Visualisation for Shoulder Replacement Surgery

Although honest researchers with families have been drawn, quartered and shot for far better definitions of scientific visualisation, I'm going to risk it and show the shortest one I know of:

***Scientific visualisation is the art of turning raw data into pretty pictures.** [1, page 1]*

One of the reasons to make these pretty pictures is to utilise the extraordinarily well-developed human visual system (HVS). The HVS is able to recognise patterns and features in visual data with a speed and accuracy that are unmatched. This visual recognition assists detection and comprehension of the phenomena responsible for the raw data and that is, after all, the whole purpose of acquiring the raw data in the first place!

A major application of scientific visualisation is in the field of medicine where clinicians have to deal with an increasing amount of patient-specific data generated by modern acquisition modalities, such as Computerised Tomography (CT) and Magnetic Resonance Imaging (MRI). Much of the diagnostically useful information locked up in these data is often not utilised due to the sheer amount and unstructuredness of the data. Visualisation techniques can alleviate this problem.

Project 2 of DIPEX (Development of Improved EndoProstheses for the upper EXtremities[2]) deals specifically with the use of visualisation and related techniques in order to help improve shoulder joint replacement, also known as shoulder arthroplasty.

The Problem

What exactly is shoulder arthroplasty, you ask? Figure 1 is a drawing of the human shoulder girdle. In short, shoulder arthroplasty, or replacement, entails that the top of the

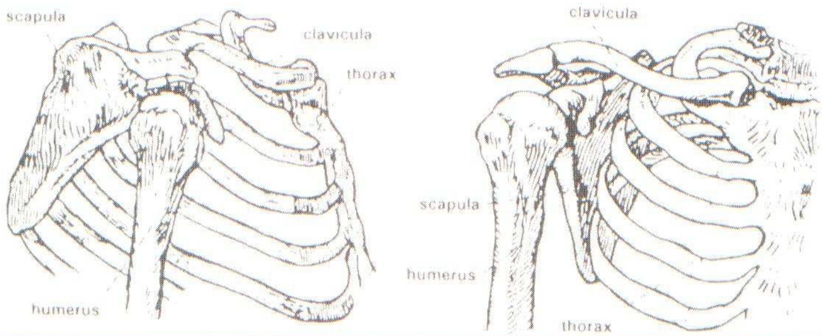


Figure 1

Sketches showing the bony structures of the shoulder girdle. Courtesy of the Delft Shoulder Group.

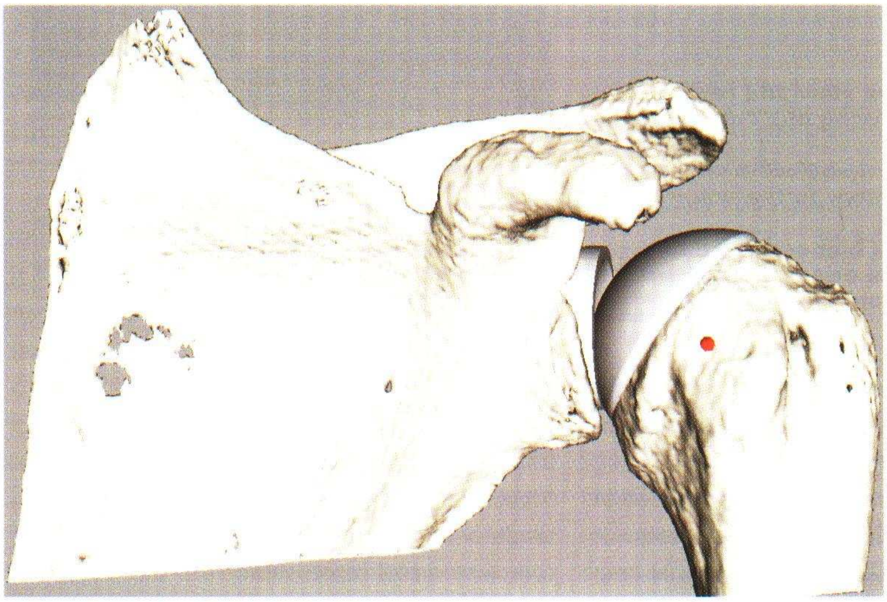


Figure 2

Visualisation of human shoulder with artificial glenoid component and humeral head implanted, i.e. a post-arthroplasty shoulder.

