EG UK Theory and Practice of Computer Graphics (2009)
Wen Tang, John Collomosse (Editors)

Developing an Application to Provide Interactive Three-dimensional Visualisation of Bone Fractures

A. F. Wilson [1], P. B. Musgrove[1], K. A. Buckley[1], G. Pearce[1], and J. Geoghegan[2]
[1] School of Computing and I.T., University of Wolverhampton, Wolverhampton. UK
[2] Derbyshire Royal Infirmary, Derby, UK.

Abstract

The main research question for this work is: What are the factors involved in developing a three-dimensional (3D) interactive model of a bone fracture and how best may these be addressed? This paper presents work in progress of the development of an Interactive Bone Fragment Manipulation tool which could be used as an aid for pre-operative planning of surgery on complex fractures.

Categories and Subject Descriptors (according to ACM CCS): I.3.5 [Computer Graphics]: Computational Geometry and Object Modelling: Curve, surface, solid, and object representations

1. Introduction

This work in progress is looking at using computer visualisation as a medical imaging aid to help surgeons in the repair of bone fractures. Previous work, which was looking at two-dimensional (2D) images [WMB*06 and WMB*07], has been further developed to deal with three-dimensional (3D) images. This paper uses data from a wrist fracture to illustrate the progress of the research.

Medicine has successfully used imaging and visualisation for many years [DEV99]. X-rays, or radiographs, were the first medical images used for diagnosis and training. Before such images were developed, medical training in anatomy had to be done on cadavers [CZ07]. X-rays are images that show a cross-section of internal structures, showing dense tissues, such as bone, more clearly than soft tissues, such as muscle. Using X-rays for diagnosis has been developed further by Computed Tomography (CT) scans which produce a series of slices of data. It is also known as computed axial tomography because the series of images are taken around a single axis of rotation orthogonal to the length of the body. The Visible Human Project [Ban02] is an example of CT scans where a person's whole body was scanned to provide anatomical information to further medical research.

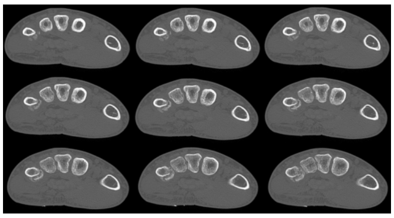

Figure 1: *Series of nine 2D slices of a wrist fracture (data acquired from Derbyshire Royal Infirmary).*

From the individual CT slices (figure 1) a 3D image can be built up (figure 2), which can provide useful information about skeletal fractures in a non-invasive way, thus removing the need to cut open a patient to discover the relative positions of the bone fragments. Such information could allow surgeons to see images of the fracture on-screen and plan appropriate surgery before actually performing the operation. This research investigates using data from CT scans to produce an image where bone fragments can be manipulated interactively by the surgeon as part of the pre-operative planning process.

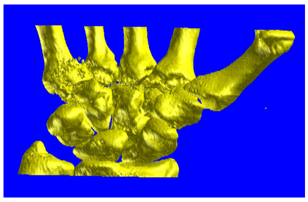

Figure 2: *3D image of a wrist fracture. (Image created using AVS/Express software).*

2. Two-dimensional Visualisation from CT Scans

This research is investigating an approach to the visualisation of data from CT scans which will allow interactive manipulation of individual objects within the image. To allow the user to understand fully the movement that an object has made within the whole scene in relation to the other objects, several views are needed of the data. Related research by Cohen and Brodlie [CB04] suggests that several different 2D views of the whole scene could help the user understand the result of manipulation of a bone fragment in relation to the main piece of bone.

Currently this work offers three different 2D views of the bone fracture, coronal (view from the front), axial (from above), and sagittal (from the side), together with a 3D image of the whole fracture. The 2D views allow no interaction with the images, they simply display the relative current positions of the bone fragments. The 3D view, however, allows the user to select a bone fragment in the 3D view and then manipulate it in relation to the main piece of bone. Each of the 2D images will then show the new position of the fragment from their direction of view.

DOI: 10.2312/LocalChapterEvents/TPCG/TPCG09/145-148

3. Edge Detection and Segmentation

Before manipulation of a fragment of bone is possible, some pre-processing of the data is required to segment the data into bone and individual bone fragments. The first process in this work uses the Sobel edge detection algorithm on each individual slice of data to find the edges of both bone and soft tissue, and then further processing eliminates edges of soft tissues that have been detected. Figure 3 shows an original CT slice where the outline of the skin can been seen in dark grey and within that area five wrist bones are outlined in paler grey.

