Neonatal Intubation Simulation with Virtual Reality and Haptic Feedback

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Abstract

Respiratory distress syndrome (RDS), a neonatal disease characterized by difficulty breathing, is remarkably common among premature infants, affecting up to 60% of the population. Patient outcomes resulting from RDS are undesirably poor. Neonatal intubation, the primary treatment for RDS, is an extremely difficult procedure to perform. Unsatisfactory patient outcomes are in part due to ineffective training methods, which include video instruction and intubation performed on mannequins. A more realistic training method that better replicates the procedure's technical challenges and stressful nature would enhance physician competency, resulting in improved clinical outcomes. Virtual reality (VR) is an innovative tool becoming increasingly used in the medical field, particularly for simulations. VR provides a means by which individuals can be visually and acoustically immersed in a non-physical, yet responsive, environment. Via the incorporation of haptic feedback devices, virtual simulations can include somatosensory feedback, greatly increasing simulation realism. Cutting edge medical VR simulations with haptic feedback already exist and represent the future of medical training. Integration of a well-designed virtual environment with haptic devices that imitate a neonatal intubation procedure would provide a more effective means of training. Currently, the simulation includes a prototype operating room, 3D models of the tools used in the procedure, and a proof-of-concept deformable sphere serving as a foundation for future soft-tissue development. Further progress is intended to increase the simulation's effectiveness, reaching the standards set by existing surgical simulations. Successful implementation of the proposed system would increase training efficacy, lower healthcare costs, and improve patient outcomes.

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I. Introduction

Respiratory distress syndrome (RDS) is characterized by difficulty breathing in neonates and is the leading cause of death for newborns [1,2]. In the U.S. in 2015, infant mortality rates were nearly 6%, with 13.4% of those deaths attributable to RDS [3,4]. Around 7% of infants experience respiratory distress worldwide, with domestic rates closer to 1% [2,5]. RDS prevalence in neonates can range from 10-60% depending on gestation age, with increased rates in premature infants [2]. According to the World Health Organization, in 2005, nearly 10% of all births were premature, with higher numbers in lesser-developed countries, and it is expected that this number has increased due to a rise in the frequency of Cesarean section procedures [6]. Given the current state of medical technology, these numbers seem surprisingly high.

Currently, RDS is treated via a variety of methods including surfactant replacement therapy, oxygen therapy, and breathing support from a nasal continuous positive airway pressure (NCPAP) machine. For each of these methods, it is often required that a neonatal intubation procedure be performed [7]. While each method is accompanied by its own difficulties, neonatal intubation is a difficult procedure to perform. Neonatal intubation must be performed quickly, precisely, and gently. Failure to comply by these guidelines can result in suffocation, tissue damage, or even head trauma [8]. According to a variety of studies, neonatal intubation attempts are often unsuccessful, especially among residents (as would be expected). One study listed success rates of resident intubations as low as 24%, while that of fellows and consultants was closer to 80% [9]. Other studies have revealed similar results [10,11].

According to an expert in the field, Dr. Ryan McAdams, one of the primary reasons for poor outcomes is the lack of adequate training methods for physicians. Current methods are mainly restricted to video demonstration and intubation practice on neonate mannequins [12,13]. Video demonstrations can be useful, but do not emulate the high-stress environment of the delivery room, and do not involve any physical manipulations. Similarly, the hard shelled mannequins with easily identifiable vocal cords, and the stress free environment in which practice intubations are performed provide a poor representation of the actual procedure. Based on the low success rates in residents, it is obvious that these methods are not sufficient and effective training comes primarily from experience. Thus, it would be extremely beneficial to develop more effective and accessible training methods that could improve patient outcomes.

Virtual reality (VR) is an emerging tool in clinical medicine with functionalities ranging from medical training to pain management [14]. Current methods are usually limited to VR alone, but 3D Systems (Rock Hill, SC) produces cutting edge simulations which incorporate haptic feedback devices [15]. The use of haptic feedback motor arms allows developers to give virtual objects apparent physical properties by providing force feedback when an individual “touches” an object in virtual space with the motor arm stylus. VR with haptic feedback provides a possibility to create a wide variety of advanced medical training methods, which will allow for the development of realistic and effective medical training, encompassing the future of medical procedural training. Successful implementation of devices like these could reduce medical training costs, increase patient outcomes, advance medical treatments, and provide avenues by which effective medical training could be implemented in less developed regions of the world.

Neonatal intubation is a difficult procedure with poor patient outcomes, and an increase in procedural efficacy provides an opportunity to substantially decrease infant mortality rates. Current training methods including video instruction and intubation on neonatal mannequins are seemingly inadequate based on procedural success rates among medical residents [9-11]. An advancement in training techniques is thus desirable, and VR with haptic feedback provides a promising alternative to current training methods. The development of a novel VR simulation that incorporates haptic feedback to accurately emulate a neonatal intubation procedure could greatly improve patient outcomes, reduce medical costs, and expand medical training capabilities far beyond its current state.

II. Background

Dr. Ryan McAdams, our client and chief of neonatology at University of Wisconsin Hospital, is seeking a VR system incorporating haptic feedback to provide a method of neonatal intubation training for emergent physicians. Dr. McAdams has a great deal of experience in this area, having completed a fellowship in neonatology in 2005, and having performed intubations across the globe in parts of Asia and Africa as well as the United States. He stresses the importance of proper preparation before attempting to perform intubations oneself.

Prior to conducting a neonatal intubation firsthand, it is critical that residents and practicing physicians alike receive sufficient training. It is common for preterm infants to weigh less than five pounds [16], leaving these underdeveloped neonates in an incredibly fragile state. The physician's dexterity and precision is vital in preserving an infant's health when performing intubation. The procedure must be conducted gently yet quickly; if performed carelessly, brain bleeds and tracheal scuffing are possible [8]. If done too slowly, the neonate could suffocate [8].

