

Design, Development, and Evaluation of a Novel Device for Visualization of Volumetric Medical Images

Paria Alipour⁽¹⁾, Bryan Palogan⁽²⁾, Leslie Simms⁽²⁾, Sumit Laha⁽³⁾, Ulas Bagci⁽³⁾, and Sang-Eun Song⁽²⁾

Interventional Robotics Lab (IRL)
Department of Mechanical and Materials Engineering
University of Central Florida

(1) Department of Biology, University of Central Florida, Orlando, Florida

(2) Department of Mechanical and Materials Engineering, University of Central Florida, Orlando, Florida

(3) Department of Computer Science and Engineering, University of Central Florida, Orlando, Florida

paria@knights.ucf.edu, bryanpa@knights.ucf.edu, leslie.simms.44@Knights.ucf.edu, sumitlaha@Knights.ucf.edu,
bagci@ucf.edu, s.song@ucf.edu

ABSTRACT

The proposed device offers virtual slicing of medical images with realistic spatial operation, boosts intuition and interaction, and enables users to view an anatomical target from any angle. The user holds the two handles of a monitor on each side and sweeps it through a virtual human body to view from the desired angle. The monitor is mounted on an encoded counter-balanced arm, which is movable with minimum effort through the human body volume. The encoders trace the position of the monitor which is used to compute the cross-sectional view. Our system generated cross-sectional views as the user moved the monitor within the defined workspace. The computed slices then are visualized on the Graphical User Interface. This device could enhance current digital education and radiology reading techniques by providing a practical and engaging tool to visualize the hidden features of a human body. Widespread adoption of 3D visualization techniques to observe medical images such as MRI scans will result in more accurate and detailed diagnosis techniques, as well as a more informative and resourceful academic environment.

INTRODUCTION

Medical imaging is ubiquitous in medical diagnosis, cancer detection, and pre- and intra-operative intervention planning. Whether the images come from Computed Tomography (CT) or Magnetic Resonance Imaging (MRI), visualization is the vital interface which reveals the internal structure of human body. Thus, visualization of medical images for end-users is of interest. To this end, various novel visualization techniques and new processing algorithms have been created.

The vision of this work is to develop an easy-to-use device for 3D visualization of volumetric medical images. Other

devices for this purpose have been introduced but they mainly suffer from complexity such that even a trained user has difficulty to operate those devices. In addition to the complexity of the use, such systems are complicated in terms of design and development. Furthermore, they are not technologically mature enough to be employed in serious scenarios such as operation rooms or clinical settings. Moreover, most of the existing technologies are purely virtual, while an augmented system might outperform as it physically engages the user.

Related Work. The introduction of computed tomography has significantly impacted diagnostic radiology. Radiologists use X-ray, MRIs, and CT scans for diagnosis in emergencies (e.g. intracranial hemorrhage, etc.) as well as detecting and locating tumors in prostate [1], breast [2], colorectal [3], liver [4] and the brain [5]. In the US alone, over 70 millions CT scans are performed annually [6].

MRIs have especially gained popularity as they do not expose the subject to ionizing radiation as opposed to CT scans, while providing excellent soft-tissue contrast and resolution, allowing precise quantification of health and risk assessments [7]. To date, many studies have utilized medical imaging for noninvasive diagnosis, including but not limited to, investigation of gastrointestinal dysfunctions [8], transperineal prostate biopsy [9], evaluation of patients with suspected adnexal masses in ovarian cancer [10], ultrasound and magnetic resonance transient elastography for liver fibrosis [4]. Medical imaging is also used for surgical simulation and planning [11], [12].

Similarly, visualization of 3D medical images is prerequisite for many procedures. 3D Slicer (www.slicer.org), for instance, is an open-source platform that enables pre- and intra-procedural intervention planning. It is similar to a radiology workstation that enables versatile visualization [13] and it has been applied to image guided surgery, brain

mapping, and virtual colonoscopy [14]. Many studies have been devoted to software development of 3D Slicer including segmentation algorithm [15]–[18], surgical planning and navigation [19]–[22] and atlas generation [23].

