Techniques for Simulating Data Visualization of the Digital Patient

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ABSTRACT

Volumetric rendering has become a reliable tool to perform image analysis and diagnostics. As the adoption of 3D medical imagery grew, enhancements were needed to increase the comprehension of patient conditions. We present an expansion upon existing methodologies for volumetric rendering. We provide a literature survey that describes existing algorithms and methods and highlights our contribution to the technology. Our approach combines the following techniques into a single gaming environment:

- Improved human anatomy representation with real-time manipulation of depth and shadows
- Simulation of x-ray appearance and density coloring for data visualization options
- Volumetric rendering within Virtual Reality (VR) for intuitive interaction with simulated patient data

This paper presents a study on the success of these combined techniques to better evaluate anomalies in medical data. Viewing medical data in VR empowered the observer with a better understanding of the data relationships. The digital patient could be inspected from all angles in relation to multiple scan types. This observation practice was computationally expensive; using VR to interact with rendered volumes increased the need for performance enhancements. Our approach addresses optimization methods necessary to perform the listed techniques and maintain framerates to provide a quality user experience. To effectively examine our approach, a use case study was performed. Our study used a rare variation of a coronary anomaly, specifically a coronary anomalous origin of the left circumflex artery as an independent branch from the right coronary cusp, because it is understood to be historically challenging to visualize and analyze using traditional methods. Healthcare professionals trained in medical imaging analyzed and interpreted images of patients affected by the condition. They performed this analysis with and without our methods. The results were used to showcase the potential diagnostic benefits of our volume rendering workflow for medical modeling and simulation. Our approach presents methods that can also be adapted to create visual representations of non-destructive testing and evaluation data for weapons systems that has been captured with computed tomography (CT) imaging scanners. The healthcare community is embracing digital patient methodology as an effective means to engage with patients' medical history and concerns. These advancements in VR training simulations also hold the potential to be reimagined for medical emergency scenarios relevant to the Department of Defense (DoD). By leveraging the principles and tools developed in this research, DoD personnel can benefit from immersive and realistic training experiences tailored to their specific medical contexts, fostering enhanced preparedness and response capabilities.

ABOUT THE AUTHORS

Ms. Liv Weaver is a Technical Artist and Software Engineer at Intuitive Research and Technology Corporation. She is responsible for developing complex data visualizations, interactive mixed reality experience prototypes, and technology demonstrators. She attended the School of the Art Institute of Chicago and recently graduated from the University of Alabama in Huntsville with a BS in Computer Science with a minor in Game Design.

Ms. Harleigh Bass is a Technical Artist at Intuitive Research and Technology Corporation. As a member of the research and development team, she is responsible for creating and implementing both the designs and functionality of technology demonstrators, web applications, and data visualizations. She earned a BFA in Digital Animation at the University of Alabama in Huntsville with minors in Computer Languages and Systems and in Game Design.

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INTRODUCTION

Simulation innovation is in high demand for medical diagnostics. As healthcare practices become more complex and technology continues to advance, there is an increasing need for the benefits offered by medical simulations. These simulations, ranging from VR training modules to sophisticated surgical simulators, provide healthcare professionals with safe and controlled environments to practice and refine their skills. As medical procedures become more specialized, simulations offer an invaluable platform for training physicians and healthcare teams in intricate procedures without risking patient well-being. The incorporation of simulation technologies allows for the exploration and evaluation of novel medical techniques before their implementation in real-world scenarios.

As a result of increased simulation adoption, the demand for digital patient innovation grows. A digital patient, also known as a virtual patient or digital twin, is a simulation comprised of an individual's medical history, likeness, and health conditions. This concept has the potential to shape the future of medical education, training, and patient care as a dynamic resource for treatment planning, diagnosis, and imaging analysis. One of the many methods used to create a digital patient is called volume rendering. This technique has a rich history for conducting image analysis and diagnostics on Two-Dimensional (2D) sequential images. Using volume rendering, medical professionals can visualize and analyze Three-Dimensional (3D) medical imagery such as CT and Magnetic Resonance Imaging (MRI) to aid in the accurate identification and assessment of various medical conditions.

We present an enhanced approach to existing methodologies of volumetric rendering for medical imaging by integrating different simulation techniques to vitalize the depiction of the digital patient. These techniques are observed within VR to provide intuitive interaction with the simulated patient data. We improve upon traditional human anatomy representation with real-time manipulation of depth and shadows. This is achieved with a dynamic lighting tool that affects the rendered volume. We also provide a simulated 3D x-ray visual representation, and we incorporate various density-based coloring options as data visualization alternatives.