Though technically challenging, intubation is a straightforward procedure, typically requiring around 20 seconds to perform [17]. First, the newborn is laid face-up, with a raised support beneath its shoulders. The head is then tilted upwards, exposing the larynx, and a laryngoscope blade is inserted into the mouth with the nondominant hand. The tongue is scooped or depressed until the vocal cords are visible. Finally, with the dominant hand, the endotracheal tube is inserted through the vocal cords into the trachea, the stylet is removed, and the tube is secured, allotting a steady flow of oxygen to the lungs via a respirator [18].

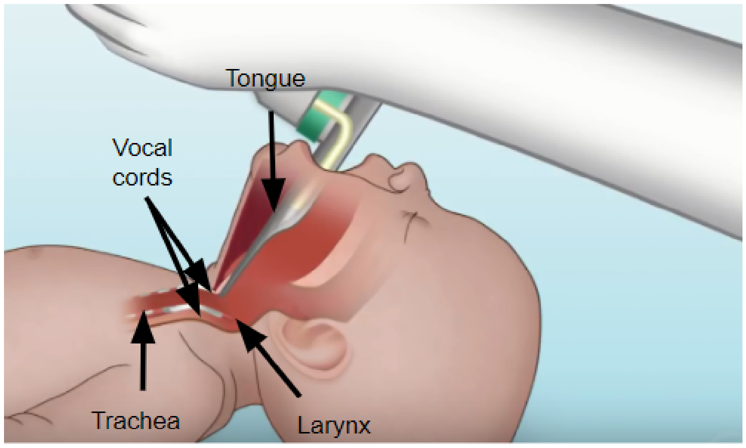

Figure 1: A diagram illustrating the anatomy of an infant's mouth and throat during a neonatal intubation. During insertion, tilting the head is important to keep the pathway to the trachea unobstructed [18].

This procedure is typically rehearsed using roughly proportioned neonate mannequins, which can cost more than $1000 [19] and do not offer sufficient anatomical accuracy or lifelike texture. Virtual simulations with haptic feedback could offer a promising alternative, allowing precise yet alterable anatomical features to be constructed using CAD software and made tangible via haptic systems.

VR, most commonly used in video games and flight training simulations, has also been used to provide additional realism to medical simulations [20]. The Oculus Rift, manufactured by Oculus (Menlo Park, CA), is regarded as the leading piece of VR display technology in the industry, and is commonly paired with the Unity game engine made by Unity Technologies (San Francisco, California) [21]. While innovative, this technology is not an effective means of procedural training by itself; tactile sensation is necessary when developing the muscle memory and confidence sufficient to conduct a successful operation. Haptic feedback fills this role.

Designed to relay intuitive analog feedback to a user's physical input, haptic devices have application in a wide variety of fields. Haptic technology has become a popular feature in automobiles, video games, and military simulations because of its capability to increase the user’s proprioceptive awareness [22]. Unsurprisingly, haptic-driven medical simulations are not a new concept. Haptic feedback devices have been used to quantify the efficacy of virtual procedures performed by physicians as a method of minimizing surgical error. Virtual procedural simulations using haptic feedback have existed for at least ten years, integrating haptic devices manufactured by SenseAble Technologies (Woburn, MA) with detailed models of the human body to give physicians a highly anatomically accurate and consistent method of honing their skills [23]. Systems such as these, which incorporate visual, auditory, and somatosensory feedback, have been successfully implemented in laparoscopy and prostatectomy [24, 25].The PHANToM Touch (now owned by 3D Systems) was one of the first haptic devices available on the market, allowing the user to “feel” virtual elements along a single point of contact manipulated via a stylus integrated with a responsive motor arm [22].

Figure 2: The image depicts a PHANToM Touch (3D Systems), comprised of a handheld stylus attached to a motor arm. The device interacts with an independent computer running Geomagic software via USB [26].

The PHANToM Touch and its successors, the PHANToM Touch X and the PHANToM Premium, remain the most commercially popular haptic feedback systems on the market and dominate the playing field in medical VR simulations [27,28]. We will be using the PHANToM Touch to simulate procedural motions and generate feedback during VR simulation.

The force feedback provided by the PHANToM stylus is subjective, depending on the pseudo-physics integrated by the developer. A perfect physical simulation using a haptic device is impossible due to its finite processing capabilities. However, algorithms are capable of approximating a wide variety of physical materials. Compressible materials (such as human tissues) are inherently more complex to model than incompressible ones due to their dynamic physical properties, but have been approximated sufficiently to create artificial skin [23].

III. Preliminary Designs

Virtual Reality Headsets

There are a wide range of headsets available that are used to create the display in VR systems. They generally fall into two categories: Standalone VR headsets and Mobile phone VR headsets. Standalone headsets tend to be more realistic but more expensive, while mobile phone VR headsets are generally cheaper and feel less realistic.

Standalone VR headsets: Oculus Rift

There are a few standalone VR headsets currently on the market but the Oculus Rift is the most reasonable for our budget. The Rift costs $400-500 and has an OLED display. This display has a resolution of 2160 x 1200 pixels and a refresh rate of 90 Hz. The field of view is 110 degrees and has an 8 x 8 feet tracking area when using three sensors. The Rift also comes with custom motion tracked controllers known as Oculus Touch. The controllers have a joystick and button setup that allow for simple gesture mapping based on how the user is holding the controller [29].

Figure 3: An Oculus Rift headset.

