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Volume visualization using a spatially aware mobile display device

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ABSTRACT

Volume visualization is a difficult three-dimensional task and a significant amount of research is devoted to the development of a suitable computer input device for it. Most of the proposed models use fixed displays, thus rendering extracted slices in orientations unrelated to their real locations within the volume. We present a new device which takes a different approach, as it leaves the volume in a fixed location and demands the user to change his or her posture to explore it from different angles. To implement this, we built a prototype based on a mobile display equipped with sensors that allows it to track its position, which is related to the location of the slice plane within the volume. Therefore, the user can manipulate this plane by displacing and rotating the display, which is a very intuitive method with minimum learning time. Furthermore, the postural changes required to use the device add a new channel of feedback, which effectively helps to reduce the cognitive load imposed on the user. We built a prototype device and tested it with two groups of volunteers who were asked to use it in a medical imaging application. Statistical analysis of the results shows that explorations made with the proposed device were considerably faster with no penalty in precision. We believe that, with further work, the proposed device can be developed into an useful tool for radiology and neurosurgery.

1. Introduction

Many scientific disciplines, especially medical imaging, use volume visualization to explore three-dimensional (3D) datasets. As these cannot be displayed with a single image, many visualization techniques have been developed, such as iso-surfaces and slices. In the latter, a plane is intersected with the volume at a certain location and takes a slice from it, which is displayed as a bi-dimensional image. The user must displace and rotate the slice plane within the volume to explore the internal structure of the data. A complete manipulation of a slice plane, however, is not a simple task, as it requires control over multiple degrees of freedom (DOF) and a clear mental picture of the whole volume in the head of the user. Fortunately, these problems can be solved, or at least minimized, if a suitable input device is used. The majority of the input devices used in 3D applications, such as the mouse, joystick or hand-held "flying" mouse, share a common feature: the user moves the explored objects meanwhile the physical screen remains stationary. However, there are devices which take the opposite approach: the explored object remains fixed in space and the user must move the display to view it from different angles. Head Mounted Devices (HMD) and the models based on the *window-in-hand* [1] implement this idea. A HMD is a helmet worn by the user which can track its position in space and change the viewpoint in the 3D scene accordingly. Usually, the final image is rendered on a pair of stereoscopic lenses, also worn by the user. These kind of devices have been around for many years, but they are not still widely accepted, due to their bulky size and because they do not allow the user to see his or her surroundings while wearing them. On the other hand, the *window-in-hand* idea [2] gives the user a hand-held display, which acts as a window used to look into a 3D world. The display is equipped with sensors that track its position, which is related to the location of the viewpoint in the 3D world. Hereby, the user can explore the 3D scene by moving and rotating this virtual window, which is a very intuitive method with minimum learning time. Nowadays, existing devices based on the *window-in-hand* are focused in non-scientific applications. As far as we know, there is not an implementation for volume visualization, although it offers many advantages: it has a very intuitive navigation system, it provides rich spatial feedback and the hand-held display offers a tangible representation of the slice plane, so it becomes easier for the user to "feel" how his or her movements are being translated into the 3D virtual world. Besides, the explored volumes can be rendered with variable scaling factors, allowing to "see" them with the same size and aspect they had in the real world. For example,

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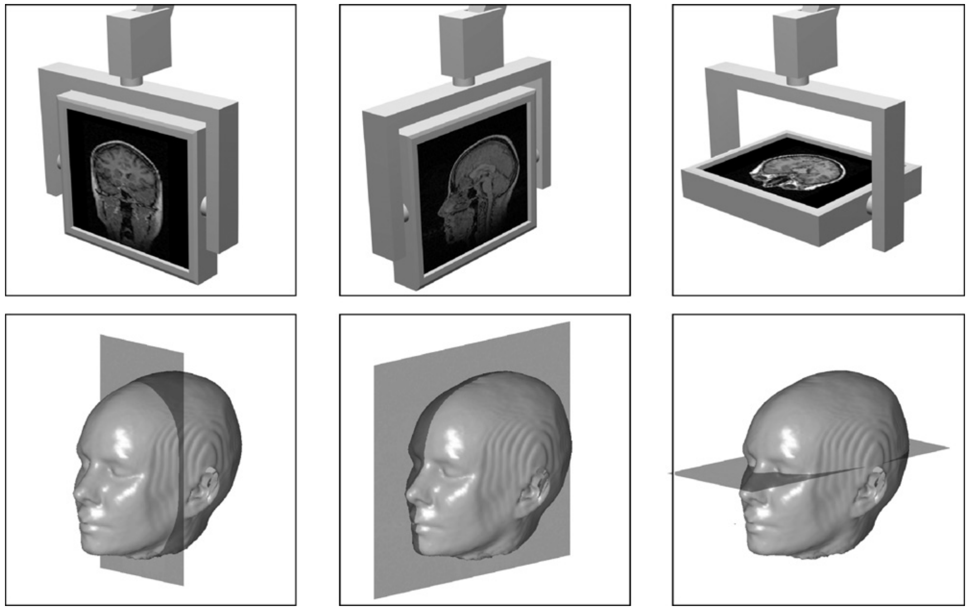

