Multi-Touch Table System for Medical Visualization

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Figure 1: *The 2015 version of the developed medical visualization table.*

Abstract

Medical imaging plays a central role in a vast range of healthcare practices. While the usefulness of 3D visualizations is well known, the adoption of such technology has previously been limited in many medical areas. This paper, awarded the Dirk Bartz Prize for Visual Computing in Medicine 2015, describes the development of a medical multi-touch visualization table that successfully has reached its aim to bring 3D visualization to a wider clinical audience. The descriptions summarize the targeted clinical scenarios, the key characteristics of the system, and the user feedback obtained.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation—I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—H.5.2 [User Interfaces]: Input devices and strategies—

1. Introduction

This paper describes a research effort awarded with the Dirk Bartz Prize for Visual Computing in Medicine 2015. The medical application of computer graphics technology in question is a set of novel methods and components manifested in a system: the Medical Visualization Table (MVT). The research behind the MVT has spanned several years. In essence, it has consisted of building thorough understanding of the needs and prerequisites in certain health care subdomains, and then utilizing that knowledge to develop novel and carefully tailored visualization technology. Thanks to the MVT, the value of 3D visualizations in medicine can now reach a substantially wider range of usage scenarios.

2. Corresponding needs of the medical domain

During the development of the MVT, several relevant medical applications have been identified and studied. A first theme of usage scenarios relates to surgery workflows, as outlined in figure 2. The first of these activities is a Multidiscipliary Team Meeting (MDT) where *initial assessment* of injuries and treatment options at an image-centered session with a radiologist and one or more surgeons.

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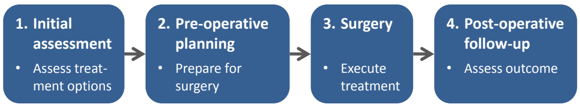

Figure 2: *Overview of workflow connected to surgical procedures. Visualization table assistance is relevant for all steps.*

A second session is the *pre-operative planning*, where tasks such as planning entry passages and selecting appropriate materials can be very challenging. The planning can be done individually but also consultations occur. Employing the MVT in *intra-operative use* is possible but of limited value as the environment does not allow extensive interaction. In contrast, *post-operative follow-up* is highly relevant for MVT practice. The surgical specialities that so far has expressed the strongest anticipated benefits of the MVT are orthopedic, colorectal, and abdominal surgeons.

The initial target area for our development was autopsies. Autopsies have traditionally been a cornerstone for improving quality of health care. To include Post-Mortem Imaging (PMI) in the procedure has been shown to add value [BU07]. Outside of health care, PMI is increasingly being used also for forensic purposes, which further widens the application space for the MVT. The three first parts in figure 2 are relevant here: initial assessment, pre-autopsy planning and intra-autopsy guidance. The MDT meeting is perhaps the lowest hanging fruit, where the MVT can support the collaborative discussion between the radiologist and the forensic pathologist.

Thirdly, a very important application area for the MVT is medical education, in particular anatomy and pathology studies. In addition to cadaver use, images and 3D visualizations are increasingly seen as a valuable and cost-efficient material [SWK*08]. Compared to anatomical models, the ability to use clinical patients makes it possible for the students to review a broad range of normal variants, rather than just a single example.

3. Development phases

The development of the MVT consisted of several phases, where different parts of the collaborating constellation have been the development lead at different times. The starting point was the work on high-performance volume rendering of large data sets, applied to the autopsy scenario as described by Ljung et al. [LWP*06]. The effort was a collaboration between C-research and the Center for Medical Image Science and Visualization (CMIV), both at Linköping University, and Sectra AB.

The volume rendering software was then combined with multi-touch table technology into a Virtual Autopsy Table (VAT) demonstrator specifically targeting PMI, see figure 3.

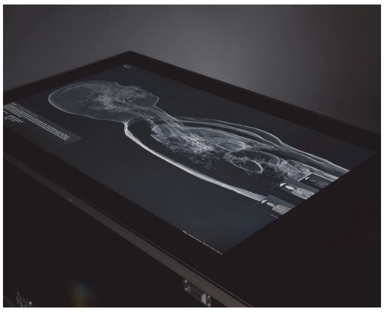

Figure 3: *The Virtual Autopsy Table demonstrator, the predecessor of the Medical Visualization Table that also has evolved into a version for museums and science centers.*

The effort was lead by the Swedish ICT Interactive Institute in collaboration with C-research and CMIV. While multi-touch technology and surface computing had been identified as promising for medical imaging applications in general, the VAT project aimed to go further in demonstrating concrete advantages for a specific application, namely the PMI process. Apart from PMI needs, VAT design considerations were also influenced by the fact that public exhibitions was a primary target for the demonstrator.

In the next phase, the first system intended for medical end users was created, the MVT. This was a research and development effort driven by Sectra AB in collaboration with the three partners behind the VAT. In its first version several potential application areas were explored, including a thorough user study within orthopedic surgery by Lundström et al. [LRF*11]. Recent development of the MVT has primarily been directed to medical education, where also the largest uptake has occurred – the system is now in daily use across four continents.