Dimensions: 184 x 114 x 89 mm [30]

Mobile phone VR headsets: Samsung Gear VR

The most popular mobile phone VR headset is the Gear VR, developed by Samsung (Seoul, South Korea). The Gear VR headset costs $99 but requires a Samsung phone to operate, which would increase the price slightly. The super AMOLED display has a resolution of 2560 x 1440 pixels with a 60 Hz refresh rate. The field of view is 96 degrees. The Gear VR headset comes with a remote that allows the user to point and click in the Virtual environment; however, this remote lacks motion tracking capabilities [29].

Figure 4a: Samsung Gear VR Headset.

Dimensions: 208 x 123 x 99 mm [31].

Figure 4b: A Samsung phone used with the Gear VR [31].

Virtual Object Development Platforms

In order to develop realistic 3D models for the simulation, a development platform must be used. In order to simplify the project, one development platform must be agreed on to develop all models. This will minimize the potential for problems with transferring models between software. Regardless of the platform chosen, it must be used in conjunction with Blender, a 3D design and animation software, made by The Blender Institute (Amsterdam, Netherlands). Blender is a free, powerful, and widely used 3D animation software which can be used to make extremely realistic virtual models.

Solidworks

Solidworks, manufactured by Dassault Systèmes (Vélizy-Villacoublay France) is a computer aided design software that is free to UW students and used extensively in the medical field to create realistic 3D models. Solidworks has a wide range of advanced surfacing features that will be useful when creating a realistic neonate. Solidworks also supports 2D Drawing, 3D Modeling, Parametric Modeling, Photorealistic Rendering, and 3D viewing. Additionally, Solidworks has 21 writable file types, allowing for compatibility with a wide range of software [32].

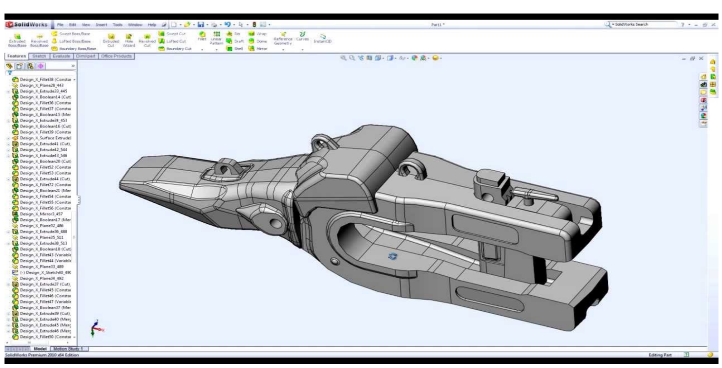

Figure 5: A 3D model Created in Solidworks [33].

Geomagic 3D

Geomagic 3D is a software from 3D Systems that is directly compatible with their haptic devices. It would cost around $2000 for 4 copies of the software. Geomagic 3D lacks most advanced surfacing features and has 12 writable file types. Geomagic 3D supports 2D Drawing, 3D Modeling, Parametric Modeling, Photorealistic Rendering, and 3D viewing. Geomagic 3D also directly supports 3D printing [32].

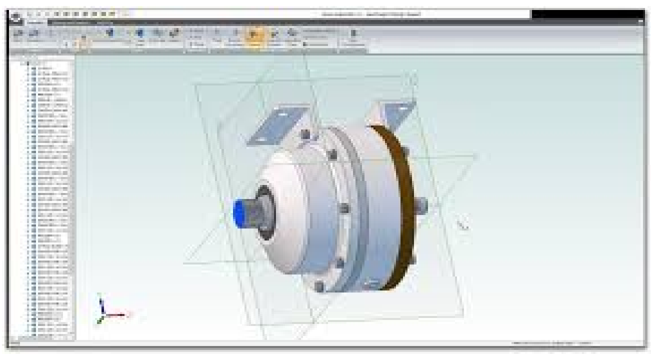

Figure 6: A 3D model Created in Geomagic 3D [34].

IV. Preliminary Design Evaluation

Virtual Reality Headset Design Matrix

Design Criteria (weight)	Oculus Rift	Samsung Gear VR
Cost (35)	2/5 (14)	5/5 (35)
Resolution (20)	4/5 (16)	5/5 (20)
Refresh Rate (20)	5/5 (20)	3/5 (12)
Cranial Tracking Ability (15)	5/5 (15)	4/5 (12)
Versatility (10)	3/5 (6)	4/5 (8)
Total (100)	71	87

Table 1: VR headset technologies are compared based on a variety of criteria. Total weight is out of 100.

Cost:

Overall weight: Currently, cost is the most important factor because of our client's limited budget. In full-scale production, high-quality headset hardware would be paramount to the product's success. In this stage of development, though, a relatively simple proof-of-concept prototype will suffice. Additionally, a low overall cost will make the system more globally accessible. Cost is weighted at 35% of our total matrix.

Score Rationale: The Samsung Gear VR headset is cheaper than the Oculus Rift by around $400. Samsung is also more widely established and accessible globally. The Samsung Gear VR earns 5/5 in this category, while the Oculus Rift earns 2/5.

Resolution:

Overall weight: High resolution is vital in making a simulation feel lifelike. Furthermore, neonatal intubation is an incredibly precision-oriented procedure, and visibility issues could compromise the user's experience. Again, however, a proof-of-concept device does not need to operate at full functionality.

Score Rationale: The Samsung Gear VR headset received a higher score because the Samsung Galaxy S6 resolution is higher by 42 percent, with newer phones emerging with even finer resolution [29]. The Oculus Rift is limited to only one resolution. The Samsung VR headset scores 5/5 due its greater resolution, leaving the Oculus Rift with a 4/5.

Refresh rate:

Overall weight: A high refresh rate prevents lag and buffering while simulation is taking place. Refresh weight has been evaluated at 20% of our total matrix.

Score Rationale: In this category the Oculus Rift has a higher refresh rate by 50%, earning it the edge in this category. The Samsung VR headset earns a 3/5 while the Oculus Rift earns a 5/5.