Fig. 1. Graphical description of the proposed device. The movements applied to the computer display produce a corresponding movement of the slice plane within the volume, as displayed in the lower frames of the figure.

a surgeon could explore a volume of a human head which had the same size and proportions of a real head, hereby improving the perception of the volume as “more real”. We propose that fixing the volume in space and allowing the user to move the viewpoint can be an efficient method for volume visualization, especially when a slice plane is used. To prove this, we propose an input device based on a spatially aware display which, as we pointed previously, has considerable advantages for this kind of application (Fig. 1).

2. Related work

A considerable research effort has been made to develop a suitable input device for visualization of slices from volumetric data. Many different approaches have been taken for this problem, most of them focused in *proprioception*, defined as the inner sense of position and state of the body parts; and exploiting bi-manual interaction. As most of the feedback received by a person when interacting with the computer is visual, extending the range of senses involved improves performance, although vision remains as the dominant channel of information [3]. Proprioceptive feedback produced by an actively maintained posture is especially effective to improve performance in computer interaction [4].

Examples of devices designed for volume visualization are the PassProps [5], the Cubic Mouse [6], the models designed by Guzman et al. [7], and the devices proposed by Qi and Martens [8]. All of these employ devices manipulated by the user and tracked by magnetic sensors or cameras, which represent the volume and the slice plane. To extract a slice from the volumetric dataset, the user must place manually the volume and the slice plane objects at a relative distance. Typically, the extracted slice is displayed in a fixed display placed in front of the user.

Examples of the *window-in-hand* model of computer interaction are the “Chameleon” [2] and its improved version: the “Boom Chameleon” [9,10], the “virtual vehicle project” [11], the “Planar” [12], the “Peephole” displays [13], the “Installation project” [14], the “LightSense” system [15], the “PaperLens” [16] and the spatially aware handhelds devices proposed by Olwal and Feiner [17]. Despite the large number of projects and the advantages which the *window-in-hand* has for volume visualization in medical applications, no device based on this idea has been specifically designed for this task.

3. Prototype design and construction

We designed a prototype device as a proof of concept, which consists of a Samsung SyncMaster 710N 17 in. flat display supported by a mechanical arm that allows movements in three directions and rotations around two axes, giving 5 DOF in total. Five 10 kΩ audio potentiometers, placed on the armature joints, measure the angles between the arm segments. The sensors are placed in specially built housings and a custom $\pm$10 V power supply was built to energize them. All connections to the potentiometers are made with shielded cables, which reduce the amount of noise picked up by the signal lines.

The sensors’ signals are measured by a National Instruments USB-6008 data acquisition (DAQ) board, which has a resolution of 11 bits for single-ended inputs, a sampling rate of 10 000 samples per second (S/s) – giving an effective sampling rate of 2 kS/s per channel – and operates at the $\pm$10 V range. As the angular range of the potentiometers is 300° and $2^{11} = 2048$ levels are available in the DAQ, the minimum measurable angle is 300/2048 = 0.1465° or 0.0026 rad. Although this angle is small, we must consider that the display is manipulated at a distance of about 1 meter from the base of the arm, so the minimum measurable distance is 2.6 mm. This value does not pose a problem for the manipulation of the device (it is difficult to move the display manually with a precision of a few millimeters), but the quantization errors produce an unpleasant shaking in the displayed image. However, it must be remarked that the only effective source of noise in the system is the quantization error, as the cables’ shielding is able to eliminate most of the noise picked up by the signal lines.

Custom software was written to implement the two stages of the visualization process, which are the estimation of the armature’s pose and the rendering of the extracted slice. The first stage is completed by the *armServer* application, which reads the DAQ signals using National Instruments’ NI-DAQmx library and estimates the armature’s pose solving its direct kinematics using the arm’s Denavit and Hartenberg’s parameters [18]. Data transmission rate is set by the client that connects to the *armServer* socket, as data