By integrating these visualization options, simulations can be built with more complexity. Increased realism and interaction with a simulated patient enhance the effectiveness of medical trainers and tools for surgical planning and diagnosis. Currently, our research is in support of furthering innovation for radiology training, but we believe there are many other applications where simulation techniques could be further explored, such as commercial or Department of Defense military training and data analysis operations. Virtual simulations can be used to train nursing students and military medical staff in a variety of critical care responses. Studies have rendered hostile battle fields where users had to quickly identify risks and determine best-case responses (Mao & Chen, 2019). These studies show how immersive simulations can provide ample exposure to complex scenarios, increase a user's competence to handle them, and reduce risk of failure in real-world applications.

This paper presents a study to investigate the effectiveness of these combined simulation techniques to better evaluate anomalies in patient medical data. Our approach will enhance the physician's experience of diagnosis and comprehension of patient conditions by providing a digital 3D representation of the patient within VR.

PRIOR RESEARCH

Volume Rendering

Volume rendering is a well-established technique for visualizing 3D materials and creating visual effects. Unlike in 3D polygon rendering where models are hollow, volume rendering supplies the interior elements of a model, taking into consideration how they would look and interact with light. This inner data consists of volume elements, or voxels, that hold location and other data values to describe the object they represent. Drebin et al. (1988) from Pixar present one of the earliest applications of volume rendering improvements with the use of color and opacity. Their method allows colorization of both the interior of a material and the boundary between them to aid comprehension of the rendered material's composition, where previous methods had only rendered their shared boundaries.

Volumetric Modeling for Healthcare

Volume rendering is used to generate atmospheric effects like clouds as well as organic shapes with curved surfaces and interiors. Volume rendering is ideal for creating digital models of patient anatomy in healthcare due to the human body's complex curved surfaces and interiors. To render a digital model, 2D scans are re-constructed into 3D volumetric models that represent a patient. The healthcare domain has many applications for 2D and 3D visualizations of patient data. The radiologist must navigate, inspect, and review the [generally] 2D images to make a diagnosis; while the surgeon can use 3D models of the patient and the associated pathology to plan treatment (Zhang et al., 2011). The surgical team and referring physicians can also use generated 3D models to explain the anatomy, pathology, and treatment plan to non-medically trained stakeholders; this includes the patient and caregivers. Changing protocols from viewing standard 2D orthogonal slices in the axial, sagittal, and coronal views to viewing 3D volumetric models may enhance radiologists' and surgeons' performance in diagnosis and treatment. Perandini et al. (2010) postulate that the use of volume rendering may aid in diagnosis of several common conditions or circumstances including subtle lumen thrombosis, airways stenosis, post-surgery changes, exophytic cancer of hollow organs, and even traumatic disorders.

Enhancement and adoption of 3D visualization algorithms are encouraging the rendering method to migrate from research environments to clinical practice. In parallel, the increasing capabilities of CT and MRI scanners to acquire patient volumetric data with better resolution, contrast, and algorithmic reconstruction are fueling the improvement of the rendering algorithms themselves. Volume rendering has numerous related algorithms, each with its own pros and cons for image quality, rendering speed, and computational expense. Two popular visualization techniques are maximum intensity projection (MIP) and 3D volume rendering (Duran et al., 2019). These methods can be applied to medical imaging data obtained from CT, MRI, ultrasound (US), and positron emission tomography (PET). Weaver and Marx (2022) present a combination of applications with volume rendering to improve comprehension of patient conditions including a method for fusion rendering of CT and PET data to allow simultaneous viewing of both data sets on a co-registered 3D digital patient.

Virtual Reality for Healthcare

Though VR systems and applications are popular for gaming purposes, they also benefit other domains including simulation, military procedural training, and healthcare. VR healthcare applications continue to grow with rapidly expanding product lines from major hardware manufactures. Coupled with increased system performance in terms of resolutions and frame rate, these strides provide an excellent development opportunity for 3D digital patient models. VR systems provide an innovative means to communicate patient anatomy and pathology to stakeholders across the healthcare ecosystem. With the immersion of a learner in a virtual world, VR can provide a higher level of learning, comprehension, and knowledge retention compared to the use of traditional textbooks or online learning methods for examination of the human body. Advances in capabilities of medical scanners, rendering methods, and VR presentations is increasing evaluation and adoption of VR technologies in medicine. Early uses of VR in healthcare were focused on patient-as-user application; but the advancing era of VR and Augmented Reality (AR) technology provides an opportunity for wider adoption of clinician-as-user application (Sutherland et al., 2019).