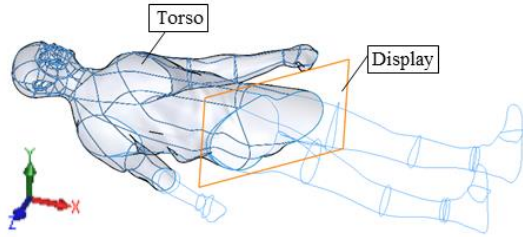


Fig. 1. The cross-section is visualized on the display. A virtual object (human body in this case) is arbitrarily sliced using a physical display

METHODS

A. Concept

The idea is to visualize a cutaway of a virtual object on a display (Fig. 1). That is, a virtual object is arbitrarily sliced using a physical display. Our system is different than previous approaches in terms of: 1) intuition: as opposed to 3D software, we believe moving the display while the object remains still matches the user’s intuition; 2) simplicity of use: we believe the system is attractive to users as they can dissect the torso at any angles and go in and out at any directions; 3) generality: the virtual object can be replaced or scale down/up to satisfy the user needs; and 4) scalability: the open-source and simplicity of system integration allows the system to be assembled and used by potential users.

B. Mechanical Design

Design requirement. Key requirements and challenges are operational workspace, maneuverability, and localization.

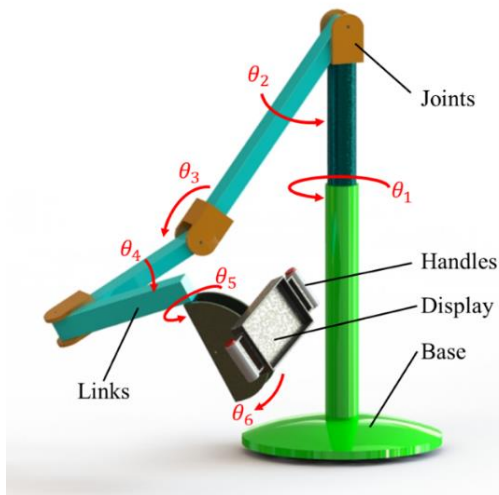


Fig. 2. CAD model of the arm and joint angles

Maneuverability is the ability of accessing an arbitrary cross-section which is the display-body intersection shown in Fig. 1. This requires the display to be freely translated along and rotated about the global coordinate system axes. Localization is positioning an object within a known coordinate system. In this study, localization detects the display pose (the local coordinate system attached to the display’s center of mass). Operational workspace is the volume that the display must be provided with full maneuverability and depends on the size of the virtual object.

Device Design. Shown in Fig. 1, this consists of a six-bar linkage, where the fixed link is the base and the five remaining links are free to rotate around their pivot points. The joint angular movements are measured by encoders which are installed at the joints. The position of the endpoint, where the tablet is mounted, is calculated by equations derived from forward kinematic analysis.

Device Optimization. The main structure of the device is designed to support a tablet with weight of up to 1 kg while it provides smooth movement when a user pushes/pulls the table. The length of the links is chosen to be sufficient to cover the required volume.

The arm has 6 DOF with maximum vertical and horizontal reach of 30 and 100 cm, respectively. The monitor tilts and rotates by 75 and 360 degrees, respectively. These dimensions provide sufficient workspace as a typical torso has the dimensions of 30x40x160 cm. Using Solidworks software, a CAD model of the arm was created. The arm has six DOFs to meet the design requirement for full dexterity of the tablet attached at the endpoint, as was needed.

Kinematic Analysis. Using MATLAB software, the kinematics of the arm was formulated by Eqs (1)-(5). The purpose of this analysis is to calculate the endpoint position given the measured joints angles. It should be noted that the joint angles are measured via optical encoders installed at joints.

For kinematic analysis, Denavit-Hartenberg (DH) parameters were used, which provide a series of transformation matrices from consecutive coordinate systems. The final transformation matrix is obtained as the product of

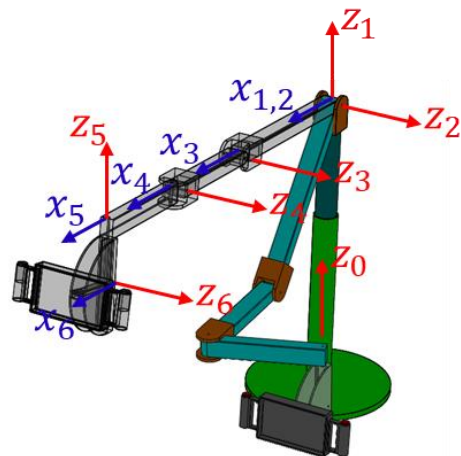


Fig. 3. The assignment of the coordinate system

consecutive matrices. Figure 1 shows the coordinate systems attached to each joint. Eq (1) is a transformation matrix.