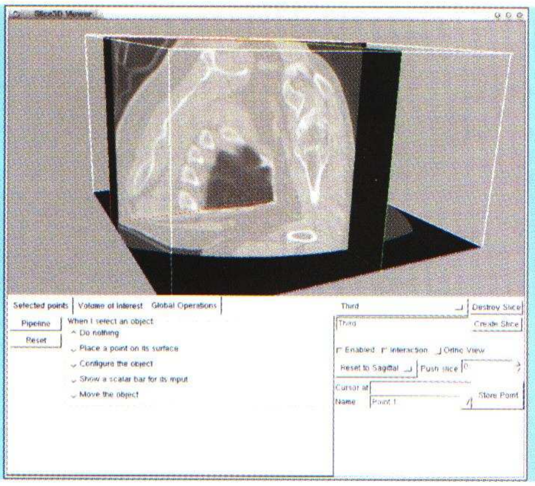
humerus (upper-arm bone) is removed and replaced with an artificial humeral head. The flat part of the scapula against which the humeral head normally rests, also known as the glenoid, is also replaced. This is done by removing some bone from the surface and then implanting an artificial glenoid component. Figure 2 shows a visualisation of a post-arthroplasty human shoulder. Only the scapula and humera head and their implants are shown.

Hip and knee replacements are very successful procedures for the treatment of rheumatoid arthritis, osteo-arthritis and trauma. Shoulder replacements, however, are far less successful: shoulder pain is mostly alleviated, but the post-operative mobility of the affected arm is often not up to expectation. In addition, the prosthetic components loosen more easily than in other joint arthroplasties and the patient has to return for a revision operation. According to some estimates, shoulder replacement technology is 15 years behind that of knee and hip replacement.

The reason for this lag is three-fold: the shoulder joint is mechanically far more complex than the hip or the knee, shoulder prosthesis design is far from a perfected art and implanting shoulder prostheses is exceptionally difficult due to the complex anatomy.

Visualisation to the Rescue!

The DIPEX project aims to improve the state of the art in shoulder replacement by optimising the actual implantation process, designing next-



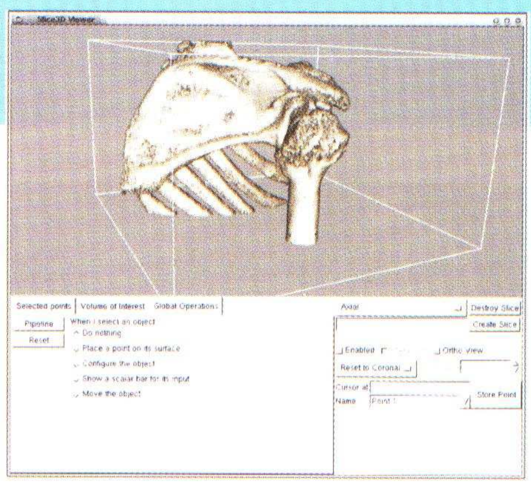


Figure 3

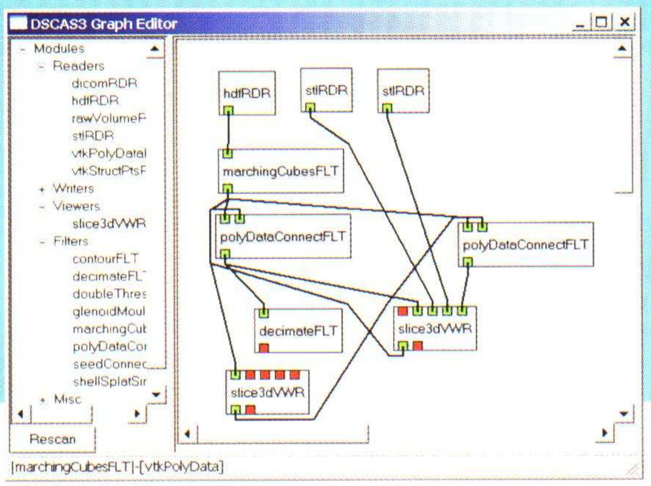
A simple slice-based view and real-time direct volume rendering of CT-data acquired from a patient shortly before a shoulder replacement operation. In the volume rendering, note the degeneration of the humeral head as well as its abnormal orientation with respect to the glenoid.

generation prostheses, modelling the structural qualities of bones and prostheses and predicting the post-operative mobility. The visualisation aspect of DIPEX creates software systems for novel pre-operative planning schemes that help the orthopaedic surgeon to better plan and execute the shoulder replacement operation.