Cranial tracking ability:

Overall weight: The ability to accurately follow the motions of the user's head is highly dependent on the system's hardware. Cranial tracking ability will be crucial in positioning one's point of reference. The ability to position oneself in VR should be as effortless as possible, as in real life.

Score Rationale: The Oculus Rift has more precise proprioceptive capabilities than the Samsung VR earning it a score of 5/5. Despite this, the Samsung VR still does an excellent job tracking movement, yielding a score of 4/5.

Versatility:

Overall weight: Versatility is evaluated in regards to the headsets interfacing capabilities. In order to emulate a realistic virtual environment, a multitude of third-party softwares will likely need to be incorporated into the virtual system. Thus, the headset needs to be compatible with all software ranging from the gaming engine to the haptic device. In many circumstances, compatibility issues can be worked around, however, earning this category a weight of 10.

Score Rationale: The Samsung Gear VR headset is connected to Google Play, the open-source app store offered by Android. Oculus Rift, however, is run from a Windows operating system. This gives the Samsung Gear VR headset access to a wider range of third party tools and plugins that are not available on a Windows computer.

Virtual Object Developing Platform Design Matrix

Design Criteria (weight)	Solidworks	Geomagic 3D
Cost (30)	5/5 (30)	3/5 (18)
Haptic Compatibility (20)	3/5 (12)	5/5 (20)
Anatomical Accuracy (20)	4/5 (16)	4/5 (16)
Ease of Use/Design Capabilities (20)	5/5 (20)	4/5 (16)
VR Platform Compatibility (10)	5/5 (10)	4/5 (8)
Total (100)	88	78

Table 2: VR object developing platforms are compared based on a variety of criteria. Total weight is out of 100.

Cost:

Overall Weight: Similar to the headset evaluation, cost is a primary concern for our design as one of the primary motivations for this project is to create a more accessible training tool for medical students. Thus, cost was given the largest weight of 30%.

Score Rationale: The Geomagic 3D software costs around $500 per instance, while Solidworks is free through the University. Furthermore, if this project is passed on to another BME team they can simply continue using Solidworks instead of purchasing another instance of Geomagic 3D. Thus, Solidworks received a score of 5/5 while Geomagic 3D only earned a score of 3/5.

Haptic compatibility:

Overall Weight: Haptic compatibility is an evaluation of how readily the software provides physical properties to the virtual objects. This is an important consideration for this project as one of the most difficult challenges will be accurately emulating tissue-like physical properties in the virtual environment. Compatibility issues could serve as a barrier to effective training garnering this category a weight of 20%.

Score Rationale: Geomagic 3D is designed to integrate easily with the haptic devices and thus received the higher score of 5/5. Solidworks is still compatible with such devices, but accurate emulation of tissue-like properties will likely require clever programming using additional 3D Systems software. Solidworks received a score of 3/5 as its compatibility issues are more of a nuisance than an obstacle.

Anatomical Accuracy:

Overall Weight: Anatomical accuracy refers to how well the created 3D models will mimic neonatal anatomy. While the haptic compatibility focused on somatosensory properties, this category is primarily concerned with visual accuracy. Anatomical accuracy is also high priority because in order to provide effective training, the simulation must accurately emulate what the trainee may see in the delivery room earning this category a weight of 20%.

Score Rationale: Both Geomagic 3D and Solidworks can be used to produce unique and intricate models. Furthermore, Solidworks and 3D Systems have both been used to accurately replicate precise anatomical models, thus, both platforms earned a score of 4/5 [33].

Ease of Use/Design capabilities:

Overall Weight: Ease of use is defined as how well we would be able to use the program given our current abilities. If substantial amounts of time are wasted learning the basic functionality of an unfamiliar software, project progress will be slowed. Furthermore, limited developing capabilities may impede accurate anatomical design.

Score Rationale: Moreover, Solidworks is a widely used platform and has been used extensively used in the medical field to accurately replicate anatomical models [35]. Furthermore, the design team is familiar with Solidworks, and as a result of its popularity there exist a multitude of tutorials and forums for advice, earning it a score of 5/5. Geomagic 3D, on the other hand, is not widely used and troubleshooting must be performed through a representative, garnering it a score of 4/5.

VR Platform Compatibility:

Overall Weight: VR platform compatibility refers to how easily the 3D models can be exported to the VR platform, specifically, Unity. A development platform with more writable file types can be easily transferred to other software for further development. If the file types are not compatible, it could slow progress on the project or stop it completely until an alternative is found.

Score Rationale: Items in Solidworks can be imported to Unity in one click of a button. Geomagic 3D, conversely, does not offer clear information on how files can be transferred into VR development platforms. Solidworks is also better established than Geomagic 3D, which increases the availability of resources we could turn to for assistance. Because of this, Solidworks earns 5/5 in this category, while Geomagic 3D earns 3/5.

Proposed Final Design:

The final design will incorporate models developed in Solidworks, the Unity 3D development environment, 3D Systems Touch haptic device, and Samsung Gear VR headset to create the VR simulation and environment. The 3D models of the neonate and the surroundings will be created in Solidworks, refined in Blender, and then exported to Unity. Unity allows for the 3D models to easily be placed and moved around to create an environment. Unity will also serve as a game engine and will be responsible for handling the physics and creating the user interface of the simulation. In order to give our simulation haptic feedback, 3D Systems Touch Haptic device will be used. This device works alongside 3D Systems OpenHaptics software to give physical properties to 3D objects in the virtual environment. OpenHaptics will essentially serve as the link between the game engine and the Touch. When a collision occurs in the virtual environment, OpenHaptics will receive the information and communicate with the Touch to create the proper physical resistance of that collision. Finally, the Samsung Gear VR headset will be used in conjunction with a Samsung phone to generate the display. A computer will serve as the link between the various components previously described. Due to the high performance requirements of this simulation, it is likely that a powerful computing server will be needed to perform the calculations required to create realistic physics properties in real time. This server would be called using the Samsung phone so the phone would need to use very little processing power.

