WEB-BASED
'COMPUTER ASSISTED SURGICAL ANATOMY MAPPING'

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Abstract: In surgery one of the major problems is a safe approach of the operation site. For surgeons it is paramount to know the location of surgically relevant nerves and vessels. Especially in surgery of the lateral (outside) foot, the anatomy is not always completely clear since the location of nerves and vessels is highly variable. Therefore CASAM is developed by students in Delft and Rotterdam (Netherlands). This web-application is based on the Django-framework and is a useful tool for three usergroups: 1) Researchers: After photographing dissected specimen a Thin Plate Spline transformation is used to compute an average foot and the pictures of individual specimen are warped to match this reference, average-foot. Renditions can be made to depict relevant surgical anatomy. Finally the researchers can define a zone in the lateral foot in which it is safe to approach the operation site. 2) Surgeons: Relevant anatomy (gathered by the researcher) can be warped over the picture of the patient. This pre-operative planning using CASAM assists the surgeon in determining a 'tailor made' safe-zone for each patient. 3) Students: For educational purposes, a drawn incision line can be compared to the computed location of nerves and vessels, thus providing personal feedback.

1 INTRODUCTION

In surgery one of the major problems is the safe approach of the operation site. Exposure of this operation site is the most important aspect but tissue sparing is just as important. In order to make a good evaluation between exposure and tissue sparing the knowledge of the related human anatomy is of paramount importance. For surgeons though, it is impossible to exactly know the anatomy of the complete human body mainly because:

1) There is an enormous inter- and intra-individual variety in human anatomy. The location of nerves, arteries and veins differs between each patient.

2) Since the dimensions of each specimen are different (shape, size, length width, etc) it is impossible to compare the anatomy of different specimen.

3) As new techniques are being developed to lessen complications the surgical procedures themselves often become more complex.

4) Some surgical procedures are very rare and a surgeon only does three or four of them per year.

Iatrogenic damage to nerves and vessels and hence postoperative pain and poor wound healing are a very common complication in surgery. To avoid damage of nerves and vessels it is imperative for a surgeon to know the exact location of important anatomical structures.

In order to overcome (some of) these problems, researchers at the Erasmus Medical Centre in Rotterdam began to map the human anatomy related to the 25 most current surgical procedures. In cooperation with the Delft Technical University: Faculty of Electrical Engineering, Mathematics and Computer Science; dept. of medical and data visualisation (head: Dr. C. Botha/ Dr. F.H. Post), a

web-based tool was developed. The main focus of the tool was to be able to compare the anatomy of different specimen and relate it to a specific patient. Also, the application needed to be fast, user friendly and scientifically verifiable. Finally it needed to be easily accessible for our three main focus groups: researchers, surgeons, and surgical residents.

Many surgeons have dreamed of a preoperatively, real time available and easily accessible database to compare their patients to. The current web-based system tries to make a step forward in having this kind of database.

2 APPLICATION

One of the surgical procedures that illustrates these problems is the lateral (outside) approach of the calcaneus (heel bone) for fractured ankles. Up to 15% post-operative pain due to damage of the nerves and up to 10% wound necrosis due to damage of the arteries is reported (Poeze, 2008). As a fracture of the calcaneus is rare (Barei, 2000) surgeons on average only perform four of these surgical procedures per year.

2.1 User Groups

This application can benefit three user-groups:

2.1.1 Researchers

A Thin Plate Spline transformation is used to project each picture of each individual specimen to match a reference, average-foot. Renditions can then be made to depict the relevant surgical anatomy (figure 1). As an additional feature, the Point Distribution Model can display variations within anatomical structures. Using these tools the members of our CASAM research project group can define a zone in the lateral foot in which it is safe to approach the operation site.

2.1.2 Surgeons

A simplified intuitive version of the web-application allows the surgeon to upload a picture of the ankle of his specific patient, after which he can warp the relevant anatomy (provided by the CASAM research group) over the picture of his patient (figure 1). In this way the surgeon has an easily accessible database at his disposal to optimise his pre-operative planning and determine a 'tailor made' safe zone in each patient.

Figure 1: A patients lateral ankle depicting the surgically relevant anatomy of ten dissected sural nerves and six posterior tibial arteries.

2.1.3 Surgical Residents

Another version of the web-application allows the resident/student to upload a reference picture (for example real time, during an anatomy course) of a drawn incision line. Then, for educational purposes, this incision line can be compared to the gold standard or the computed location of nerves and vessels, thus providing personal feedback and hence making his /her learning curve steeper (figure 1 and figure 2).
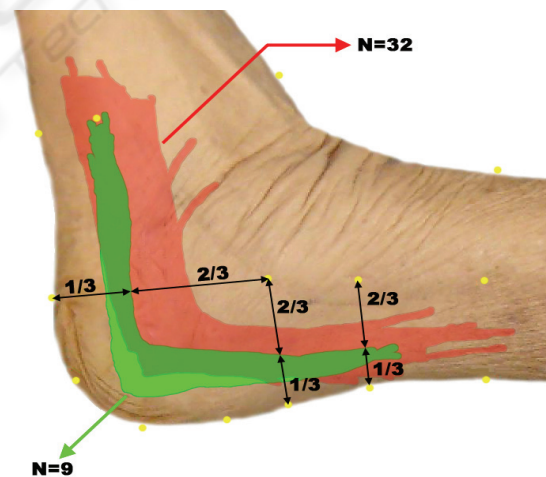

Figure 2: CASAM-generated image, depicting an average leg in which 43 incisions drawn by 23 surgeons were evaluated. Red area: Incisions that were marked as 'wrong' (N=32). Green area: Incisions that were marked as 'good' (N=9).

