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Medical Manikin Augmented Reality Simulation (M2ARS)

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1 ABSTRACT

The Medical Manikin Augmented Reality Simulation (M2ARS) is an augmented reality simulation application built for the Microsoft HoloLens 2 that uses the principles of anatomy transfer to overlay human anatomical structures onto a medical manikin digitally. These structures currently consist of the skeletal, muscular, and circulatory systems. In addition, a model of the lungs and an animated heart are also available within the simulation. M2ARS allows the user to view these structures in a manner that is both visually and spatially accurate to the human body. This application contains two modes; an augmented reality mode, which uses a manikin, and a standalone virtual environment, which does not require a manikin. M2ARS aims to assist medical students and practitioners in their studies by providing an interactive method to better understand anatomical structures.

Keywords: Augmented Reality, Medical Simulation, Virtual Environment

2 BACKGROUND

2.1 Introduction

Medical simulations are an essential component of the industry. From training to research studies, medical simulations help prepare and provide an in-depth understanding of the system represented. This same reasoning can be applied to M2ARS, as users gain insight into the location and a 360-degree view of anatomical structures. Medical simulations must become more economically viable and accessible to accommodate for all entering the industry, which calls for a need in further developing anatomical education.

Anatomy is traditionally studied using two-dimensional graphics, commonly found in textbooks and online images, which do not display all viewpoints or show the approximate location relative to the human body. As a result, reliance on these graphics creates difficulty visualizing and understanding the anatomical systems represented. The use of physical 3D models and cadavers for all students and practitioners is possible. Still, these resources are not as accessible economically and physically. The solution lies in software applications that meet both challenges to combat this resource deficiency. These applications include virtual environments and augmented reality simulations.

Augmented reality and virtual environments allow computer-generated models to appear within a physical environment. When applied to the study of anatomy, 3D visualizations of anatomical systems can be interacted with intuitively. Users can view and manipulate these systems, which may help in improving their understanding as compared to a 2D image of the same design. The increased engagement that a user would experience using these technologies may increase the exposure to fully understanding anatomical structures.

2.2 Related Works

Anatomy Transfer (AT) uses a 3D anatomical surface to insert anatomical structures according to the model's position. Most methods alternated between three steps to register the model's AT: estimation of spares correspondences, optimizing the extrinsic and correspondence completion, and regularization to achieve plausible dense displacement fields. In 2013, the first semi-automated method was developed using a partial registration process. Skin surfaces were first registered based on MRI data, and the interior was estimated using interpolation and anatomical rules [1]. This method was quicker than the previous methods and allowed for anatomy modeling for both realistic and fictional characters. This original AT is not available open-source, but other tools enable similar functionality. Ziva Dynamics used Maya over a set of tools to implement anatomy transfer like that described by Dicko et Al.

Other software like Photoshop, ZBrush, and Blender uses rigging to define a model's movement points. Rigging is the technique of skeletal animation to represent a 3D character model with interconnected bones [2]. The rigging process is not entirely automatic, but it can be used to implement an AT. Rigging has been used to implement human anatomy in various medical simulations [3] [4] [5]. In this project, we used Maya's rigging to implement the anatomy transfer.

2.2 Broader Impact

With augmented reality technology impacting medical simulations and studies, M2ARS provides an intuitive and accessible alternative to studying human anatomy. M2ARS overlays anatomical structures onto a physical manikin in an augmented scene through the principle of anatomy transfer. This method replicates the location of these systems relative to the human body, simulating the use of a cadaver. Even without a manikin present, users can utilize the virtual environment mode to view the same structures on a virtual manikin. These models can be interacted with and manipulated, thus increasing user engagement during anatomy studies. Through M2ARS, medical students and practitioners will be able to study anatomy through an economically viable and intuitive application interactively.

3 DESIGN

3.1 Model Generation

3.1.1 Manikin Model Generation

A 3D model must be generated using the appropriate MTG settings to complete this process. Effective Model Targets are geometrically rigid and scaled to the size of the physical object. In this project, the medical manikin utilized is SimMan, produced by Laerdal, which is 1.8 meters tall. The manikin was positioned supine with its palms facing up shown in Figure 1.

