COMPUTER AIDED LONG-BONE SEGMENTATION AND FRACTURE DETECTION

by

Martin Donnelley BSc, BEng (Biomed Hons) Flinders University of South Australia, 2001

A thesis presented to the

Flinders University of South Australia

in total fulfillment of the requirements for the degree of

Doctor of Philosophy

Adelaide, South Australia

Submission date: 15th January, 2008

Dedicated to Adam Lane.

You will always be remembered.

Abstract

Medical imaging has advanced at a tremendous rate since x-rays were discovered in 1895. Today, x-ray machines produce extremely high-quality images for radiologists to interpret. However, the methods of interpretation have only recently begun to be augmented by advances in computer technology. Computer aided diagnosis (CAD) systems that guide healthcare professionals to making the correct diagnosis are slowly becoming more prevalent throughout the medical field.

Bone fractures are a relatively common occurrence. In most developed countries the number of fractures associated with age-related bone loss is increasing rapidly. Regardless of the treating physician's level of experience, accurate detection and evaluation of musculoskeletal trauma is often problematic. Each year, the presence of many fractures is missed during x-ray diagnosis. For a trauma patient, a mis-diagnosis can lead to ineffective patient management, increased dissatisfaction, and expensive litigation. As a result, detection of long-bone fractures is an important orthopaedic and radiologic problem, and it is proposed that a novel CAD system could help lower the miss rate. This thesis examines the development of such a system, for the detection of long-bone fractures.

A number of image processing software algorithms useful for automating the fracture detection process have been created. The first algorithm is a non-linear scale-space smoothing technique that allows edge information to be extracted from the x-ray image. The degree of smoothing is controlled by the scale parameter, and allows the amount of image detail that should be retained to be adjusted for each stage of the analysis. The result is demonstrated to be superior to the Canny edge detection algorithm. The second utilises the edge information to determine a set of parameters that approximate the shaft of the long-bone. This is achieved using a modified Hough Transform, and specially designed peak and line endpoint detectors.

The third stage uses the shaft approximation data to locate the bone centre-lines and then perform diaphysis segmentation to separate the diaphysis from the epiphyses. Two segmentation algorithms are presented and one is shown to not only produce better results, but also be suitable for application to all long-bone images. The final stage applies a gradient based fracture detection algorithm to the segmented regions. This algorithm utilises a tool called the gradient composite measure to identify abnormal regions, including fractures, within the image. These regions are then identified and highlighted if they are deemed to be part of a fracture.

A database of fracture images from trauma patients was collected from the emergency department at the Flinders Medical Centre. From this complete set of images, a development set and test set were created. Experiments on the test set show that diaphysis segmentation and fracture detection are both performed with an accuracy of 83%. Therefore these tools can consistently identify the boundaries between the bone segments, and then accurately highlight midshaft long-bone fractures within the marked diaphysis.

Two of the algorithms—the non-linear smoothing and Hough Transform—are relatively slow to compute. Methods of decreasing the diagnosis time were investigated, and a set of parallelised algorithms were designed. These algorithms significantly reduced the total calculation time, making use of the algorithm much more feasible.

The thesis concludes with an outline of future research and proposed techniques that—along with the methods and results presented—will improve CAD systems for fracture detection, resulting in more accurate diagnosis of fractures, and a reduction of the fracture miss rate.

Contents

List of Figures

List of Tables

Declaration

I certify that this thesis does not incorporate without acknowledgement, any material previously submitted for a degree or diploma in any university, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person, except where due reference is made in the text.

Martin Donnelley

Acknowledgements

This work was supported by an Australian Postgraduate Award Research Scholarship. None of this would have been possible without the support of a great many people whom I would like to thank:

- First and foremost, my wife Ivanka, for being there when I needed it most. Thank you, I could not have completed this without you. You have been extremely patient at every step of the way, understood when there have been long delays, and supported me when I simultaneously pursued other ventures. Most of all, you always believed that I would finish, and that helped me to believe it too! Thankyou, and best of luck with your own PhD.

- All of my family, Brian, Carla, Selina and Angus, for their constant support throughout my entire candidature. Thankyou especially to my father Brian for all his suggestions, guidance and proof reading.

- My close friends Rohan, Dan, Lynda, Dave, Sean and Guy. You have all been there to constantly make my life enjoyable. Thanks to Rohan for all of his helpful proof reading and comments.

- My supervisors, Greg Knowles, Trevor Hearn and Murk Bottema, for all their advice and valuable help along the way.

- Dr John Slavotinek for his assistance with the x-ray images used throughout the project.

- All my fellow PhD students in both the Engineering and Psychology departments who made me realise that I am not alone, and that there is light at the end of the tunnel.

- Finally, to everyone whom I have neglected too much whilst writing this thesis, I apologise.

Note about the images

All the x-ray images shown in this document have been modified by inverting their brightness to make them clearer when printed on paper. As a result, dense regions such as bone tissue appear darker rather than lighter.