V. Fabrication

Materials

Progress thus far in the simulation has been completely virtual. Solidworks, Blender and Unity were used to develop the operating room environment, and additional realism was added by incorporating medical props available for download at no charge on the internet.

Solidworks, downloaded for free from the UW Campus Software Library, was used to create the simulation's endotracheal tube. Blender, another free software, was used to reorient the virtual character's arms before importing them into Unity. A free version of the powerful game development platform was used to stitch together virtual components into a 3D environment.

A variety of other virtual objects were downloaded from the internet as well. A laryngoscope model and a pair of arms were downloaded for free. Similarly, the Morgue and DeKit assets were downloaded from the Unity Asset Store at no cost. These models were subsequently used to create the final prototype environment. A list of the downloaded files can be found in Appendix B.

Methods

We began constructing the virtual environment using Unity. The room itself was defined as an oblong rectangular prism, while its floor, walls, and ceiling were distinguished by altering their color. We provided the floor a tiled texture by repeatedly inserting small squares separated by thin gaps on all sides. Most props were simply imported, resized, and placed into the simulation as RigidBody entities. However, some props required more specific alterations.

The user's arms were first reoriented in Blender to more precisely replicate a first-person perspective. Once imported into Unity, the arms' orientation were made dependent on the camera's position, providing the impression that the arms belonged to the user. Rough hitboxes were defined around the arms to allow the user to interact with RigidBody items.

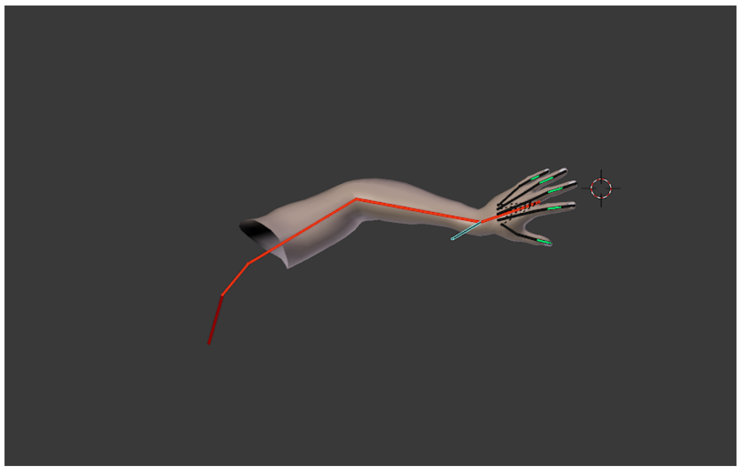

Figure 7: As downloaded, the arm was flexed, appearing slightly awkward and impractical.

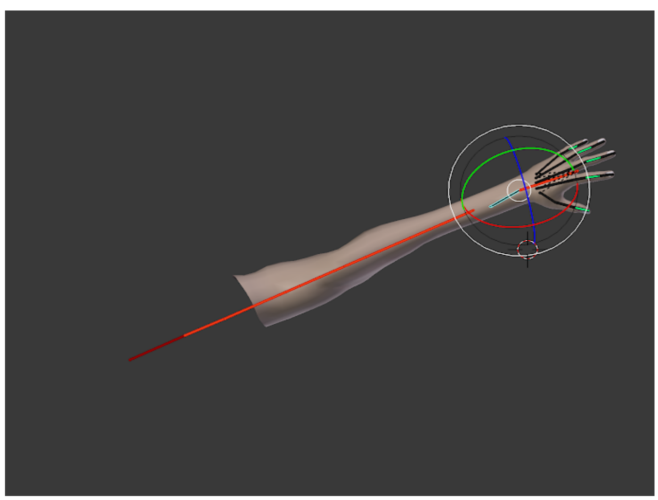

Figure 8: The modified arm model is extended, and more visible from a first-person point of view.

Rather than a RigidBody entity, the deformable sphere (Figure 9) was modelled as a series of vertices and springs. 386 vertices and 1964 springs were used. An arbitrary spring constant was experimentally derived to give the sphere deformable properties. Currently, the sphere is not intended to replicate any aspect of the procedure; it is simply intended to act as a foundation from which we create a semisolid comparable to the tissue found within the respiratory tract of a neonate.

