Human-in-the-Loop Visualization and Emergency Remediation Using Augmented Reality and Sensors

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ABSTRACT

The research summarized in this paper develops a new human-in-the-loop visualization and emergency remediation that enables emergency care providers to observe real-time measurements of the patience condition, with applications for health providers training at the school, emergency responders, and also potentially transforming the emergency responses. The main aspect of the proposed work focuses on the sharing of data for emergency responders to accelerate their understanding of the conduction around them. The new architecture transforms the observation and intervention of health care providers with access to sensor, data, and visualization without distraction from the patience, which visually informs the remediation in the event of emergencies. The new architecture enables for the first time new medical knowledge about the patient-symptom-data in a new bidirectional intervention that can accelerate identification of the emergency and a more accurate caring solution that can save lives in emergencies. The paper summarizes the design of a new application for trachea monitoring and chocking remediation, with specific attention to respiratory flow, as the data of respiration will be connected to a finite element model of the trachea of the patience, as well as better respiratory understanding with this interface.

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INTRODUCTION

In recent years, the research community in engineering and medicine have worked extensively with AR Interfaces and engineering models, including robotic manipulation [1], cracks [2], and dynamics [3]. Tracheal flow is key in the diagnosis of patients' disorders in many situations because the way cartilaginous rings shape flow and particle movement exposes underlying abnormalities [4]. The premise of this proposed framework between emergency care, AR, and modeling is that we need both models that accurately predict airflow patterns and particle deposition in the trachea and visualization tools for healthcare providers to assess airflow during emergencies [5]. Recent developments in CFD models [6, 7] have enhanced the prediction of airflow patterns. Even with the prediction capability of CFD models, their reliability is still limited in sensitive areas such as healthcare and medical emergencies. By integrating high-resolution imaging with CFD simulations [8-10] doctors will better understand tracheal pathological conditions.

PROPOSED INTERFACE

The interdisciplinary team designed a new interface between a CFD simulation of tracheal airflow that is interfaced with human in an AR headset on real time. Such an approach will enhance decision-making process by medical teams in critical situations. Figure 1 shows the proposed final interface.

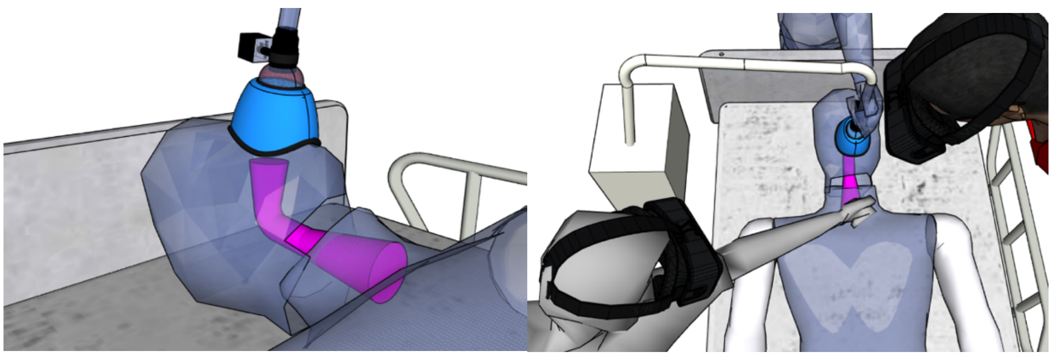

Figure 1. Proposed HPPT Interfaces: (left) speed, pressure, and temperature informs the FDM and holographic model that is overlaid in the patient; (right) health care can interact bidirectionally with patient.

COMPUTATIONAL FLUID DYNAMICS (CFD)

CFD solves the governing conservation equations for mass, momentum, and energy by advancing the solution along spatial or temporal axes, depending on the problem's nature [11,12]. Recently, CFD has been applied to biomedical engineering, where it has proven effective for a wide range of problems. In the upper respiratory tract, airflow is characterized by low-Reynolds number turbulence. Therefore, any chosen numerical scheme must be suitable for this flow regime [13]. Fernández-Parra et al. [14] studied flow conductance and pressure distribution in the upper respiratory system of dogs with different skull types. Yeom et al. [15] analyzed flow-structure interactions in the upper airways and used their model to predict locations of collapsed airways. Piemjaiswang et al. [16] conducted simulations to study aerosol deposition behavior in the trachea. Koullapis et al. [17] developed a simplified CFD model to predict airflow in the lungs.