MTG can use models generated from an occipital scanner, CAD file, or photogrammetric scans. The 3D model was created for this project by scanning the manikin with the Occipital Structure Sensor (ST01) mounted to an iPad mini. The occipital scanner emits waves of light from a laser that reflect off objects, and the sensor measures the time to return to the scanner to build the 3D mesh. The app used to produce the 3D mesh was Occipital's Scanner - Structure SDK. The scanner gathers mesh for the manikin and the objects nearby, such as the table. MeshFix, an editing tool, was used to remove the table beneath the manikin and correct the orientation of the mesh. The model was uploaded to the MTG after updating its mesh.

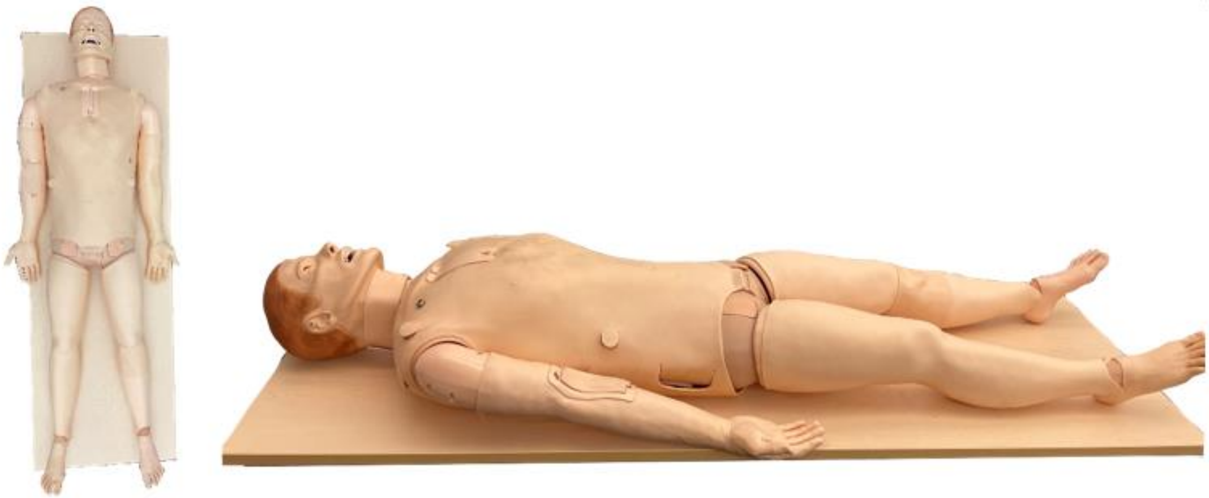

Figure 1: Manikin in a supine position. Top view (left). Side view (right)

3.1.2 Heart Model Curation

The heart model used in this project was created by Dr. Axel Loewe, Mr. Tobias Gerach, and Mr. Jonathan Krauß. This model was generated using data collected from a magnetic resonance imaging (MRI) scan from a 32-year-old volunteer. These images were taken and compiled to produce an anatomically correct heartbeat based on a series of ODEs about an electro-mechanical coupling algorithm, which made the deformations of the heart [6].

The collection of images was in the form of VTK files, where each file was a frame of the heart animation. To be utilized in Unity, the VTK files were converted through the open-source software ParaView to export as .obj files. The files were then compiled using Autodesk Maya. Within Maya, the tool known as BlendShapes was utilized with every 50th frame to create the animations to transform the mesh. Every 50th frame was used rather than all frames to reduce animation complexity without losing the fidelity of the heartbeat. BlendShapes transforms an object using meshes of similar structures and deforms the original mesh [7]. The heartbeat animation corresponds to an average heart rate of approximately 60 BPM [8]. The heart model had the surrounding tissue removed and retextured to appear translucent, allowing users to view the four chambers as they deformed over time.