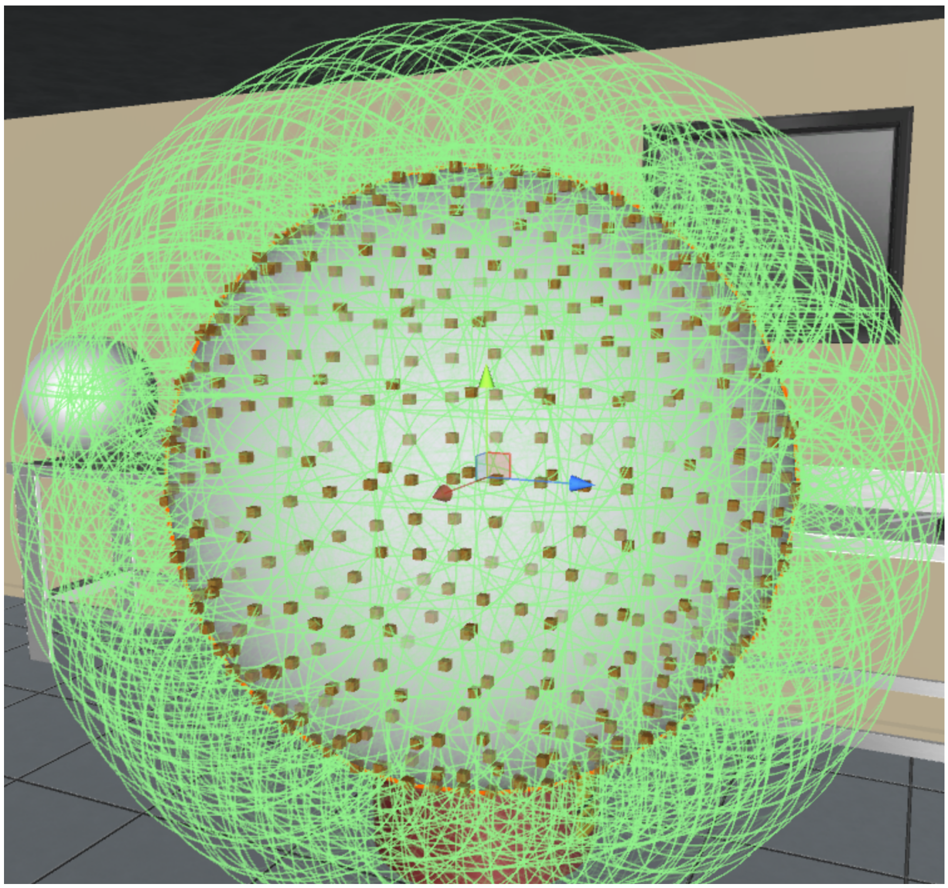

Figure 9: The deformable sphere, pictured above, is comprised of 386 vertices (brown squares) connected by a network of 1964 springs (green threads), whose stiffness can be altered by adjusting Unity's arbitrary spring constant value.

Final Prototype

The mock operating room (Figure 10) includes various props including an operating table, doors, lighting, laryngoscopes (Figure 11), an endotracheal tube (Figure 11), and a deformable sphere (Figure 12). The deformable sphere will be used as a basis for the soft tissue models that will be necessary to create a neonate with realistic textures. Additionally, the arms described above and pictured in Figures 10 and 12 are the main way the user interacts with the environment.

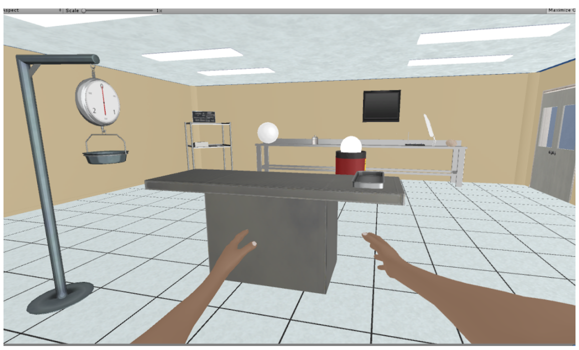

Figure 10: A first person view of the OR scene.

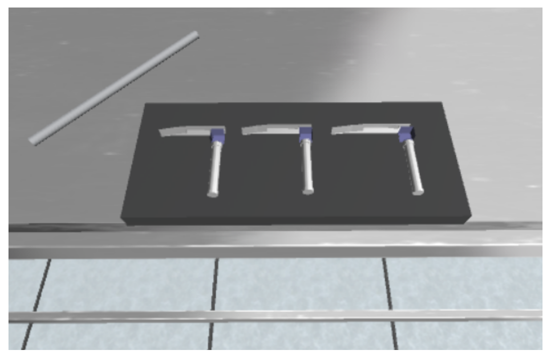

Figure 11 : Close up of models for the laryngoscopes and endotracheal tube within the OR scene.

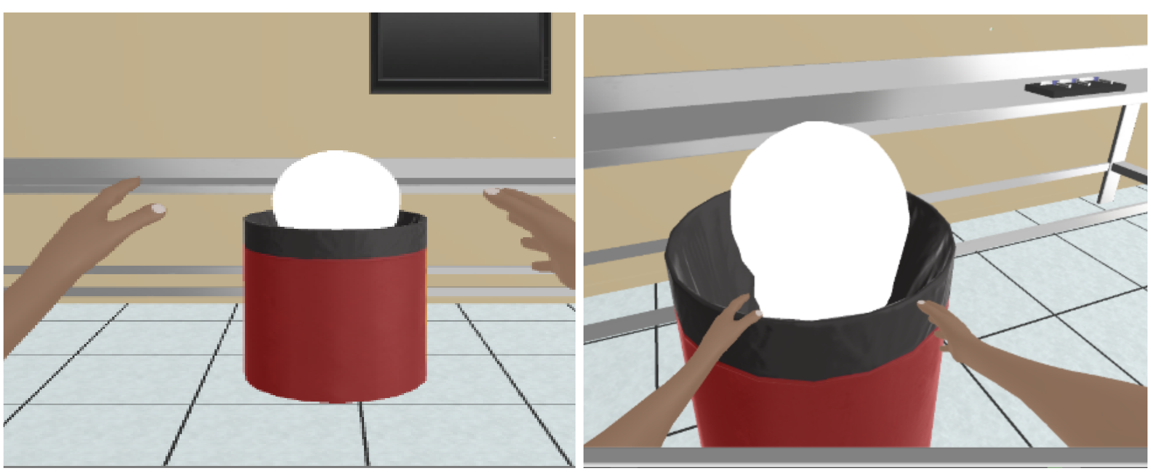

Figure 12: The deformable sphere before and after colliding with the hands.