Outside of the health care domain, the VAT system has subsequently been developed into a version for museums and science centers. This table has, for instance, received much appreciation for making it possible to unveil the secrets of ancient mummies.

4. Key characteristics

In this section we will summarize the defining features and design choices that have been instrumental for the successful adoption of the MVT. For in-depth descriptions we refer to [LRF*11]. The design process for the MVT was underpinned by feedback both from interviews with potential users and from public exhibitions of the VAT. The resulting design requirements were:

1. The learning threshold for basic interaction should be close to none.
2. Advanced interaction should be available without disturbing the ease-of-use of the basic interaction.

3. The system should be alluring such that novice users are inspired to start interacting.
4. The users should experience similarity with real-world situations in patient care.
5. The interaction should be highly responsive and robust.
6. The interaction should be equally intuitive for all positions around the table.
7. Swift but distinct changes of which person who is currently interacting should be supported.
8. The system should work in versatile environments without recurring maintenance efforts.

The hardware was selected to provide realism (req 4) in the form of a “a patient on a table" experience. This lead to the choice of a large screen, 46 inches at 1920x1080p resolution, primarily intended for horizontal display. However, to increase the versatility (req 8) a tiltable stand was developed that also allowed vertical display. The selected touch input technology is in the MVT based on infrared sensors placed on top of a regular screen. Responsiveness is high (req 5) and robust to various lighting conditions without need for recurring calibration efforts (reqs 5, 8).

A fundamental design choice to achieve simplicity and allurance (reqs 1, 3), that was made in the first VAT system and has been adhered to since, is to let the image heavily dominate the screen. This meant that Graphical User Interface (GUI) elements traditionally used in WIMP (Window, Icon, Menu, Pointer) environments such as labels, text, and buttons were intentionally left out to avoid having elements distracting the user from the image. Furthermore, the few core GUI elements that are present have been designed to be understood from any direction. This allows for effective collaboration when several persons gather round the table.

The basic movements of the image volume are controlled by simple gestures (req 1). Whereas the VAT had a 4 DOF (degree-of-freedom) paradigm for maximal simplicity in use by the public, the MVT employs a 6 DOF solution. Rotation around x- and y-axes is connected to a single-touch movement and is relative to a global reference point. The reference point is by default the middle of the volume, but can be set anywhere else through a double touch. The other DOF are rotate-scale-translate (RST) interactions achieved by two-touch pinching, which for 2D is well known in many touch applications.

A central challenge in designing the MVT was to provide a sufficiently large feature set without compromising simplicity (req 2). The approach taken is to employ movable alternator objects, referred to as “pucks” due to their round shape and behavior. The pucks activate specific feature sets: The user touches and holds the puck with one hand and performs the desired interaction with the other hand. The mobility of the pucks enables equal access for all table users, and this is further emphasized by the round shape (req 6). An additional advantage in the collaborative context is that all users know that the person with the puck is currently in control (req 7). For increased realism, the pucks are affected by virtual friction and gravity when relevant.

One puck is for Transfer Function (TF) preset selection, another for TF adjustment. The third puck activates clip plane handling. The planes were restricted to major axes in the VAT, but the MVT allows arbitrary orientation and also slabs with user-controlled thickness. A later addition is a spherical cut initiated by a circular gesture. Another feature adding to the realism is a special zoom function, where a four-point touch defining a region of interest makes the closest visible part in the region become its true size. Being a perspective rendering, this zoom factor is dependent of the depth of the object of interest.

Recently, functionality specifically targeting the education scenario has been added to the MVT (not described in earlier MVT publications). Here annotation handling plays a central part, see figure 4. Labels consist of a 3D arrow with a text at the base and a point attached to the visible surface of an anatomical part. The label is created through a combined gesture: first touch and hold on the anatomical part, then extend the arrow base as desired. When moved, the base stays at the same depth as the point in the current orientation. The text is increasingly faded as an arrow becomes perpendicular to the screen when rotating, which is an effective way of hiding irrelevant labels. There is also a feature to create a quiz by hiding all the text. Apart from bringing back the full text label, the student's learning process can be based on getting clues, exposing the label letter by letter.

Distance measurements have also been added, see figure 4. A two-point touch and hold gesture creates a measurement, fixed depth-wise to the first visible surface. The end points are denoted by circular plates whose radii correspond to the measured distance. With this glyph it is possible to appreciate the distance even when the line is close to perpendicular to the screen. Moreover, a key extension has been to enable effective case creation, management and exchange for the MVT user community. In order to broaden the usage scenarios further, other viewing hardware such as tablets have now been enabled, completing an education ecosystem centered around the MVT.

5. User feedback

The arguably most compelling evidence of usefulness and value to the medical community is the fact that many institutions have invested in the commercial MVT product. Early 2015 there are MVT installations in more than 15 countries on four continents, and the numbers are steadily increasing. In addition, there have been a few scientific investigations.