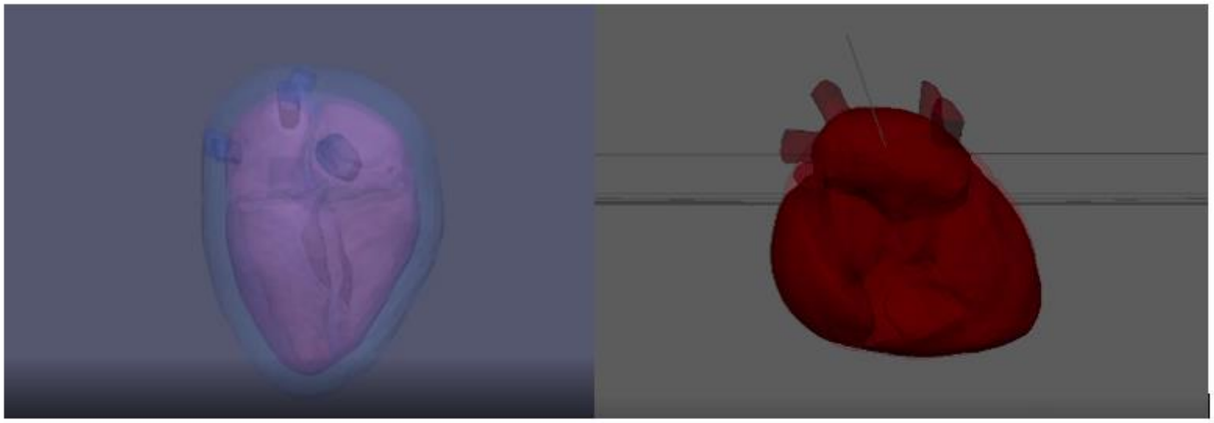

Figure 2: Original model (left) and simplified model (right)

3.2 Model Preparation

3.2.1 Decimation

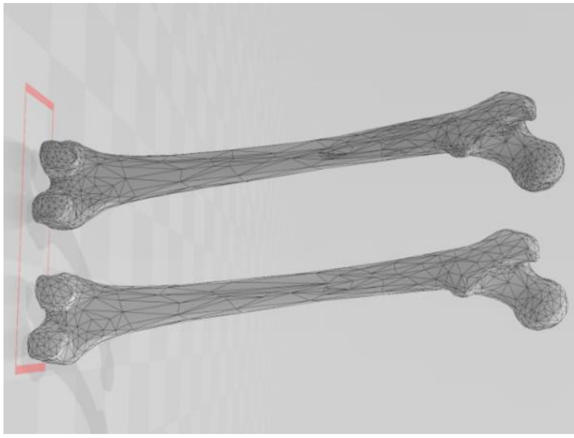

Figure 3: Original Bone Object (top), 50% Decimated Bone (bottom)

The models for the bone, muscle, circulatory system are from TurboSquid [9], and the model for the lungs is from BodyParts3D [10]. Due to the hardware constraints, the original models would result in low frame rate, so the models were decimated using the blender modeling software. Decimation is the process of reducing the vertex/face count of a mesh with minimal shape changes [11], seen in Figure 3. Without this process, the desired performance would be unachievable with our current models. Decimating the models will allow us to keep critical details while cutting out the extraneous polygons that do not contribute to essential model details.

3.2.2 Anatomy Transfer – Rigging

The bone, muscle, and circulatory system models were initially positioned in a T-pose. The model must be rigged to set these structures in a supine position. When rigging the systems, joints were created and adjusted. Joints are placed at every location the manikin can be manipulated. These movement points enable the repositioning of the model. The manikin scan was imported and used as a reference.