Testing

Due to time constraints and limited development we were not able to perform testing on the system. Further, evaluating the effectiveness of the final design will be extremely difficult. Proper testing would include finalizing the design and creating a study which compares success rates between residents that had underwent classical intubation training or had been trained using the new system. While this is a future goal, a more realistic form of testing would involve evaluating how well the different components of the design emulate a real procedure. Assessment such as this would need to be done subjectively, and would likely involve recruiting volunteer physicians who had previously performed the procedure to rate the realism of the various components of the simulation. For example, a physician would be asked to rate how well the anatomy of the neonate emulates a real model, and how realistically the tissues deform. Further, as the project progresses we plan on getting input from our clients, Drs. Tomlin and McAdams, about ways to improve the simulation. By repeatedly implementing changes and reevaluating, we will be able to fine-tune the simulation.

VI. Discussion

A successful implementation of the proposed design would drastically change neonatal intubation training and likely spur development of other simulated surgeries. Even if effective, however, accessibility to such advanced training would be limited. Initially, this project was proposed as a means of reducing training costs by avoiding incredibly expensive neonatal mannequins as well as the need for instructor supervision in hopes to provide more widespread accessibility to virtual training while also increasing effectiveness. Upon further investigation, however, access to a relatively high level facility would likely be necessary to run such an advanced simulation. The simulation would require the purchase of the devices outlined previously, such as the haptic feedback devices, VR headset, virtual reality software, and the simulation itself. Most importantly, however, the individual would need access to a powerful server to interface with the system. As mentioned in the background, realistic tissue physics is much more advanced than what conventional VR software is capable of simulating. According to VR specialists Ross Tradnick and Kevin Ponto at the University of Wisconsin - Madison, in general, video game physics engines do not operate on lifelike physics models. The incorporation of non-affine transformation physics, in other words, deformable bodies, requires much more advanced physics engines which require extensive processing power. Thus, in order to simulate a high-resolution neonate with realistic physical properties in real time would require the incorporation of a highly advanced processor, most likely in the form of a server. The cost of a powerful server would greatly limit accessibility to VR medical simulations. While they could be accessible at most educational institutions, developing nations and rural areas would have limited access. Despite this, the simulation still has the potential to greatly increase medical training effectiveness and thus improve patient outcomes.

VII. Conclusion

Respiratory distress syndrome is a common disease experienced by neonates with remarkably poor clinical outcomes overall. High prevalence of RDS in neonates increases the need for more effective treatments, or alternatively, better training to increase success rates of widely used treatments. The development of a novel medical procedure simulation module which incorporates VR and haptic feedback could be highly beneficial for training effectiveness and thus, patient outcomes. It is also desirable that this system be inexpensive to increase training availability.

The final proposed system will incorporate a multitude of components including a VR headset, two haptic feedback devices, a Samsung phone, an external computer and likely, an external server. The Samsung phone will run the visual component of the virtual reality system and relay information to the computer. The haptic devices will operate in a similar fashion. The computer will subsequently rely on the external server to perform to bulk of the computer processing, and then respond to the haptic devices and phone. The virtual objects will be created using Solidworks and Blender, and virtual-physical properties will be attributed to objects using 3D Systems software. Finally, the virtual environment will be created in Unity after uploading the various objects.

The complex nature of the proposed system presents an abundance of obstacles that must be overcome. While it is impossible to foresee every challenge that we may face in the creation of the design, it is worth highlighting some of the more obvious limitations and impediments. Firstly, it will be difficult to design an accurate virtual model of a neonate's anatomy in Unity. As far as we know, there are no existing virtual models that are nearly as precise as those that this project will require. Thus, we will have to incorporate several submodels, and learn how to set appropriate physical relations between these models (e.g. if the tongue were to move in the virtual model, the rest of the neonate would need to remain stationary, not moving in the same direction as the tongue). If we are unable to find adequate existing anatomical models online, we can use Computer Tomography (CT) scan data as an alternative. By reconstructing the 3D data as a Unity-compatible file, we can import accurate neonatal anatomy directly into Unity, Solidworks and Blender for further refinement. CT scan data will be accessible with the help of our client, Dr. McAdams. An advantage of this approach is undoubtable anatomical accuracy, as the data will be coming from actual patients. Regardless, a downloadable model would be preferable because animating and modifying the CT data in Blender and Solidworks would be extremely difficult and time consuming.

Another barrier to success lies in the possible compatibility issues between the various software elements. While through preliminary evaluation it seems as if each software will be compatible, it is quite possible that updates in any of the various components could present further obstacles down the road.

The most daunting hurdle will likely be designating realistic physical properties to the virtual objects to ensure that the haptic force feedback feels natural. Not only are there limitations in the motor arms themselves, such as only being able to provide force feedback from a single point at any given time, but the computer-modeling of deformable bodies is an extremely high level topic. Given the team's level of expertise, we will need to incorporate existing soft-body physics algorithms in our design, rather than build them from scratch. Further, to successfully assign physical properties to objects we will need to create equations which explain how the tissue should deform when forces are applied to it. Extensive research and testing will need to be done to define those equations. Another long term goal is the introduction of multiple difficulty levels to the procedure. For example, by altering parameters such as the airway size, amount of neonatal head movement, or amount of fluid in the throat, the difficulty could be drastically altered.

Such a project is no easy task and will take time and effort. Moving forward we must conquer various aspects of the design in small increments. Next semester we plan on obtaining a haptic feedback device and developing viscoelastic models that more accurately reflect a neonate's soft tissues, in addition to outfitting our existing operating room with improved visuals and incorporating lifelike acoustics. If all goes well, we will have an interface between the simulation and haptic device which acts as a proof of concept design that the incorporation of all of the components is possible. The task at hand is tremendous, but represents the forefront of medical technology. In the coming years it is likely that VR technology will become more prevalent, and will be more easily implementable to increase physician training, lower costs, and ultimately, improve clinical outcomes.