$${}^{n-1}T_n = \begin{bmatrix} c\theta_n & -s\theta_n c\alpha_n & s\theta_n s\alpha_n & r_n c\theta_n \\ s\theta_n & c\theta_n c\alpha_n & -c\theta_n s\alpha_n & r_n s\theta_n \\ 0 & s\alpha_n & c\alpha_n & d_n \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where c and s denote sine and cosine, respectively. The DH parameters are d , θ , r , and α , where they are respectively represented as follows.

d : the offset along previous z to the common normal;

θ : angle about previous z , from old x to new x ;

r : length of the common normal. Assuming a revolute joint, this is the radius about previous z ;

α : angle about common normal, from old z axis to new z axis.



Fig.4. Electronic circuit for to read joint angles

C. Electrical Circuit

The electronic unit consists of a hollow bore optical encoder (US Digital HB5M) with bore diameter of $1/4$ " , a data acquisition card (National Instruments myDAQ PCI-6110), and power and connecting cable (USB A to B Cable).

A LabVIEW program was implemented to read the signals of the encoders and calibrate them by mapping the range of the analog voltage signals to range of motion of each joint.

D. Software

A visualization software is created using Qt 5.9.0 application framework. Since Qt is a cross-platform application framework, the software is portable to any operating systems (linux, windows, macOS). The following libraries have been used: a) Insight Segmentation and Registration Toolkit (ITK) 4.12.0, b) Visualization Toolkit (VTK) 8.0 and c) Grassroots DICOM (GDCM) 2.6.6.

The software architecture has three main layers – a) reading images using GDCM and ITK, b) data conversion from ITK to VTK and c) data visualization using VTK.

Since DICOM is the conventional and mostly used medical imaging format, we have designed our system to work on this format. In future versions, we intend to expand this feature to other medical image formats if necessary. The GDCM library handles the DICOM format. Note that both ITK and VTK can be used to read DICOM data, ITK helps processing algorithms while VTK provides visualization sources.

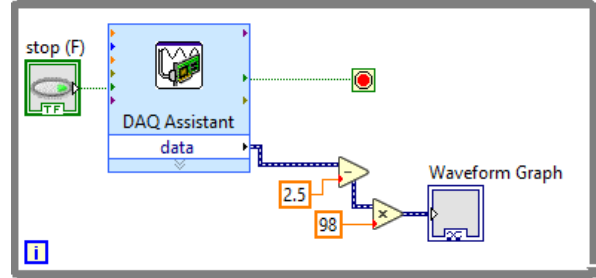


Fig. 5. LabVIEW circuit to read the encoder

In the next step, an image is displayed using VTK. From a single volumetric scan, three views (axial, coronal, and sagittal) are generated. A fourth view displays the cross-sections of the image when the display is placed parallel to any plane. To visualize the data at any plane other than the standard x - y , y - z , or z - x planes, the data is interpolated at that plane as illustrated in Fig. 5. The location information is fed to software continuously in real time from the Polaris system as the user moves the display along the virtual body.

E. Experimental Design

In order to test the simplicity of use of the proposed device, two survey-based experiments were designed. In both scenarios, 10 subjected were asked to conduct given tasks using a mouse and then repeat the same task with the proposed device.

In the first experiment, participants were asked to slice the torso such that the 2D image shown on the screen always remained perpendicular to the given path. In the end, subjects were asked to state which method they found easier.

In the second experiment, participants were requested to seek hidden objects in the torso using 3D slicer. The shape of the objects were unknown to them. They were measured for time taken until objects were successfully found. They were then asked to either draw the shape or choose from a multiple-choice quiz. Then they repeated the task with the proposed device

RESULTS

Device Prototype. At this stage of development, a simplified version of the device was prototyped. To prove the overall concept, a motion tracking system was used to trace the movement of the tablet. We used Microsoft Surface as a display. The Polaris read the pose of the tool from the markers, which were attached on the back side of the Surface (Fig. 6) and sent the results to the software. We initialized the system by specifying the center and dimension of the workspace prior to the test. Our system generated cross-sectional views as the user moved the Surface within the defined workspace. The

computed slices were then visualized on the Graphical User Interface.