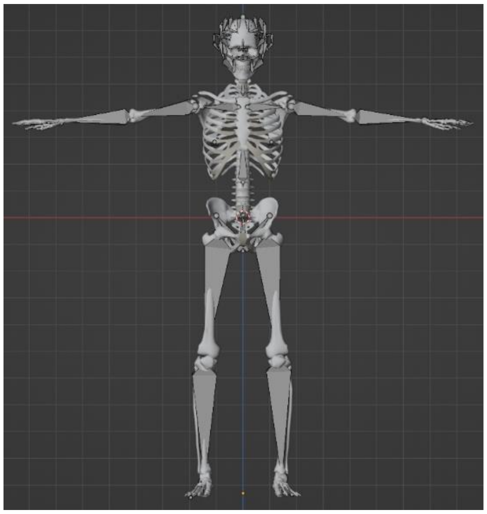

Figure 4: Bone Model Rigging in Maya

3.2.3 Model Target Generation

The Model Target Generator (MTG) produced by Vuforia allows developers to convert 3D models into a database that can be used within Unity to recognize and track a physical object. This database is used by the Model Target GameObject with Vuforia Engine in Unity to enable AR.

To create a Model Target with the MTG, three parameters must be defined: the model's characteristics, functionality, and viewing angles. The model's characteristics identified by the MTG are the 3D model's up vector, units, and model type. The characteristics selected for the manikin were: Z vector, 1818.77 x 682.3955 x 239.193 millimeters, and scan. Selecting the Z up vector ensures that the model is oriented correctly in the software. The units ensure the dimensions of the 3D object are the same as the physical object. The model type informs the MTG that the 3D model was created from a scan. These selections confirm critical operating criteria for the MTG.

The model's functionality in the software is referred to as "Motion Hint," which refers to how frequently the object is moved in the environment. If the object is stationary, then the STATIC mode is best. If the object has limited motion, the ADAPTIVE mode is ideal. If the object is in constant motion, the DYNAMIC mode is preferred. For this project, it is assumed that the manikin will remain stationary in the simulation, so the STATIC mode was selected.

Then, the viewing angles of the model were selected. This step confirmed the viewing device, the angles at which the object will be viewed, and the recognition ranges of the model. The viewing device for this project is the HoloLens 2, so the "HoloLens" device type was selected. The type of view selected was "Advanced View" and "360° Dome". Advanced view allows the object to be recognized from any angle with no alignment of a guide view, and the 360° Dome is optimal for stationary objects. Lastly, the

"Guide Views" was established. Guide views are model viewpoints that make up the recognition ranges for the database training. For this model, 8 viewpoints were created.
After these settings were identified, the model was trained in Vuforia's cloud database, which produced a Unity package containing the Model Target.

3.3 Model Setup in Unity

M2ARS was developed inside the game engine Unity, with two different scenes: an augmented reality (AR) scene and a virtual environment (VE) scene. The AR scene utilizes the Vuforia Engine as this allows the tracking of the manikin. The VE scene is developed similarly to the AR scene except for the Vuforia Engine plug-in, as there is no tracking required to operate the scene. Scene development for both modes is further discussed in their respective sections.

3.3.1 Microsoft Mixed Reality Toolkit (MRTK)

The Mixed Reality Toolkit (MRTK) for Unity was implemented as a plug-in to develop M2ARS for the Microsoft HoloLens 2. The MRTK provided many features utilized in the development of M2ARS to enhance the user's experience with the application. These include the object manipulator, hand menus, and voice commands [12]. In addition, the MRTK allows for a simulated display of the HoloLens for development testing without having the device. The object manipulator allows objects placed in the scene to be repositioned, rotated, and scaled with either one or both hands [12]. The hand menu displays a UI to allow users to modify the visible layers and change scenes. The UI is further discussed in a later section. The voice command feature allows for speech input using keywords to change the displayed layers.

3.3.2 Virtual Environment Mode

The default setting for M2ARS is the AR mode. The user must turn off the AR mode using the hand UI to access the VE scene. The VE scene was developed utilizing the MRTK. Once the models were adjusted using Autodesk Maya, these were imported into the Unity scene. All models were given the ObjectManipulator and NearGrabbable scripts provided by the MRTK to allow user interactions [13]. The user can view the anatomical systems of their choice and access a 360-degree view of each system. Each model will spawn in the same position.

3.3.3 Augmented Reality Mode

The AR scene was developed utilizing the Vuforia Engine and the MRTK. These SDKs work with the HoloLens to recognize the manikin and display the digital overlays. The Model Target GameObject was created by importing the Unity package and assigning the trained database. For the anatomical structures to be adequately overlayed on the manikin, the structures must be children of the Model Target. Lastly, the main camera GameObject was assigned the VuforiaBehaviour script, which enabled the MRTK and the Vuforia Engine to work together [14].