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X. Appendix

A. Problem Design Specifications

Problem Statement

The client wishes to develop a virtual simulation environment that accurately models a neonatal intubation procedure. Tentatively, the client desires that a virtual environment be created which mimics the upper respiratory tract, throat, and mouth of a neonate. The virtual system should precisely emulate a clinical environment in order to function as a novel neonatal intubation training method for physicians. Furthermore, the virtual components should be integrated with a haptic feedback motor arm which pairs physical traits to the virtual objects, thus mimicking a clinical procedure with only the use of virtual reality and a portable haptic feedback device. Ultimately, this device should serve as a virtual, but effective, surgery training method.

Client Requirements:

- The virtual environment must accurately emulate the physical characteristics of an infant's tongue, larynx, trachea, and vocal cords to a degree of precision within the scope of a neonatal intubation procedure.
- A haptic interface must allow the user to provide manual inputs, to be visually represented precisely in a virtual environment. The interface must also register interactions in virtual space between the user's input and a preprogrammed objects, and relay these interactions back to the user via a haptic motor arm.
- The system must include a user-friendly software allowing changes in procedural specifications.

Design requirements:

1. Physical and Operational Characteristics

a. Performance requirements:

- The system must be constructed for use in both clinical and rural settings, demanding portability and durability.
- The system must be capable of running up to 25 full simulations per day.
- A virtual environment must be capable of simulating neonates in the range of 1-10 lbs.

b. Safety: Any electronic components must be enclosed within appropriate housing to minimize the risk of injury due to electric shock.

c. Accuracy and Reliability: The system must be accurate to .02 mm to compete with current haptic feedback systems and provide a realistic surgical environment.

d. Life in Service: The system must last at least 5 years with minimal maintenance.

e. Shelf Life: The device will be stored inside and will not be exposed to extreme weather conditions. It should not need maintenance while not in use.

f. Operating Environment: The system should be capable of operating in a variety of environments, including clinical and outdoor settings. The virtual simulation will be perfected by using feedback from expert neonatologists to accurately emulate a neonatal intubation procedure.

g. Ergonomics: The device should be intuitive to use and feel very similar to tools used during neonatal intubation such as the laryngoscope and endotracheal tube.

h. Size: The device must be small enough be carried around in a backpack or other case.

i. Weight: The device must weigh less than 40 lbs, light enough to be easily transported in a backpack or other case.

j. Materials: The system will be comprised of a pair of virtual reality goggles, a haptic feedback motor arm, and any computer hardware required to render the environment and power the system.

k. Aesthetics, Appearance, and Finish: The virtual reality should not be blurry. The user should be able to interact with the environment without noticeable buffering.

2. Production Characteristics

a. Quantity: One functional prototype will suffice for BME 301. Ultimately, however, the aim is to provide worldwide accessibility.

b. Target Product Cost: The device should cost under $5000.

3. Miscellaneous

a. Standards and Specifications: If successful, the device would require IRB and FDA approval to serve as a credible source of medical training.

b. Customer: The system will be used by training physicians who are practicing neonatal intubation procedures. Consequently, they will demand a realistic virtual environment with physical characteristics which accurately model a neonates anatomy and physiology.

c. Patient-related concerns: No concerns should arise from the use of this device as it will serve as an additional form of medical training, not an alternative to current training.

d. Competition: Competition exists among virtual reality platforms, but to our knowledge, there only exists a single haptic feedback system on the market currently, and there are no integrative VR and haptic feedback systems which are used for medical simulation.

B. Downloaded Files

Prop	Website name	Author	Filename	Link
Laryngoscope Blade	3D Warehouse	ProviderOfRandomStargateStuff	Laryngoscope	https://3dwarehouse.sketchup.com/model/515e8861e0f3c2bfdcd154f0c7575f7f/Laryngoscope
DefKit asset	Unity Asset Store	Dr. Korzen	DefKit	https://assetstore.unity.com/packages/tools/physics/defkit-50767
Morgue scene	Unity Asset Store	Rokay3D	Morgue Room PBR	https://assetstore.unity.com/packages/3d/enviroents/morgue-room-pbr-65817nm
Arms	Sketchfab	DavidFischer	First Person Hands Rigged	https://sketchfab.com/models/547a45535f0c4fe787948f7a7a6a88db

Table 3: Files that were downloaded and incorporated into the current prototype.

C. Estimated Costs

Material	Approximate Cost	Explanation	Link
Touch Haptic Device	$2200	This is an integral component to the simulation and one of these devices will need to be purchased for us to begin development.	N/A
Unity Plugins	$200	In order to develop a life like simulation we may need to purchase more advanced Unity plugins than the ones provided for free. It is impossible to definitively say whether we will need additional plugins, but it is definitely possible that we require more advanced tools as we progress. Functionalities that we may need plugins for include more advance soft-body physics plugins or possibly texture plugins to give provide more realistic texture to the neonate. Finally, if we do end up purchasing such plugins we may also need to buy a monthly Unity subscription ($30/month). Once again, it's not clear whether this will be required but it's worth mentioning.	One advanced soft body physics plugin can be found here: https://assetstore.unity.com/packages/tools/truss-physics-41801
3D Anatomical Models	$300	While we plan to create many of the anatomical features in Solidworks (and possibly by reconstructing CT images, there are a few features which we would definitely like to purchase due to their complexity. The most complex of which is the tongue. We think that it would be extremely difficult to create an accurate model of the tongue from scratch so we would prefer to use a pre-existing, accurate model. Further, we're not sure whether it will be easy to replicate the trachea and may want to purchase a model of that as well. Finally, we may wish to purchase a model of a newborn.	Layrynx ($99): https://www.cgstudio.com/3d-model/human-larynx-anatomy-4145 Tongue ($79): https://www.cgstudio.com/3d-model/human-larynx-anatomy-4145 Infant: https://www.cgstudio.com/3d-model/human-fetus-41-weeks-3ds-max-rigged-38479
	$2700		

Table 4: Estimated costs for simulation development for next semester.