VR systems are also being developed for medical training applications. Samadbeik et al. (2018) present results of a study showing how VR can improve training for different medical trainees. Their research demonstrated that VR improved both learning and accuracy for professionals and students of medical sciences. O'Connor et al. (2020) also present results of a study that allows students to develop their clinical skills in a safe [simulated, digital] environment. Their work indicated that most respondents (58%) reported enjoying the VR simulation experience and 94% percent would recommend the system to other students. O'Connor et al. (2021) results quantify the benefits of simulation-

based learning on students preparing for medical practice. They present that VR-trained students performed significantly better than the control group in several criteria including positioning patients for x-rays, selecting exposure factors, image appraisal of patient positioning and image appraisal of image quality. Their comprehension of clinical indications, equipment set up, and explanation of the procedure was also significantly better.

Specific Use Cases

Mastering the ability to mentally transform a set of 2D images into a single 3D representation of the patient poses a significant challenge in the field of radiology. This task increases in difficulty when dealing with small structures that curve through multiple planes and reside within close proximity to areas of similar density. This expertise aids understanding of anatomical relationships and offers insights into pathological processes. While the analysis and interpretation of 2D Digital Imaging and Communications in Medicine (DICOM) images are sufficient for most patient conditions and pathologies, certain diagnostic scenarios can greatly benefit from the utilization of 3D data visualization, models, and VR presentations. Some use cases include breast cancers, with tumors and tendrils that extend into surrounding tissues. They also include relatively rare conditions such as Chiari malformations, in which brain tissue extends into the spinal canal. Certain regions that are a complex, interwoven musculature structure, such as the pelvis and organs that have intricate 3D anatomical structures, such as coronary arteries, can also benefit from this technology.

Upon the detection of these anomalies, effective communication of their presence with both the patient and their medical team becomes imperative. Medical imaging provides a straightforward method of communication with patients about these types of conditions. Computed tomography angiography (CTA) for cardiac imaging has gained traction for triaging of patients with chest symptoms. This imaging modality distinguishes individuals that would benefit from invasive coronary angiography, commonly referred to as a "heart cath," and those who would not. Due to the increase in imaging utilization, the once rarely seen anatomical variation has become a common occurrence. Coronary artery anomalies involve small vessels next to other vessels of similar attenuation and take unusual courses to their destinations. This type of anomaly occurs when the left circumflex coronary artery arises from a separate ostium on the right coronary cusp of the aortic valve instead of as a branch vessel from the left main coronary artery. Even though this particular anomaly is considered benign, meaning patients with this variation are at no increased risk of health issues than the standard population, it is still important to be aware of its presence for procedure planning and patient education. Demonstrating the left circumflex artery within a CTA image of the heart is more efficient and practical than verbally conveying its precise location, its relationships with other structures, and where it ends. Performing post-processing of original images to generate a 3D comprehensive depiction of the relevant anatomy can significantly augment the overall comprehension of the digital patient and their health concerns.

Simulation technology and 3D visualization of digital patients also prove valuable for cross-utilizing imaging modalities. The term "medical imaging modality" includes techniques like CT scans, angiographies, and electrocardiographs, among others. A common and cost-efficient cross-utilization of imaging modality is the use of MRI to evaluate the lumbar spine instead of relying on CT scans. No single imaging method stands out as the definitive choice for assessing spinal conditions. In general, CT scans are better than MRIs for scanning dense structure such as bones. However, CTs expose patients to a small dose of radiation while MRI scans do not. MRI is preferred for diagnosing soft tissue and spinal ligament pathologies as it excels in discerning various components like ligaments, tendons, and muscles related to shoulder or knee injuries. MRI of the lumbar spine is unique in that it provides insight into the cauda equina, commonly referred to as the nerve roots. They provide sensation and motor control to the pelvis and lower extremities throughout the body. Employing volumetric rendering has the potential to utilize the generated data from MRI scans for evaluation of structures like the nerve roots, instead of relying on a CT scan.

OUR RESEARCH

This paper presents a comprehensive study aimed at examining the efficacy of utilizing integrated simulation techniques to enhance the evaluation of anomalies in patient medical data. The proposed approach endeavors to augment physicians' diagnostic capabilities by simulating a VR-based digital 3D representation of the patient to enrich their diagnostic experience. This study is completed with two specific use cases – a coronary artery anomaly and the condition and cross-over application of MRI to evaluate the spine.