Within each of these groups rights can be assigned to different users, to allow access to specific projects for specified users only. Also it is possible to differentiate between 'read-write' and 'read-only'

access. A time-out for inactivity prevents unauthorized use of the data.

2.2 Features

Our software enables users to do their work in an efficient and intuitive manner. After log-in the user is presented with available projects (figure 3).
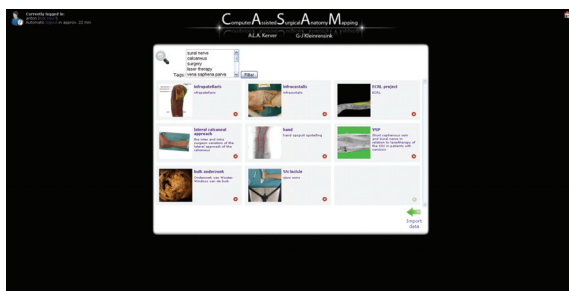

Figure 3: The project selection screen in the web interface.

After selecting a project the main work area is shown where the user can view and edit (only when permitted) existing data or add new data (figure 4). Implemented features include:

Figure 4: The web-interface work-area for researchers.

Adding tags to projects for easy project reference;

- Adding relevant scientific papers and URLs to projects;
- Fast adding and editing of shape-defining and anatomical landmarks;
- Accurate landmark-placement with the zoom-function;
- Transparency sliders for layered viewing and comparing of multiple images and overlays;
- Drawing bitmap overlays in any color to highlight structures of interest;
- Saving compositions of images, landmarks and bitmaps as states;
- Exporting project data to a zip- or CSV-file.

3 IMPLEMENTATION

3.1 Technologies

At the heart of this project Python, the Visualization Toolkit (VTK) and Python Imaging Library (PIL) were used for the required image processing techniques. Also the Web framework Django was used. Its Object-relational mapper allowed to define our datamodels in Python and allow for dynamic database-access. The built-in automatic admin interface saved a lot of work. The present application also uses JavaScript and two JavaScript frameworks: Scriptaculous for some visual effects and Prototype for easy class-driven development and Ajax. For the webpage itself HTML and CSS was used. For the drawing application Flash was used.

Django was extensively used, especially its database and templating capabilities. This allowed for testing using a simple SQLite Database, whilst MySQL was used when deploying the system on a server. Another advantage of Django's database features is that no SQL queries had to be written, since Django handles these. This made it possible to write expressive queries, whose purpose is clear from looking at them. Django's templating system made it easy to separate the HTML code from the Python code. This results in a separation between logic and presentation, which is considered to be good coding practice.

The use of JavaScript makes our system highly interactive. Prototype allowed for creating a number of different classes within this system, so that users could be allowed to easily drag-and-drop the different landmarks, change the order of the different images, and even undo the (re)placement of the landmarks. Prototype also allows for easy access to Ajax-calls, so that most changes can be stored in the database, through the use of Django's mapper, without the users noticing it.

3.2 Image processing

The first feature is a calculation of the Point Distribution Model (PDM), as developed by Tim Cootes, given a set of landmarks. This is a part of the Active Shape Model Cootes developed (Cootes, 2000). This model gives an overview of the average positions of the landmarks and local variations.

The second feature is an improvement of the original morphing technique. By defining several shape defining landmarks (for example, bony landmarks: anatomical landmarks that are palpable) per specimen all the drawn overlays can be morphed

to the selected specimen, which serves as a 'gold standard specimen'. The morphing is done using a Thin Plate Spline (Bookstein, 1989) transformation. The end result is an image of the target specimen and the drawn overlays of other specimens morphed to the target specimen.

3.3 Exporting Data

Lastly, an export feature is provided, which makes it possible to export all data from the system into an archive. This archive can then be backed up to disk, and restored later in the event of a disk failure or similar. These imports can also be restored on another system, allowing for an easy way to exchange data between different researchers. Additionally, a method is provided to export landmarks as a comma separated value (CSV) file, which enables other researchers such as statisticians to work with the data.

4 DISCUSSION

All variations of a nerve or vessel cannot be mapped, as this would require an immense number of human specimen. Therefore CASAM cannot provide a definitive safe-zone. It can however make the range for safe approach to the surgical area more precise and hence decrease the occurrence of postoperative pain and wound management problems due to unintended iatrogenic lesions of nerves and vessels

As the CASAM method relies on extended image adjustments and computer calculations it is not 100% accurate. However, the CASAM method proved to be a great asset to visualize the complex anatomy and can be used in addition to conventional means of anatomy data gathering.

In this paper, the surgically relevant anatomy of the lateral (outside) foot and the surgical approach to the calcaneus were used as an example of the successful use of the application. The CASAM method, however, can be very useful for any 2D anatomy research.

At the moment the website with the CASAM database is improved to be more user-friendly and easily accessible to surgeons and residents around the world. Currently, several projects are performed to extend CASAM to a tool used for 3-D anatomy mapping .

5 CONCLUSIONS

The web-based CASAM method can prove to be a great asset to visualize the complex anatomy of the human body and can be used in addition to conventional means of anatomy data gathering. The gathered data is also more applicable for surgeons than the current situation. The data can easily be related to an individual patient and 'tailor made' safe zones and advised incision lines might prove to lessen surgical complications. Students might benefit from more accurate safe zones and personal feedback on drawn incision lines might reduce the learning curve of modern complex surgeries.

Several improvements are planned for the web-application. Features we are still working on include:

- Compatibility with file formats other than JPEG;
- Use of multiple colors in one image in the drawing application;
- Replacing the Flash drawing application with a canvas implementation;
- Storing statistical data with landmarks;
- Measuring distances within images;
- Creating new graphical user interfaces for surgeons and students;
- Multi-level zooming.
- Verification of all anatomical data in embalmed specimen.
- Determine the clinical significance and functionality of the CASAM system.

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