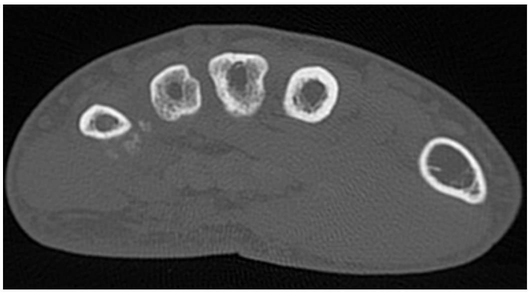

Figure 3: *A slice from the CT data of the wrist fracture.*

Figure 4 shows the same data slice where edges of both soft tissues and bones of the wrist have been highlighted, and Figure 5 has eliminated edges of all but the bones. Note that the algorithm has detected both the outside of the bone and the hollow centre.

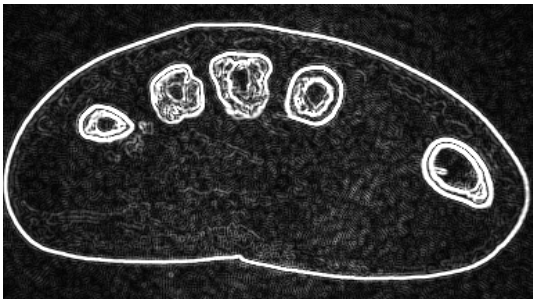

Figure 4: *The same slice from the CT data of the wrist fracture where edges have been highlighted.*

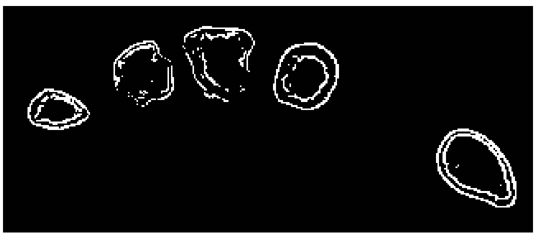

Figure 5: *The same slice from the CT data of the wrist fracture where edges of all but the bone have been eliminated.*

The Sobel edge detector was chosen because it also provides information about the direction of the edge. This is particularly useful because, once an edge of the bone has been found, the process needs to follow the edge with the intention of completely encircling the bone. The Rotating Squares method of edge following [Map00] which is based on Lorensen and Cline's Marching Squares [LC87] has also contributed to this work. It is easier to follow an edge if the direction is known. Figure 6 shows the same CT slice where the direction of the edges has been visualised using colours.

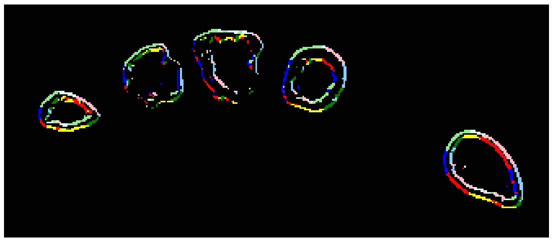

Figure 6: *The directions of the edges coloured.*

The colour scheme which was used to represent each direction, for example yellow represents direction to the right, is shown in figure 7 below.

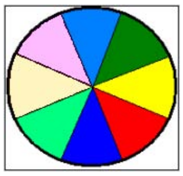

Figure 7: *A different colour is used to represent each of the angles of direction.*

A "zoom in" feature was included at this stage to allow the user to view the result more easily. Figure 8, the outlines of the little finger and the thumb, shows how this makes it easier for the user to see the edges of two of the bones. Note that the inner edge runs clockwise according to the colours but the outer edge is anti-clockwise.

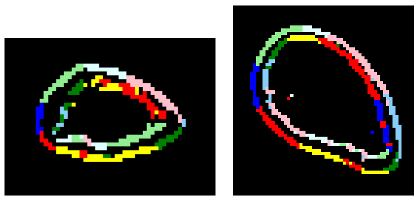

Figure 8: *A little finger, and a thumb.*

One problem that was discovered at this stage was that a clear edge is not always easily detected to completely surround every bone fragment. For example, the outlines (in figures 5 and 6) of the middle and ring fingers are not complete. Figure 9 shows the result of edge detection for both the middle and little fingers. The red pixels indicate where the outside edge of the bone has been detected. The middle finger (on the right) is incomplete whereas the little finger (on the left) shows that a complete edge has been found all the way around the finger.

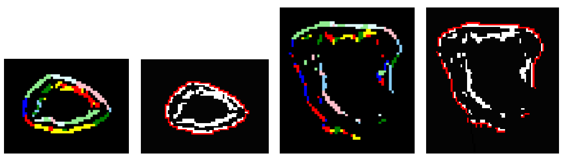

Figure 9: *Middle finger (right) shows an incomplete edge whereas little finger edge (left) is complete.*

Incomplete edges proved a problem for the next stage of the process, the segmentation of the bone fragments, so fuzzy logic was used to inspect edges of adjacent slices and thus fill the gaps left by the Sobel edge detection by determining the most likely position of the edges of the bone.