Volume Rendering

For visualizing medical data within VR, our proposed methodology uses a ray marching-based algorithm. Ray marching is an image-oriented technique that establishes a correspondence between each pixel in the dataset and a ray within the virtual scene. The process begins with the emission of a ray into the scene designated for volume rendering. Incremental advancement along the ray path facilitates the sampling of density values within the 3D spatial coordinates. These coordinates are derived from the patient dataset which enables an accurate depiction of density at specific sampled positions. Using the sampled density value, we can then set the pixel color and opacity of that portion within the resultant volume. This is known as a transfer function- where a density value can be highlighted and mapped on a scale. In our practice, we employ transfer functions to establish a direct correlation between high density values and high opacity levels. The inverse relationship is computed for low density values. This approach enables the rendering and accentuation of regions with high density, such as bone structures, while simultaneously excluding the rendering of vacant air spaces, such as the interior of the lungs. Using transparency to omit empty scan areas allows the viewer to examine detail within hollows, holes, and cavities of scans.

Consider the 2D sagittal scan (left) provided in Figure 1. This image depicts a sagittal slice of a cranial volumetric. The dark gray pixels represent vacant air spaces surrounding the skull. The elimination of vacant air spaces (right) enhances the visibility of the silhouette and cavity edges in the digital patient. This outcome is accomplished by employing density mapping to eliminate low-density pixel values that might otherwise obscure critical visual patient data. Pixels that are black are returned with an opacity of zero whereas pixels that are white are returned with an opacity of one. These pixels are then assigned a color value using a color scale to map higher density tissues like bone to white and lower density tissues like organs and skin to reds and burgundies. Many color maps used for volumetric rendering are non-perceptual which can introduce bias. To enhance the rendered volume, improve perception of the medical data, and avoid introducing bias, we employ a color mapping method provided by Silverstein et al. (2008) to delineate between the four main regions of air, fat, tissue, and bone. This produces an anatomically realistic base color.

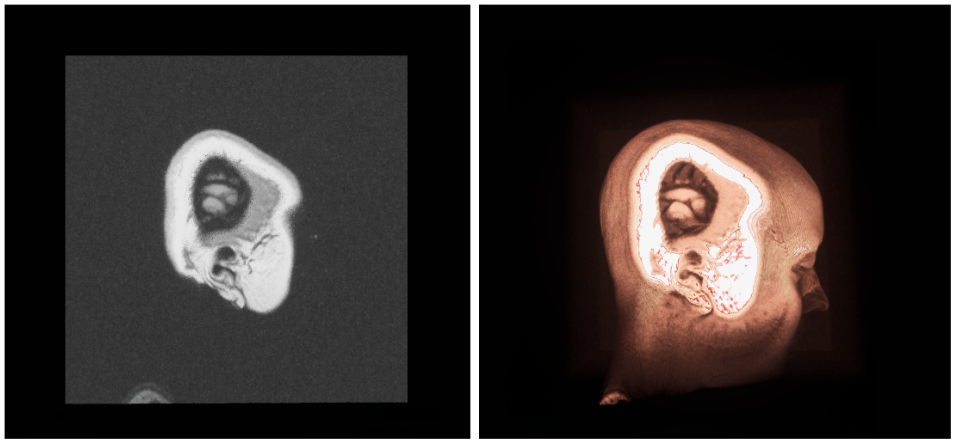

Figure 1. A 2D grayscale sagittal CT scan of a cranium (left) juxtaposed with a 3D render of a cranium (right) with our methods of density coloring and dynamic lighting applied in VR. Dataset was obtained from The UCLA Brain Mapping Center. (UCLA, 2020).

The quality of the resulting render with a ray marching approach is fundamentally dependent on the quality of the input data (Fishman, 1987). Other volume rendering methods can improve the appearance of realism by approximating pixels to add smoothing effects. Though these methods achieve results, they do not uphold the integrity of the patient's input data. Our approach maintains the original fidelity and makes usage of transparency, coloring, and a dynamic light vector to enhance the appearance of depth and realistic patient simulation.

Data Visualization Techniques

To further improve human anatomy representation, we present an interactive dynamic light. We have utilized a light vector to allow for real-time manipulation of depth and shadows. This provides an interactive examination experience within VR. The volume receives an input lighting angle as a vector from a tool the user can manipulate. The user can

interact with the tool to dynamically change shadows and lighting of the volume to examine depressions in real-time. Figure 2 depicts the same set of sagittal cranial scans as Figure 1 from a different viewing angle. The underlit volume (left) allows the user to see details within the brain tissues that are enhanced from the dynamic shadows. The top lit volume (right) highlights the skin, top of the cranium, and allows for closer observation of the eyelids and nose. As the lighting angle is changed in real-time, details within the volume become more apparent and the user can manipulate the light vector to enhance their areas of interest. The combination of improved depiction of depth with transparency and a dynamic light creates a powerful tool for users to interact within VR.

