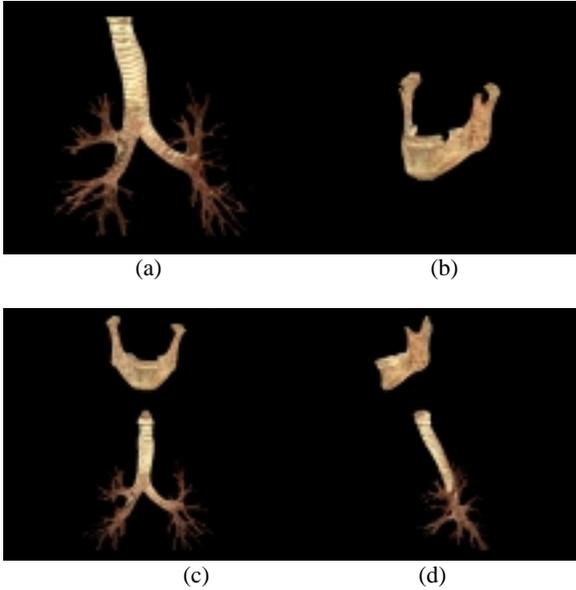


Fig.5 3D visualization of bronchial tree (a), and mandible (b), from the Visible Human Male dataset using 3D Vesalius™ Visualizer. (c)-(d) 3D relationship between the trachea and mandible from different viewpoints.

CT and MR images will be used to create patient-specific visualizations and to perform a study on a variation of human anatomy relevant to this procedure. For patient data acquisition, we shall investigate the method of Chen, et al, at SUNY Stony Brook [12]. A spiral CT scan of a normal larynx will be obtained, and the data reconstructed into 0.3mm thickness slices. MR imaging of a normal larynx, at 1mm slice thickness, will also be used. The Chen protocol generates 0.3mm cubic voxels (CT) and 1mm cubic voxels (MR).

In generating the models, key anatomical structures for the procedure (e.g. trachea, mandible, larynx, and vocal cords) have to be segmented, modeled and presented in 3D. We will start with rigid anatomical models. The anatomical structures will be hand segmented, then modeled and visualized by the 3D Vesalius Visualizer [13], an in-house 3D visualization software developed at Columbia under the Vesalius¹ Project™. We will identify anatomical landmarks on the trachea, mandible, larynx and vocal cords that can be used in transformation of the generic models into patient-specific anatomy obtained from patient data before the intubation procedure. From the CT/MRI patient data, a study will be conducted to determine the variation in size and shape of the key anatomical structures. The radiological data will be segmented with the hybrid automated segmentation methods developed by Columbia University under the Insight Consortium contract sponsored by the National Library of Medicine (www.itk.org) [14,15].

¹ Trademark held by Columbia University. The Vesalius Project™ is named after Andreas Vesalius, a sixteenth century anatomist whose work laid the foundation for all subsequent anatomical research. Columbia University trademarked the name Vesalius in 1997 for use in the production of educational software.

Based on our preliminary work on registering a model of the trachea on the HPS, the 3D model must include the mandible in correct anatomical relationship with the trachea. Interestingly, the understanding of the 3D spatial relationships between the anatomical structures, e.g. mandible and trachea, is crucial for planning and understanding the virtual endotracheal intubation procedure as well. Patient data will provide us with the variability in these 3D relationships that must be understood well by an operator performing the procedure.

In 3D modeling of the anatomical structures, a tradeoff must be achieved between the detailed and realistic representation of the virtual environment and the real-time interaction. The Visible Human data based models must be reduced substantially from the initial *maximal* [13] representation. The realistic color texture of the maximal models is not necessarily needed. Thus only the shape of the structures and an approximate texture will be first retained and reduced to the level where the detail of the crucial anatomical landmarks is present. A pseudo-color texture will be applied. In the future, we would like provide the system with an augmented realism that will include deformable models to depict the elasticity of the anatomical structures. This extremely difficult problem deals with the simulation of physiologically correct involuntary motion of organs and deformation under pressure.

SCENARIOS FOR TRAINING AND EVALUATION

Another issue to address is the need to create different scenarios for training. Given our research on the coordination of maneuvers for endotracheal intubation, we would like the diameter and shape of the larynx and vocal cords to be adjustable, and to be able to create obstacles in the airway, such as blood and vomitus. In addition, the structures must be subject to deformation by the endotracheal tube and the laryngoscope, just as they are in real life.

Evaluation of the system will not deal as much with segmentation and visualization methodology that will enable generation of “true” models of larynx, trachea and other structures, except as it pertains to usability. Because the purpose of the system is training, to qualitatively measure the process we must ask if the system is cost-effective, safe, whether the users enjoy using the system, whether the process is physically comfortable, and whether the system is reliable. To quantitatively measure the outcome, we must measure whether the system decreases mortality and morbidity of the patients requiring intubation, whether patients are intubated more quickly and whether they leave the hospital sooner. Other quantitative measures will include whether the system results in more successful intubations, whether those who trained on the system require fewer tries before success, and whether the system results in fewer traumatic intubations.

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