The next stage, when the edges of the bones and bone fragments have been found, is to allow the user to choose the fragment which is to be manipulated. Currently the user can choose the fragment from the 2D coronal view by drawing around the fragment with the mouse. Figure 10 shows an example where the little finger has been selected, shown outlined in orange.

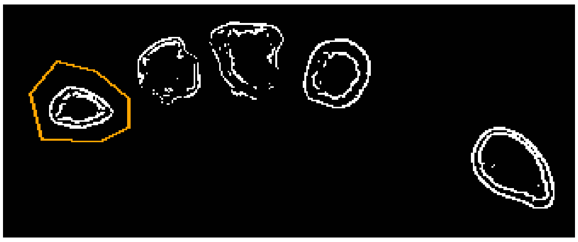

Figure 10: *2D coronal view showing little finger chosen.*

Once the fragment to be manipulated has been chosen, a user interface containing images in both 2D and 3D is displayed. The 2D images are orthoslice views through the object in each of the x, y, and z planes. The interface allows the user to choose the position of each orthoslice by providing interaction with an outline cube, as shown in figure 11. The user can use the mouse to click on a position within the cube, or use the arrows to fine-tune the position of each one individually. The yellow lines, representing the position of the coronal view (from the front) within the block of CT data, can be moved closer or further away. The blue line, representing the position of the axial view (from above), can be moved up or down, and the green line representing the sagittal view (from the right) can be moved to the left or right.

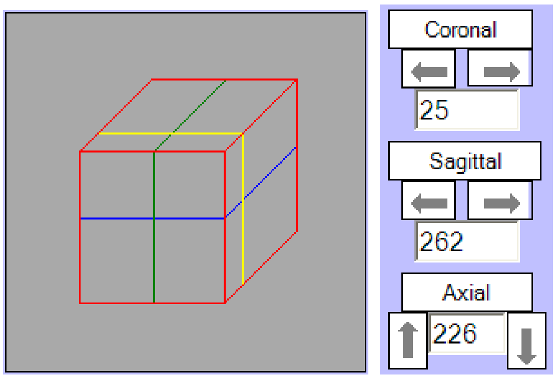

Figure 11: *User interface to control position of the three orthoslices through the CT data.*

The user needs to be able to choose the positions of the three orthoslices so that each view cuts through the bone fragment the user wants to manipulate. Figure 12 shows three orthoslices of the wrist fracture for the relative positions in the data indicated in figure 11.

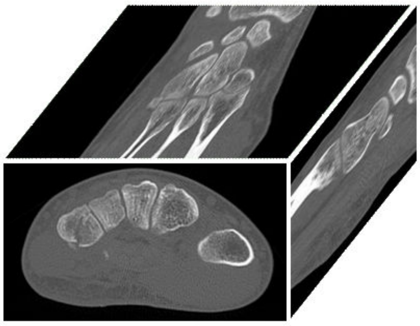

Figure 12: *Coronal, axial, and sagittal views.*

4. Three-dimensional Visualisation

Several 3D views of the bone fracture can be seen. Figure 13 shows the axial view from above and figure 14 shows the coronal view from the front.

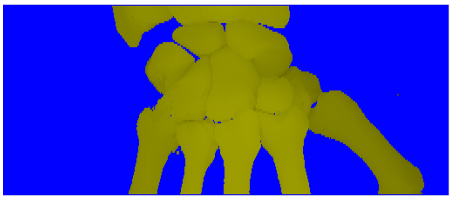

Figure 13: *3D view from above (axial view).*

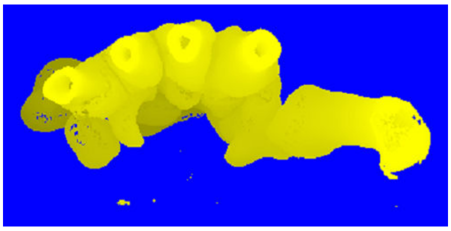

Figure 14: *3D view from the front (coronal view).*

The user can choose the fragment to be manipulated from the 2D coronal view, and then control the movement of the fragment with the mouse in the 3D view, also using the displays in the three orthoslice views as a guide.

To illustrate this, the thumb bone is segmented from the rest of the image and then manipulated. The thumb was chosen for this example because it is larger than the actual bone fragments and therefore better illustrates the process. Figure 15 shows the 3D image of the wrist fracture where the thumb bone is coloured green to distinguish it from the other bones which are coloured yellow. The thumb bone can be moved relative to the rest of the bones in any combination of rotations and translations.