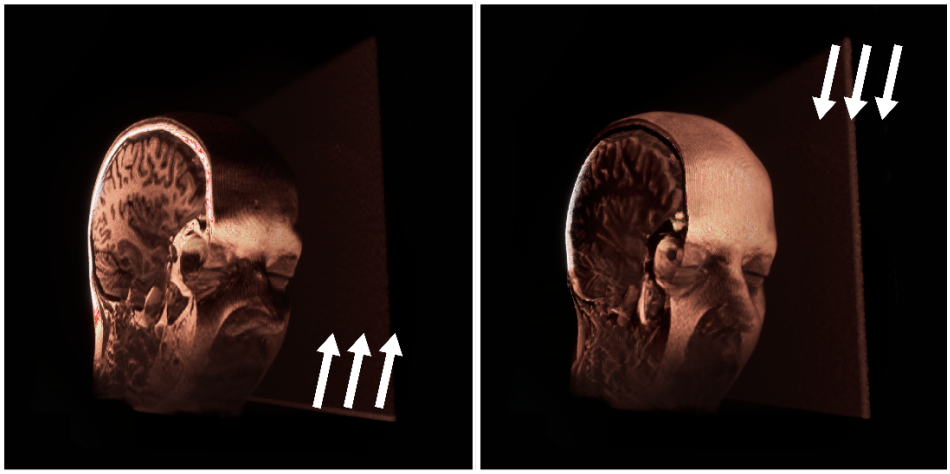

Figure 2. A 3D volume of a sagittal CT cranium with our data visualization techniques applied. The volume is lit below (left) and lit from above (right). Dataset was obtained from The UCLA Brain Mapping Center. (UCLA, 2020).

We provide another data visualization option for rendering patient data in the form of x-ray simulation. This simulation improves the delineation of soft and hard tissue densities by rendering the volume to resemble an x-ray in 3D space. Radiological scans lend themselves well to this simulation as they are grayscale in nature. These scans color the input data correspondingly with the highest density value pixels closest to white and lowest value pixels closest to black. By combining these grayscale scans with an accumulated density rendering method, we can mimic the appearance of x-ray imagery. To achieve this appearance, a ray is marched through the volume for each screen space pixel. For each step of the ray march, the density of the scan is evaluated, scaled by the size of each step, and accumulated for each voxel of the scan hit until the ray exits the volume. This method results in a volume that contains distinct high-density areas that are bright white and opaque along with low-density areas that are dark and more transparent. The resulting calculated translucency presents a new technique for examination of many radiology scans at once as the viewer can see within the volume through each semi-transparent scan. Figure 3 depicts a volume render of a torso in grayscale (left) and using our 3D x-ray simulation method (right). The grayscale render only visualizes the surface of the volumetric at a glance. The x-ray simulation allows the viewer to scrutinize data within the volume and on the volume's surface simultaneously. The x-ray simulation allows viewers to better understand the visual data's density and find anomalies in sequential data with new perspective. The added improvement of accumulated density within the ray march and resulting translucency allows for increased efficacy in evaluating irregularities like hair-line fractures, tumors, and tissue scarring.

Virtual Reality

To enhance depth perception, our visualization techniques are deployed in a VR environment. This allows examination of the digital patient from all angles and control over lighting and shadows in real-time using VR controllers. For the best quality immersive experience, VR applications require the maintenance of high frame rates. Because volume rendering techniques can be computationally expensive, optimizations must be performed for both methodologies to coincide. To ensure high performance for VR, optimizations are made to minimize texture samples and maximize their utility. Maintaining a framerate above 90 frames per second is crucial to avoid poor user experiences and motion sickness caused by low frame rates. We reduce sampling operations and provide multiple dimensions of data from

medical imagery like CT and MRI by encoded data into different channels of a single texture. This approach enables dynamic fusion of multiple data sources while maintaining the required high framerate for VR.