Traditionally, orthopaedic surgeons plan shoulder replacements by making use of a radiograph (x-ray) of the patient's shoulder and transparencies of the available prosthesis designs. These transparencies are overlaid on the radiograph by the surgeon until a satisfactory fit is found. After this meagre planning, the surgeon is ready to perform the four-hour long replacement operation!

This situation can already be improved by supplying the surgeon with tools that enable her to work with a more natural three-dimensional representation of the patient anatomy. To illustrate this point, figure 3 shows two screenshots of a component of the software that we're creating. In the first screenshot, a traditional visualisation of the CT-data with three orthogonal slices is shown. Take into account that this is an improvement over a single x-ray, yet it's still difficult to build a complete virtual representation of the patient's shoulder. In the second screenshot, a new kind of real-time three-dimensional direct volume rendering of the exact same data is shown in more or less the same orientation. This makes it significantly easier to gain insight into the patient's shoulder anatomy. Such a three-dimensional representation can also be used to plan a replacement operation by virtually implanting the prostheses. Figure 2 was created in this way.

This was the first very small step in helping orthopaedic surgeons perform better shoulder replacements. In addition, this kind of tool is already available for hip and knee replacements. However, we're developing and testing new visualisation, interaction and feature extraction ideas every day. In order to be able to prototype ideas as quickly as possible, a new software framework had to be



developed. This framework was to supply an environment within which new ideas could be turned into demonstrable implementations.

The third generation of this software framework is known as DSCAS3 (Delft Shoulder Computer Assisted Surgery). DSCAS3 is based on the data-flow paradigm: functional modules are connected together (programmatically or graphically) and data that are to be processed flows through the resultant network so that each module has an opportunity to modify the data or extract features from it. Figure 4 shows a screenshot of the graph editor component of DSCAS3. Keep in mind that the graph editor is just one way of connecting modules together.

All processor-intensive code is implemented in C++. The rest of the application is implemented in Python, which enables us to perform death-defying tricks such as run-time object introspection and code modification. This, together with the fact that far less time is wasted on compile and link cycles, enables rapid development of new ideas.

DSCAS3 is also being used as a delivery platform for techniques developed by other participants of the DIPEX programme. For instance, at Man Machine Systems researchers have developed a complex musculo-skeletal model of the human shoulder[3]. This model can be used to predict the post-operative mobility of a patient's shoulder and thereby help the surgeon to make preoperative decisions with regards to prosthesis type and placement. For this reason, the model is being integrated with the planning functionality in DSCAS3.

Conclusion

Visualisation can be used to help clinicians make sense of their data. The more sense they make, the better they can apply their clinical knowledge to the problems that they have to solve. In the case of shoulder arthroplasty, we are working hard to create the algorithms and tools with which orthopaedic surgeons can more eciently analyse their data and make sound decisions that lead to more successful joint replacements.

If you would like to help a different kind of clinician make sense of their data by performing your graduation project in the exciting world of scientific visualisation, you could consider joining the Visible Orbit Project![4]

References

[1] W. Schroeder, K. Martin, and B. Lorensen, The Visualization Toolkit. Prentice Hall PTR, 2nd ed., 1999.
[2] "DIPEX project home page." *http://www.wbmt.tudelft.nl/mms/dipex/index.htm.*
[3] F. C. van der Helm, "A finite element musculo-skeletal model of the shoulder mechanism," Journal of Biomechanics, vol. 27, no. 5, pp. 551–569, 1994.
[4] "Visible orbit project home page." *http://visualisation.tudelft.nl/projects/vo/*