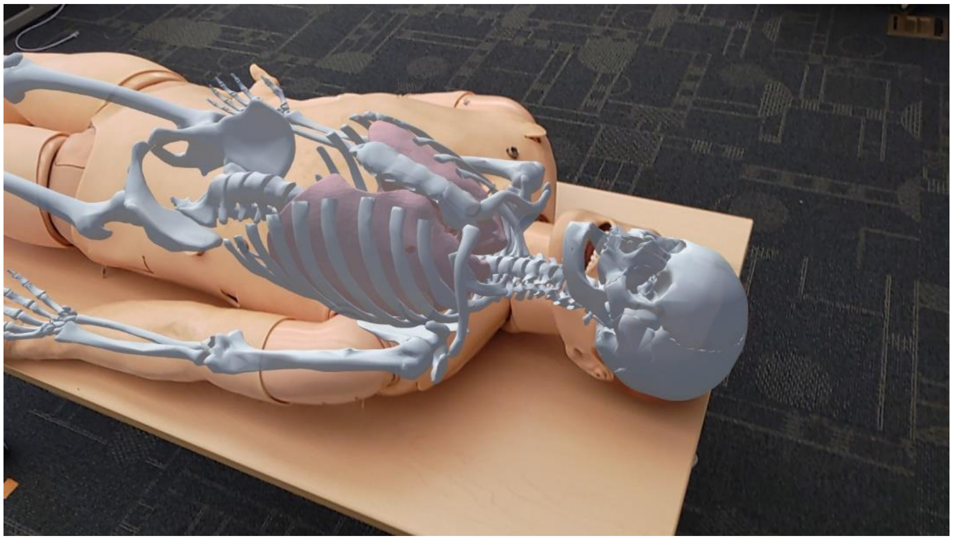

Figure 5: Bone and lung overlay in AR pictured on the Microsoft HoloLens 2

3.4 UI Design Overview

Within the application, the user will be able to select between an AR mode and a VE mode. The default mode upon application start is AR mode. The menu is accessible in either mode based on hand tracking. The menu spawns off the ulnar side of either hand with the palm facing toward the HoloLens2. The user can selectively turn on and off layers (skeleton, muscles, etc.) in either mode. Additionally, voice commands can access the menu and its functionalities. For example, saying “heart” will turn the visibility of the heart layer on and off.

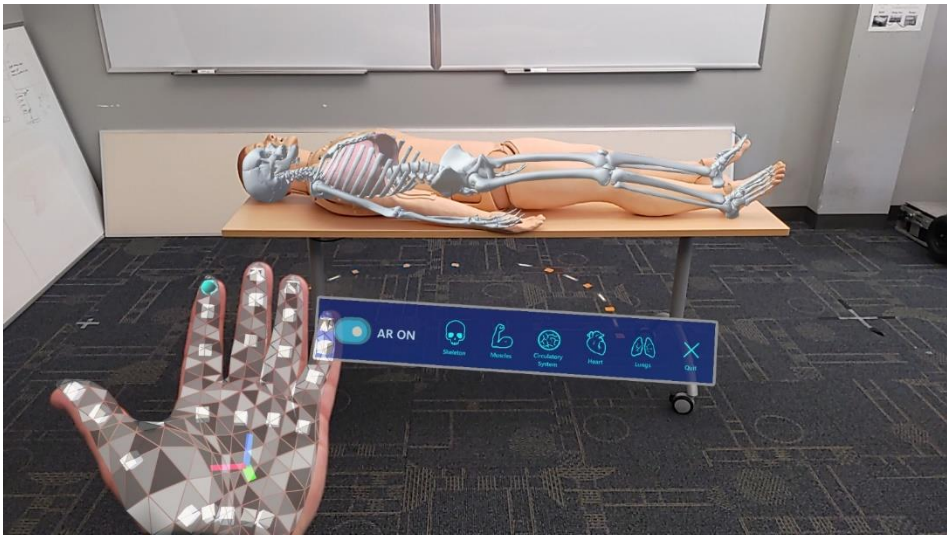

Figure 6: Hand menu pictured on the Microsoft HoloLens 2

4 VALIDATION

The validation process involves structure sensor accuracy, Model Target tracking accuracy, and subject matter expert (SME) confirmation in this project. The structure sensor and Model Target contribute to the spatial location of the anatomical structures, which a SME will evaluate.