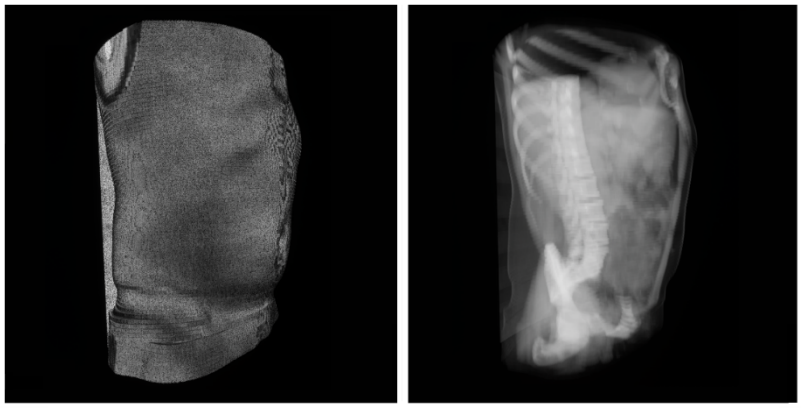

Figure 3. Volume rendering of a torso of axial grayscale CT scans (left) juxtaposed with our proposed method of volume rendering with stylization to resemble a3D x-ray. The results shown here are in whole or part based upon data generated by the TCGA Research Network: http://cancergenome.nih.gov/ (Roche, 2016).

Figure 4. Chase Mitchell, M.D. participating in our use case study by examining a coronary anomaly in VR using our method of 3D data visualization of a digital patient.

APPROACH

The objective of our study is to investigate how the use of our combined simulation techniques can improve the assessment of irregularities and anomalies in patient medical data. Our method strives to enhance a physician's diagnostic abilities by creating a VR-based digital 3D model of the patient, thereby enriching their diagnostic experience. To conduct this study, two use cases were identified as a preliminary step. These include a coronary artery anomaly and the condition and cross-over application of MRI to evaluate the spine. Datasets pertaining to these two use cases were obtained through the acquisition of patient consent via informed consent forms. A local radiologist, Dr. Chase Mitchell, was contacted to serve as the data evaluator for the study. In consideration of the limited scale of the study and datasets, the decision was made to involve a single radiologist for the completion of the evaluation. To conduct the experiment and gather quantitative data, formative evaluation questionnaires were developed, drawing inspiration from existing radiology workflows. The intention behind these questionnaires was to closely resemble the

assessment process typically followed by radiologists when evaluating datasets. Considering that Dr. Mitchell was exposed to the datasets within a VR environment for the first time, a sufficient duration was allotted to familiarize himself with the technology. Consequently, the experiment was not subjected to a time limit, facilitating a comprehensive exploration of the datasets.

While in the VR headset, Dr. Mitchell viewed each dataset in our x-ray simulation and density coloring data visualization options. He interacted with the dynamic light vector to manipulate the lighting and shadows of digital patient representations in real-time and answered our formative evaluation questions on a scale of 1 to 5. The hardware used to support our visualization methods is listed as follows:

Table 1. Hardware Specifications

Memory: 16 GB	VR Headset: VIVE Pro 2	VR Controllers: VIVE Controllers
Graphics: NVIDIA® GeForce® RTX 2070	Storage: 160GB of free storage space	Processor: AMD Ryzen™ 5 3600

RESULTS

Our formative evaluation questionnaire consisted of three survey questions that were asked for each anatomical structure within the MRI spine and coronary anomaly use case studies. These include:

1. Can you easily analyze the anatomical structure in the 2D representation (answer on scale of 1 to 5)?
2. Can you easily analyze the anatomical structure in the 3D representation (answer on scale of 1 to 5)?
3. Does the 3D representation help you analyze the anatomical structure (answer on scale of 1 to 5)?

Question 1 is meant to serve as a baseline to evaluate the overall visual quality of the input dataset. If the anatomical structure in the initial 2D capture was challenging to identify, the difficulty carried over to its 3D representation due to the quality of the input data. Question 2 gathers insight to compare the ease of identification of anatomical structures in the 3D simulation with that of the 2D scans. Question 3 inquires whether the 3D volume helped Dr. Mitchell in his analysis of the digital patient. This question is meant to analyze if the 3D simulation enhanced his ability to understand and evaluate the anatomical structures and anomalies.