The user study with orthopedic surgeons [LRF*11] provided wide and deep feedback on the MVT in a realistic setting. The setup was that the surgeons, without previous experience of the MVT and after just a few minutes of training, were tasked to do pre-operative planning for two com-

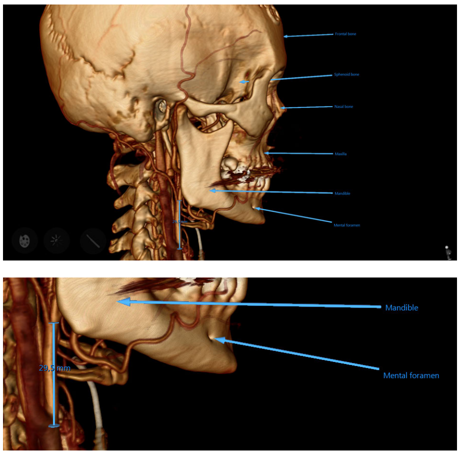

Figure 4: *Anatomy labeling with built-in quiz functionality is an important part of medical eduction use of the MVT.*

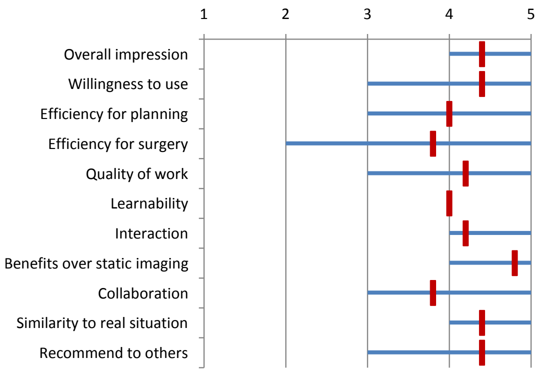

Figure 5: *The quantitative results of the user study questionnaire in [LRF*11]. Subjective satisfaction regarding use of the table was measured for the above 11 areas. The 5-point rating scale ranges from* Strongly unfavorable *(1) through* Unsure (3) *to* Strongly favorable *(5). Vertical red bars denote the mean value and horizontal blue lines denote the full span of given ratings.*

plex pelvic fractures. The results were documented in both quantitative and qualitative form. The summary of the quantitative survey is given in figure 5 and shows a high level of satisfaction among the physicians. Likewise, the findings from the qualitative interviews demonstrated that the design requirements were valid and that the MVT had largely succeeded in meeting them.

Another example is a study by Mansoori et al. [MSWB*13] where medical students' performance on an anatomy test before and after an MVT session was measured. The increase in test results were quite significant (from 12 to 18 points out of 22 in average). Subjective grading of the learning experience was also high. While far-reaching conclusions are difficult to draw from this small study, it is a clear indication that the MVT is indeed an effective education tool. The potential of the MVT for educational and clinical use was echoed also in the pilot study by Redeen et al. [RELL14].

6. Conclusions

The creation and evolution of the MVT has been a concerted cross-disciplinary effort over several years and several organizations. While early versions of the MVT have shown promise before, it is now in 2015 that a complete system has been accomplished and the full assessment of its usefulness can be established – through the feedback from actual clinical users. Given the positive evaluations and the commercial impact achieved, it can now truly be considered a success story for medical visualization research.

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References

[BU07] Burton J. L., Underwood J.: Clinical, educational, and epidemiological value of autopsy. *LANCET 369*, 9571 (2007), 1471–1480. 2

[LRF*11] Lundström C., Rydell T., Forsell C., Persson A., Ynnerman A.: Multi-touch table system for medical visualization: Application to orthopedic surgery planning. *IEEE Transactions on Visualization and Computer Graphics 17*, March (2011), 1775–1784. doi:10.1109/TVCG.2011.224. 2, 3, 4

[LWP*06] Ljung P., Winskog C., Perssson A., Lundström C., Ynnerman A.: Full Body Virtual Autopsies Using A State-of-the-art Volume Rendering Pipeline. *IEEE Transactions on Visualization and Computer Graphics (Proceedings Visualization/Information Visualization 2006) 12*, 5 (2006), 869–876. 2

[MSWB*13] Mansoori B., Seipel S., Wish-Baratz S., Herrmann K. A., Gilkeson R.: Use of 3D Visualization Table as a Learning Tool for Medical Students. In *International Association of Medical Science Educators Conference* (2013). 4

[RELL14] Redéen S., Elmhester P., Larsson R., Lindfors L.: Highlights and Potentials when Using the Visualization Table for Pre-operative Planning and Diagnosis in Seven Surgical and One Oncological Department - A Pilot Study at the University Hospital of Linköping. *American Journal of Medicine Studies 2*, 3 (2014), 42–45. 4

[SWK*08] Silén C., Wirell S., Kvist J., Nylander E., Smedby O.: Advanced 3D visualization in student-centred medical education. *Medical teacher 30*, 5 (June 2008), e115–24. URL: http://www.ncbi.nlm.nih.gov/pubmed/18576181, doi:10.1080/01421590801932228. 2