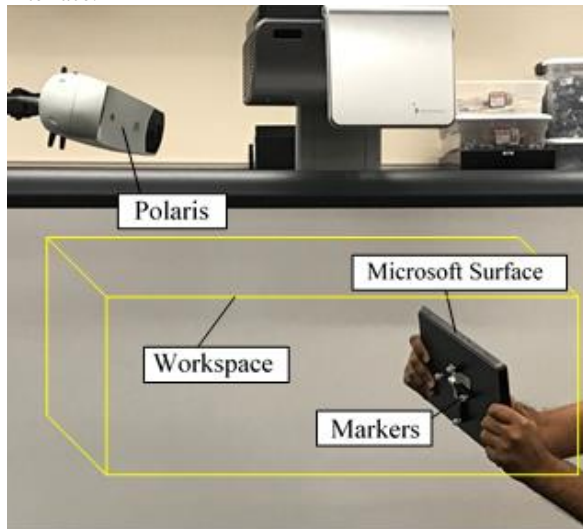


Fig. 6. Experiment

CONCLUSION

Over past decades, radiology reading has not been notably changed despite recent technological advancements. Radiologists read images for hours in front of monitors while they hold a microphone to annotate and record their vocal diagnoses. They constantly scroll back and forth across the images using standard computer input devices (i.e., mouse or keyboard) to visit different layers of images and try to visualize three-dimensional anatomy in their mind. Although recent technologies such as EchoPixel© and VisibleBody© have aimed to revolutionize visual anatomy education, these devices do not appear simple and intuitive enough to be used in pre- and intra-procedures. This study explores a novel, immersive, and interactive visualization of medical images.

Future work includes fabrication of the arm, CAD design refinement, and further software improvement. The arm can be assembled from off-the-shelf components. The length of arm's link can be optimized for an average human body.