The structure sensor (model ST01) has less than 1% precision for a depth under 3000 mm [15]. The model was scanned from a maximum distance of 1828 mm, and for more detailed parts, the manikin was scanned from less than 400mm away. Subsequently, the overall precision of the structure sensor should be negligible to the accuracy of the application.

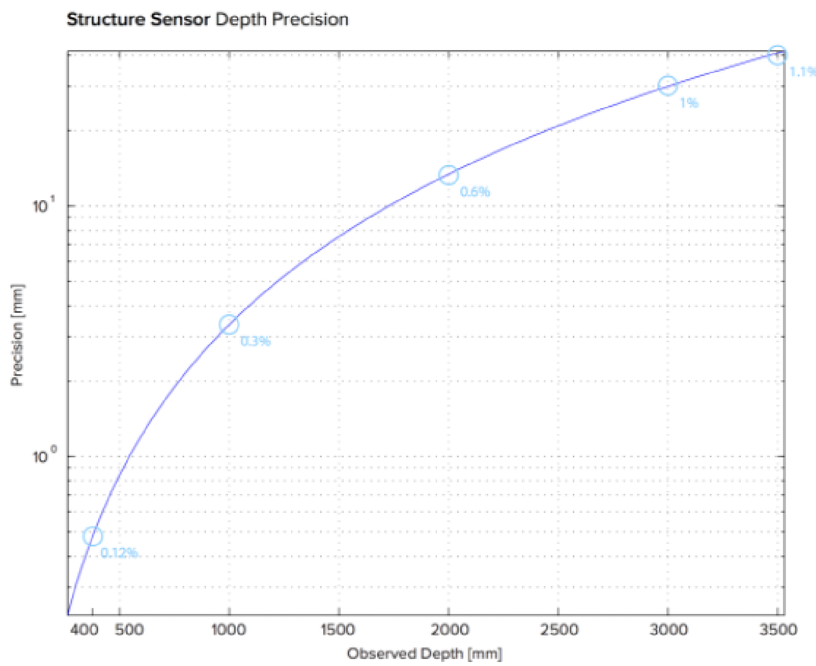

Figure 7: Structure Sensor Depth Precision Graph [15]

The Model Target's tracking accuracy depends on the model match, model material, device, and lighting environment [16]. Several properties affect the Model Target's tracking including the model's position in space, surface pattern or color, geometric detail, flexibility, number of polygons, texture, holes, missing parts, and incorrect Normals [17]. The manikin model adheres to many of the desired parameters. The model's position in space is static and has sufficient geometric detail; additionally, it is rigid, has the correct number of polygons, and has many small textures including flaps and gauges. The model's mesh has no large holes and was edited to have a few incorrect Normals. The model parameter that detracts from the tracking is the model's uniform color. The model meets nearly every "best practice" standard, so the tracking should be precise to the placement within Unity [17].

When the rigging is complete, SMEs will examine the system and give feedback on the accuracy. Adjustments will be made until the application is validated.

5 CONCLUSION

We identified existing technologies that could improve the study of human anatomy, so we created M2ARS: a HoloLens 2 application that implements the theory of anatomy transfer on a manikin to overlay human anatomy digitally. M2ARS allows users to observe and study human anatomy in an augmented or virtual environment. Currently, we are creating a comprehensive user guide and devising a method to assess the spatial accuracy of the digital overlay on the manikin. In the future, hardware improvements will allow for more detailed models. Additionally, implementing an improved animated heart with adjustable heart rates and conditions. Another potential improvement would be implementing a lung animation with flexible breathing rates and conditions.

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