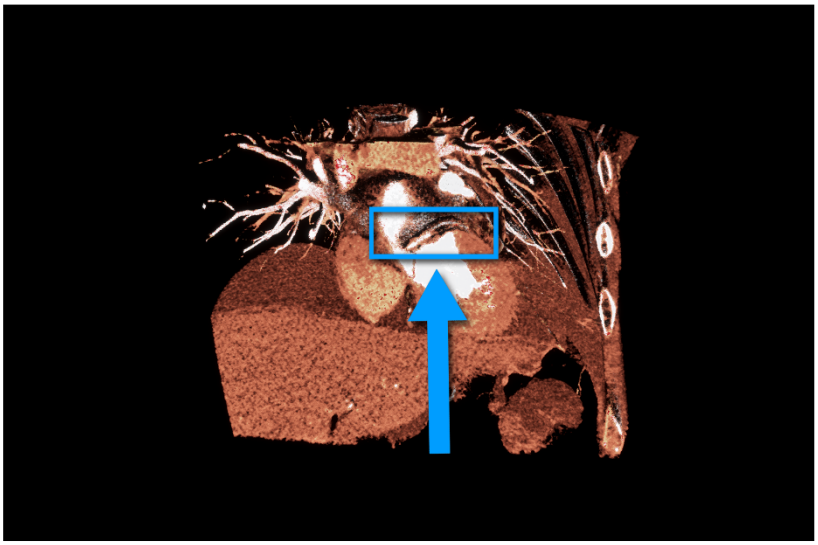

Figure 5. Volumetric render of coronary anomaly CT data using our 3D visualization techniques. The left circumflex coronary artery is clearly visible (in box).

During the spine use case study to evaluate cross-utility of imaging modalities, Dr. Mitchell was able to easily identify each of the anatomical structures selected for the study in both the native 2D scans and the 3D volume. These elements

were bones, soft tissues, ligaments, intervertebral discs, the neuroforamen (where the spinal nerve exits the spinal column), and the spinal cord and cauda equina. Larger elements, such as bones, ligaments, and soft tissue, were the easiest to see in the scans, so the 3D model was not needed to understand the digital patient's anatomical structure. In the smaller elements, such as the spinal cord, intervertebral discs, and neuroforamen, the model's functionality was somewhat useful in identifying their structure and overall condition.

The coronary use case study had a wider variety of results, primarily due to the condition of the 2D scans. Technical factors such as exposure settings, tube current or voltage, or errors in the image acquisition process can lead to some loss of image detail and a washed-out or overexposed appearance. We believe this greatly affected the results of our study. The scan set's injection duration and scan delay were configured to focus on the great vessels and main arteries, which were clearly visible in both the 2D scans and 3D volume. Other areas, such as the cardiac values and inner chambers, were either barely identifiable or slightly obscured by the brightness intensity. It took much more time to identify their overall forms. For the structures that were visible in the 2D scans, the 3D volume was helpful in clarifying the patient's structure. For smaller details, like the patient's coronary arteries and lymphatic vessels, the 3D model greatly augmented the radiologist's ability to understand the patient's data and track the smaller anatomical structures. This also held true for the great vessels of the heart. The results of these use cases are displayed in Figure 6.

Overall, the 3D representation of the digital patient amplified the radiologist's ability to evaluate different anomalies in patient medical data, especially in relation to smaller anatomical details commonly difficult to view with traditional 2D scans alone. This is best seen with the results of the coronary use case study, which features a rare, hard to identify anomaly of the left circumflex artery, depicted in Figure 5. The 3D model was able to display the arteries for the radiologist to interact with, fully supported with manipulatable lighting, shadows, and model rotation to get the most optimal viewing angles. The volume render can also be visualized with x-ray simulation and different density coloring options to help the radiologist understand the patient's overall composition and medical needs. These simulation techniques aim to provide a more comprehensive view of the digital patient. With more information at the radiologist's fingertips, the volume render provides more options for treatment, surgical planning, and more precise diagnosis of other medical anomalies.