REFERENCES

- [1] P. Kozłowski, S. D. Chang, E. C. Jones, K. W. Berean, H. Chen, and S. L. Goldenberg, "Combined diffusion-weighted and dynamic contrast-enhanced MRI for prostate cancer diagnosis—Correlation with biopsy and histopathology," *J. Magn. Reson. Imaging*, vol. 24, no. 1, pp. 108–113, Jul. 2006.
- [2] W. A. Berg *et al.*, "Detection of Breast Cancer With Addition of Annual Screening Ultrasound or a Single Screening MRI to Mammography in Women With Elevated Breast Cancer Risk," *JAMA*, vol. 307, no. 13, pp. 1394–1404, Apr. 2012.
- [3] R. M. Paspulati, S. Partovi, K. A. Herrmann, S. Krishnamurthi, C. P. Delaney, and N. C. Nguyen, "Comparison of hybrid FDG PET/MRI compared with PET/CT in colorectal cancer staging and restaging: a pilot study," *Abdom. Imaging*, vol. 40, no. 6, pp. 1415–1425, Aug. 2015.
- [4] A. E. Bohte *et al.*, "Non-invasive evaluation of liver fibrosis: a comparison of ultrasound-based transient elastography and MR elastography in patients with viral hepatitis B and C," *Eur. Radiol.*, vol. 24, no. 3, pp. 638–648, Mar. 2014.
- [5] E.-S. A. El-Dahshan, H. M. Mohsen, K. Revett, and A.-B. M. Salem, "Computer-aided diagnosis of human brain tumor through MRI: A survey and a new algorithm," *Expert Syst. Appl.*, vol. 41, no. 11, pp. 5526–5545, Sep. 2014.
- [6] A. B. de González *et al.*, "Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007," *Arch. Intern. Med.*, vol. 169, no. 22, pp. 2071–2077, Dec. 2009.
- [7] H. Dehghani, S. Laha, P. Kulkarni, P. Biswas, U. Bagci, and S.-E. Song, "'Air Slicer' for Immersive Visualization of Medical Images," *Proc. 2018 Des. Med. Devices Conf.*, Apr. 2018.
- [8] W. Schwizer, M. Fox, and A. Steingötter, "Non-invasive investigation of gastrointestinal functions with magnetic resonance imaging: towards an 'ideal' investigation of gastrointestinal function," *Gut*, vol. 52, no. suppl 4, pp. iv34–iv39, Jun. 2003.
- [9] H. Dehghani, S. Zhang, P. Kulkarni, P. Biswas, L. Simms, and S.-E. Song, "Design and Simulation of Robotic Needle Guide for Transperineal Prostate Biopsy," *Proc. 2018 Des. Med. Devices Conf.*, Apr. 2018.
- [10] K. Togashi, "Ovarian cancer: the clinical role of US, CT, and MRI," *Eur. Radiol.*, vol. 13, no. 6, pp. L87–L104, Dec. 2003.
- [11] H. Dehghani Ashkezari, A. Mirbagheri, S. Behzadipour, and F. Farahmand, "A Mass-Spring-Damper Model for Real Time Simulation of the Frictional Grasping Interactions between Surgical Tools and Large Organs," *Sci. Iran. Int. J. Sci. Technol.*, vol. 22, no. 5, pp. 1833–1841, Feb. 2015.
- [12] H. Dehghani Ashkezari, A. Mirbagheri, F. Farahmand, S. Behzadipour, and K. Firoozbakhsh, "Real time simulation of grasping procedure of large internal organs during laparoscopic surgery," in *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2012, pp. 924–927.
- [13] A. Fedorov *et al.*, "3D Slicer as an image computing platform for the Quantitative Imaging Network," *Magn. Reson. Imaging*, vol. 30, no. 9, pp. 1323–1341, Nov. 2012.
- [14] S. Pieper, M. Halle, and R. Kikinis, "3D Slicer," in *2004 2nd IEEE International Symposium on Biomedical Imaging: Nano to Macro (IEEE Cat No. 04EX821)*, 2004, pp. 632–635 Vol. 1.
- [15] R. Kikinis and S. Pieper, "3D Slicer as a tool for interactive brain tumor segmentation," in *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 2011, pp. 6982–6984.
- [16] S. S. F. Yip *et al.*, "Application of the 3D slicer chest imaging platform segmentation algorithm for large lung nodule delineation," *PLoS One*, vol. 12, no. 6, p. e0178944, 2017.
- [17] J. Egger *et al.*, "GBM Volumetry using the 3D Slicer Medical Image Computing Platform," *Sci. Rep.*, vol. 3, Mar. 2013.
- [18] E. R. Velazquez *et al.*, "Volumetric CT-based segmentation of NSCLC using 3D-Slicer," *Sci. Rep.*, vol. 3, p. srep03529, Dec. 2013.
- [19] D. T. Gering *et al.*, "An Integrated Visualization System for Surgical Planning and Guidance Using Image Fusion and Interventional Imaging," in *Medical Image Computing*

- and Computer-Assisted Intervention – MICCAI’99*, 1999, pp. 809–819.
- [20] N. Doba *et al.*, “Usefulness of 3D slicer for the planning and monitoring of hepatocellular carcinoma treatment using FUS,” *J. Ther. Ultrasound*, vol. 3, no. 1, p. O84, Jun. 2015.
- [21] X. Chen, L. Xu, H. Wang, F. Wang, Q. Wang, and R. Kikinis, “Development of a surgical navigation system based on 3D Slicer for intraoperative implant placement surgery,” *Med. Eng. Phys.*, vol. 41, pp. 81–89, Mar. 2017.
- [22] S. Kim, Y. Tan, A. Deguet, and P. Kazanzides, “Real-Time Image-Guided Telerobotic System Integrating 3D Slicer and the Da Vinci Research Kit,” in *2017 First IEEE International Conference on Robotic Computing (IRC)*, 2017, pp. 113–116.
- [23] J. Rackerseder, A. M. L. González, C. Düwel, N. Navab, and B. Frisch, “Fully Automated Multi-Modal Anatomic Atlas Generation Using 3D-Slicer,” in *Bildverarbeitung für die Medizin 2017*, Springer Vieweg, Berlin, Heidelberg, 2017, pp. 306–311.