A key step in numerical modeling is creating a geometric model that accurately represents the studied geometry. For upper respiratory airway simulations, an accurate representation of the mechanisms causing airway obstruction during sleep is essential for accurate flow field predictions [18, 19]. Typically, a 3D model is required for precise modeling. The airway is usually reconstructed from MRI or CT scans using computer-aided design (CAD) software. During this process, irrelevant or redundant features are often removed to simplify the model [20]. Generally, the geometric model serves as a simplified approximation of human airways [21]. Sul et al. [22] studied obstructed flow using a simplified model, where the respiratory tract was represented by a cylinder with varying diameters. Ignatiuk et al. [23] used a 3D model, recreated from CT images, to predict power transfer from the air to the airway tract in the upper respiratory system, as a measure of neuromuscular activity. Suga et al. [24] examined airflow and ventilation conditions in 15 patients before and after OSA treatment, using a CFD model generated from CT scans. Liu et al. [25] conducted simulations in ANSYS Fluent to analyze pressure and velocity distribution along the airway, identifying areas prone to collapse. Omid et al. concluded that sleeping position, gravitational force, and the stiffness of soft tissues are key factors contributing to upper respiratory tract collapse. Srivastav et al. [26] investigated the effects of different turbulence models by conducting simulations in ANSYS Fluent, providing guidelines for selecting an appropriate turbulence model for human respiratory system simulations.

SIMULATION FOR FLOW PATTERN

As an example, to demonstrate the feasibility the use of CFD to simulate and analyze the air flow pattern in trachea, the airflow in the upper respiratory track is being simulated. The DICOM medical images provided by the Kaohsiung Veteran General Hospital would be converted to 3D geometry. Then, a geometric model will be built using in a software before it can be converted into a computational model. The following is an example processed data – a 3D image as well as the principal dimension at selected locations is obtained by processing the original DICOM image sequence, as shown in Figure 2. Using these dimensions, a simplified geometric model that can be used to represent (or mimic) the respiratory tract was created.

TRACT FLOW FIELD

A basic CFD model was created to simulate the flow field in the tract. The results will then be analyzed for the effects of flow rate, pressure drop, drag or other types of flow resistance. This should help identify the important factors that affect the flow. The information obtained from the CFD results can be compared and cross-referenced with the clinical data. One can then determine on the important factors that affects the flow field. In the following, a representative tube with dimensions mimicking real-life respiratory tract is built in ANSYS Fluent is shown. The set of governing equations is solved to compute the resulting flow field. Figure 3 shows the velocity and temperature distributions through the respiratory tract. One can see that air velocity increases wherever the tube contracts and vice versa. This is consistent with what fluid theory have predicted.

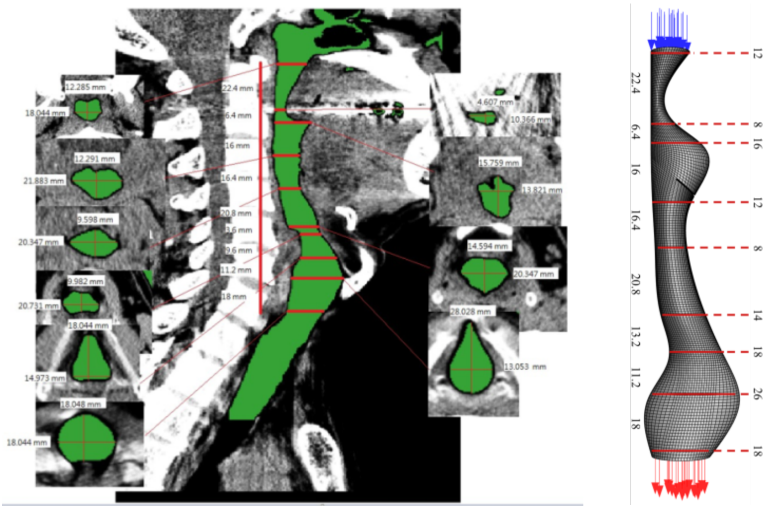

Figure 2. The 3D medical image of the respiratory tract with relevant dimensions (left) and the corresponding simplified geometric model (right).