Figure 15: *3D view showing thumb bone in green.*

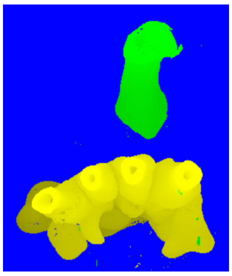

Figure 16: *3D view with thumb bone rotated 90 degrees.*

After each manipulation the images are updated to show the new position of the thumb bone and any resulting collision between the bones is coloured red in the 3D view. Figure 16 shows the thumb rotated 90 degrees and no collision is visible. Figure 17 shows the thumb translated 50 pixels which results in a slight collision between the bones which is coloured red but quite difficult to spot here.

Figure 17: *3D view with thumb bone translated 50 pixels.*

5. Further work

There are still several aspects of this work which need to be completed. The 3D display needs to be improved to make it easier for the user to see the bone fragments. Stylised rendering, as discussed by Lee et al [LYC07], may be useful here to emphasise certain relevant features. Svakhine et al [SEA09] discuss using medial illustration methods which may also prove useful in this research to enhance the images.

Collision detection algorithms need to be improved to prevent overlap of bone during manipulation. Methods suggested by Silver and Gagvane [SG00] may be relevant to this application.

Finally, it is intended that the system will use pattern recognition to analyse the final position of the bone fragments after the surgeon has completed the manipulation to indicate whether the best fit has been found, and if not, to display the positions of the fragments which do give the best fit. Automatic re-assembling of broken 3D solids, presented by Huang et al [HFG*06], offers some relevant ideas in this area. Similar problems, trying to reconstruct broken pottery, have been attempted by archaeologists [PKT01 and PK03].

The resulting prototype will be evaluated by experts in this medical field who will look at images from test data, and some samples of anonymous real data. Images of the fractures before and after manual manipulation will be compared with the results from the automatic repositioning and computer analysis of the resulting position of the bone fragments in relation to the original bone.

References

[Ban02] BANVARD R.: The Visible Human Project Image Data Set from Inception to Completion and beyond. *Proceedings CODATA* (2002).

[CB04] COHEN M., BRODLIE K.: Focus and Context for Volume Visualisation. In *Proceedings of the Theory and Practice of Computer Graphics* (2004), 32-39.

[CZ07] CHEN J.X., ZHANG T.: Anatomic Rendering and Visualisation. *IEEE Computing in Science and Engineering*, 9,1 (January/February 2007), 11-12.

[Dev99] DEV P.: Imaging and Visualisation in Medical Education. *IEEE Computer Graphics and Applications*, 19,3 (May 1999), 21-31.

[HFG*06] HUANG Q.-X., FLORY S., GELFAND N., HOFER M., POTTMANN H.: Reassembling Fractured Objects by Geometric Matching. *ACM Transactions on Graphics.* 25,3 (July 2006) 569-578.

[LC87] LORENSEN W.E., CLINE H.E.: Marching Cubes: A High Resolution 3D Surface Construction Algorithm. In *Proceedings of the 14th Annual Conference on Computer Graphics and Interactive Techniques* (1987), 163-169.

[LYC07] LEE T., YAN C., CHI M.: Stylized Rendering for Anatomic Visualization. *IEEE Computing in Science and Engineering*, 9,1 (January/February 2007), 13-19.

[Map00] MAPLE C.:Co-Planar Shape-Fitting Using the Rotating Squares Algorithm. In *Proceedings of the Fourth International Conference on Information Visualisation* (2000), 343-350.

[PK03] PAPAIOANNOU G., KARABASSI E.-A.:On the Automatic Assemblage of Arbitrary Broken Solid Artefacts. *Image and Vision Computing*, 21, (November 2003) 401-412.

[PKT01] PAPAIOANNOU G., KARABASSI E.-A., THEOHARIS T.: Virtual Archaeologist: Assembling the Past. *IEEE Computer Graphics and Applications* 21,2 (March 2001) 53-59.

[SEA09] SVAKHINE N.A., EBERT D.S., ANDREWS W.M.: Illustration-Inspired Depth Enhanced Volumetric Medical Visualization. *IEEE Computer Graphics and Applications* 29,1 (January 2009) 77-86.

[SG00] SILVER D., GAGVANI N.: Shape-Based Volumetric Collision Detection. In *Proceedings of the 2000 IEEE Symposium on Volume Visualization* (2000), 57-61.

[WMB*06] WILSON A.F., MUSGROVE P.B., BUCKLEY K.A., PEARCE G., GEOGHEGAN J.: Using computer visualisation as an aid to repairing complex intra-articular fractures. In *Proceedings of the European Modelling Symposium* (2006), 41-45.

[WMB*07] WILSON A.F., MUSGROVE P.B., BUCKLEY K.A., PEARCE G., GEOGHEGAN J.: Using 3D Visualisation in the Repair of Intra-articular Fractures. In *Proceedings of the Theory and Practice of Computer Graphics* (2007), 237-241.