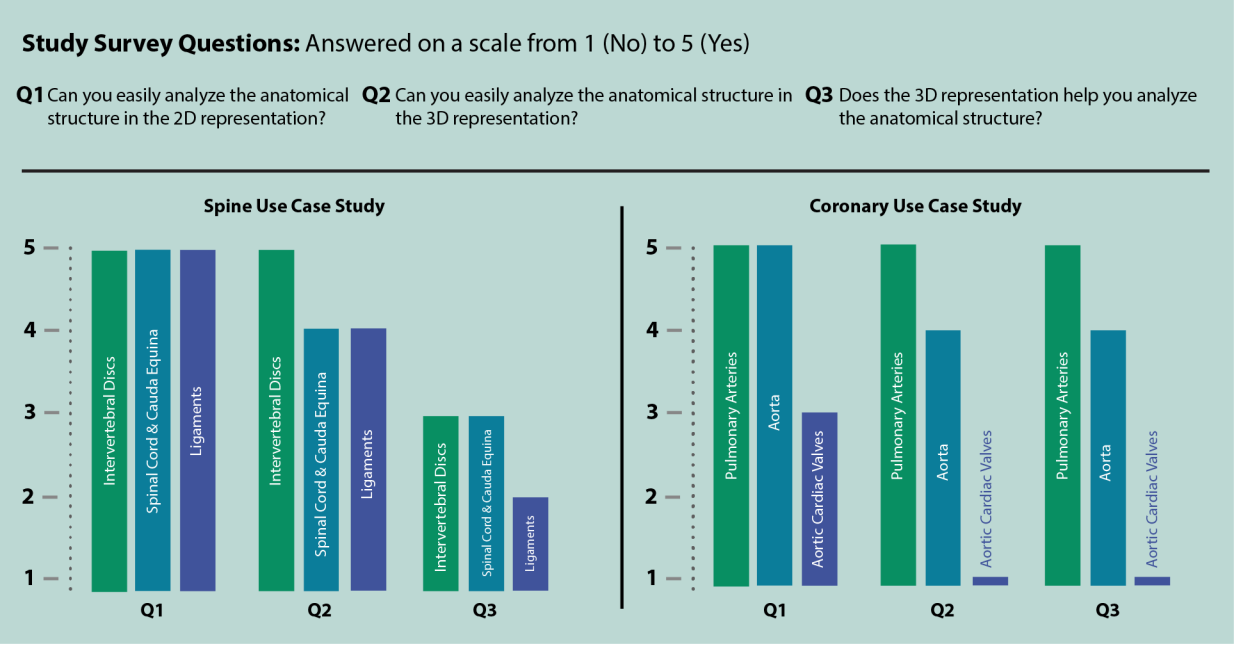

Figure 6. Bar graphs from our spine and coronary use case studies. These graphs depict results from formative evaluation questionnaires.

CONCLUSIONS AND FUTURE WORK

We present a study that explores the effectiveness of enhanced volumetric rendering techniques for analyzing medical anomalies in digital patient representations. This study was performed within a VR environment to provide intuitive interaction with the simulated patient data. A radiologist evaluated use cases to determine the efficacy of our 3D representation methods of the digital patient.

Volume rendering can help visualize small details that are difficult to track on 2D scans, like veins, lymphatic tubes, and lesions. These structures are highly dependent on the viewer to follow their shape throughout the images, where they may fade or be obscured by other objects. Volume rendering has been shown to identify smaller elements, like pulmonary nodules and coronary artery fistulas, quickly and accurately more often than its 2D counterpart, as described in studies by Lim et al. (2014) and Perandini et al. (2010). Our approach looks to enhance patient data analysis in a similar way by providing a more comprehensive view of the patient. This is supported with real-time depth and shadows that affect the volume with lighting and rotation, an x-ray simulation, and density-based coloring methods. Physicians and radiologists can use these simulation techniques to better detect patient anomalies and gain insight into treatment and surgical options.

The findings of our research demonstrated that the integration of a 3D digital patient representation yielded notable advancements in the examination of patient data. The depiction of large structures, including bone and soft tissues, exhibited a moderate enhancement, whereas small intricate structures, such as arteries, experienced significant improvements through its utilization. In our investigation, we employed a coronary use case study to acquire a scan set aimed at assessing the aorta and coronary arteries. However, the loss of image detail due to overexposure of other cardiac structures hindered some structures for evaluation. We theorize that employing an alternative combination of contrast medium and scan delay would have enhanced the visibility of the scans.

When 2D medical scans appear overexposed or underexposed, radiologists have the option to adjust their brightness and contrast. The inclusion of this functionality stands as a key objective for our future work. Upon integration into the software solution, end-users will have the capability to create the more optimal viewing conditions with contrast adjustments. This addition will mitigate some of the challenges the radiologist faced when observing the brighter scan data. Future studies can also evaluate a variety of ordered scans that differ in focus. This will allow for investigation of 2D-to-3D pipelines within the imaging software domain, wherein the optimal amalgamation of injection durations, scan delays, and scan foci for constructing an interactive digital patient can be comprehensively examined. Many sectors can benefit from innovation in 3D data visualization and representation. These include education, commercial industry, DoD applications, training simulations, product analysis of internal structure, and fast prototyping.

In conclusion, innovations for data visualization and realistic simulation offer a means to produce heightened immersion and realism in training scenarios, while concurrently enabling the evaluation of product flaws prior to their production or field deployment. Our primary objective is to employ a volumetric rendering approach that facilitates the creation of all-encompassing 3D representations of data, empowering users with direct support for their analysis and planning methodologies.

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