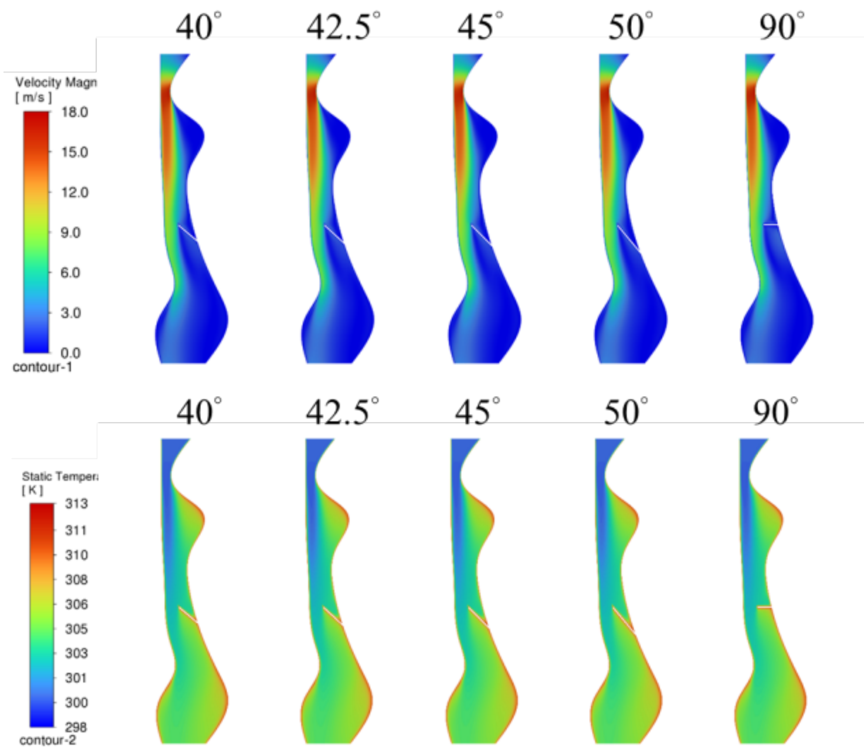

Figure 3. The equilibrium pressure and temperature distributions in the respiratory tract with the blockage oriented at different inclination angles.

FUTURE WORK

The proposed work envisions an scenario where health providers can interface with the information provided by the modeling and a human in the loop health monitoring can be assisted with the overlay of AR and the modeling (Figure 4.)

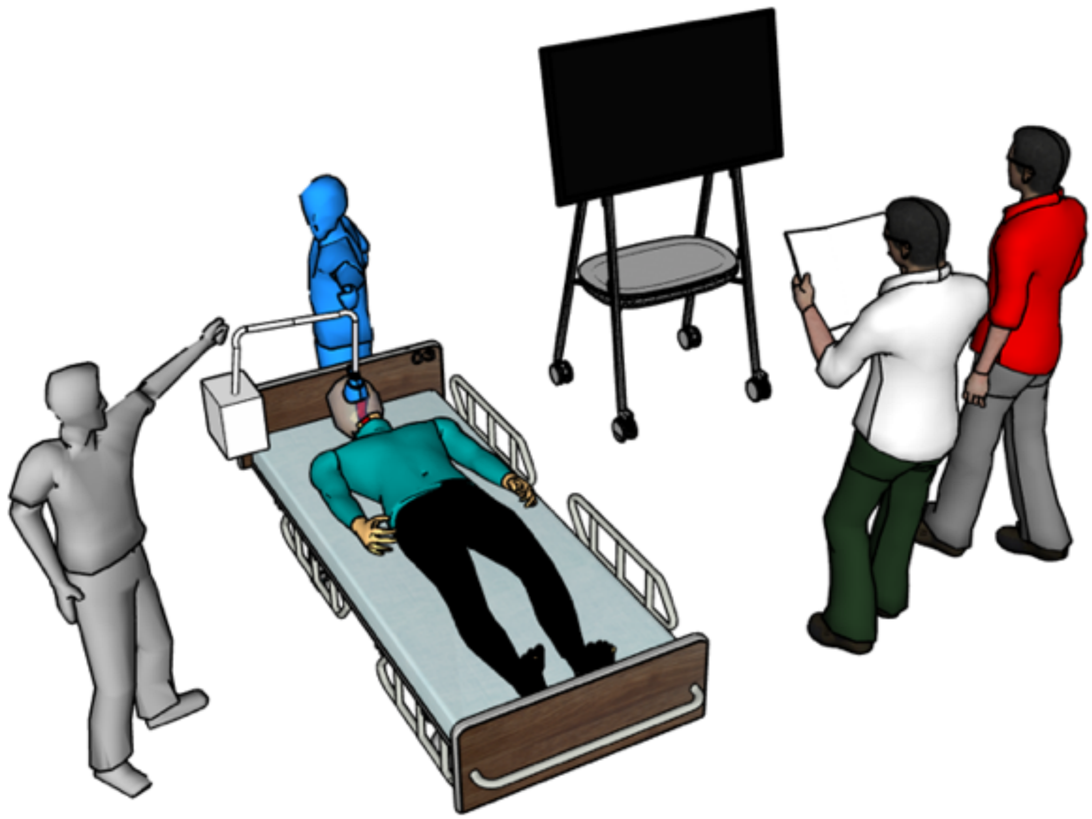

Figure 4. Human-trachea-model-health care interfaces.

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