CHAPTER V

CONCLUSIONS

Experimental results were discussed in Chapter IV and in this chapter, the merit and weakness of the proposed femur segmentation algorithm are analyzed and discussed. Suggestions to improve the algorithm, so as to be able to segment "thin" bone regions are proposed. The chapter ends with suggestions for further extended work so as to enhance the performance of the femur segmentation algorithm.

5.1 Summary

As an outcome of this research, it was found that the performance of the proposed femur segmentation algorithm is sensitive to various parameters such as the size of the ROI, location of the ROI, number of levels for the multiresolution DWT and SOM output classes. Besides this, the type of statistical classification method also influences the quality of the results obtained. It was found, as mentioned earlier in this thesis, that the proposed algorithm performed satisfactorily on MRI images with "thick" bone regions having attributes of high contrast between bone tissue and non-bone tissue and uniform bone texture. It was found that the above characteristics of the ROI are important for acceptable performance of the proposed algorithm.

The femur bone is to be segmented as a whole for the downstream application of obtaining a CAD model. An important characteristic of organic models is that of nonuniformity in shape, unsymmetrical and varying thickness unlike CAD model of mechanical parts. In CAD model of engineering objects, uniformity and symmetry are well exploited and it is relatively easy to obtain the complete model after a painstaking design of certain key sections.

However, in organic modeling every slice of the scan needs to be segmented accurately, so as to obtain a realistic model. This is particularly important for transverse sections of high curvature, due to the rapid change in the shape of the model. The proposed algorithm performed poorly at extreme ends of the femur where the bone region is relatively thin, about 2mm. This is further aggravated by the fact that rapid changes in curvature (shape) is encountered at the femur head and the knee. For accurate modeling, very fine slices are necessary at regions of high curvature and these slices needed to be segmented with resolution at pixel level.

Currently, biomodelling engineers still rely heavily on manual classification so as to meet the tight specification requirement of realistic CAD models. It is hoped that as a spin-off of this research, a partial automatic technique for the femur shaft (region of low curvature and "thick" bone region) could partially relieve the laborious, time consuming and error prone manual classification by biomodelling engineers.

5.2 Merits of the Algorithm

The use of DWT decomposition has several advantages when compared to the traditional technique of thresholding. The thresholding method popularly used in manual classification works well when the pixel intensity is uniformally distributed within a particular region of interest. The pixel value for a particular region of anatomy varies whenever the scanning parameters are modified, causing the scanned image to appear brighter or darker. The FOV is confined within 20cm in routine clinical imaging [4] being a region of linear magnetic field. However, for a span of 20cm the slices at the ends undergo rapid change in the pixel values although not noticeable visually. For example, the first slice of the female data set has a threshold value of 270 for femur extraction and the last slice of the same data set has a threshold value of 600. The proposed algorithm instead of using localized information of pixel intensity, uses a relatively invariant quantity by encoding frequency information as coefficients. The advantage of using the frequency information is that it is robust and it was found to be invariant to changes in scanning parameters. The changes in the scanning parameters affect the pixel intensity of the MRI images, but the bone shape and texture is wholly preserved.

Multiresolution DWT preserves frequency and space information of the image. Unlike Fourier transforms which preserves frequency information, space information is totally lost. The coefficient values of the DWT are stored in an array data structure and it is possible to visually distinguish the shape of the femur in the lowpass quadrant of the WT, due to the remarkable property of space localization.

5.3 Weaknesses of the Proposed Algorithm

The problem of high computational cost of space and time persists, despite the selection of a ROI. The segmentation process of 20 slices takes 8 minutes and 25 seconds on a Matlab platform using a Sun Ultra SPARC2 workstation. High computational power and data storage capacity is required for conversion of a biological model into a CAD environment [22].

The objective of this research is to come out with a semiautomatic technique of segmentation of MRI images. However, the optimal parameters for multiresolution DWT, SOM and statistical classification varies for different data sets and has to be determined heuristically. But once the parameters are set and fine-tuned it remains the same for all slices within a data set.

At the downstream end, the objective is to obtain a CAD model of the anatomical specimen using stereolithography apparatus (SLA). Current CT and MR systems are typically limited to 512×512 pixel slices with slice thickness ranging between 0.5 to 3mm [14][22][113]. The RP machines usually uses slice thickness of less than 0.25mm [14][113]. Orthodontic and peri-orthodontic surgery require models with accuracy ranging between 0.2 and 0.3mm [21]. The limited resolution of the CT and MR data, the slice thickness and inaccuracies in classification prevent the full exploitation of the accuracy in fabrication by RP machines.

The poor segmentation results near both ends of the femur disqualifies the algorithm from hip and knee surgery planning. Additional work needs to be done in refining the algorithm, in order to achieve higher accuracy and robustness of the femur segmentation algorithm, especially for slices near both ends of the femur.

5.4 Contributions

Three-dimensional imaging has potential applications in various medical fields, e.g. traumatology, neurosurgery planning, radiotheraphy planning, medical research and education [100]. With the algorithm, it is possible to extract femur shaft volume from a set of MRI images. The extracted femur shaft would be useful in population statistical analysis of femur structure, customized femur implant design, and anatomy education. The non-health hazardous nature of MRI examination permits mass data collection, which assists the analysis of population femur structure. Personalized femur implants could be implemented given the accurately segmented femur volume and its morphometrical data. The algorithm contributed to preliminary works of femur segmentation from transverse MRI images. It serves as a prototype for semi-automated femur segmentation algorithm. The algorithm greatly simplifies the segmentation effort.

5.5 Suggestions for Further Research

A technique of overcoming the "broken ring" problem is to incorporate the paradigm of *a priori* knowledge. Instead of the user manually steering the classification, an automated classification based on the shape information of the previous classified slice (template) with a preset tolerance of uncertainty can be investigated. The diffused template will serve to direct the classification around promising neighborhood and this will not only reduce the data set tremendously but will also eliminate artifacts. A possible problem with this technique is that it may not work for consecutive slices which are different beyond the specified tolerance. If the tolerance is made too big then the accuracy will be compromised with a considerable cost in space and time. The uncertainty principle will have its dramatic influence here and trade-off of accuracy and speed of classification can be investigated. The problem of consecutive slices being very different may not be a real issue when it comes to MRI or CT scans since it is possible to obtain very fine slices of 1.5mm thick. The assumption here is that where the curvature is high, very fine slices are obtained so that the change in shape is gradual and hopefully the classification will make its hit within the specified tolerance.

The various issues of accuracy, computational time, slice spacing of scans, referencing and smoothness of the surface can be explored. The algorithms that could be used are neural, fuzzy and evolutionary based algorithms.

5.6 Concluding Remarks

A novel femur segmentation algorithm using MR scanned images have been investigated. The semi-automated algorithm fully exploits the advantages of multiresolution DWT, SOM and statistical classification. This hybrid approach provides fairly good results for slices along the femur shaft but its performance deteriorates for "thin" bone slices near the ends of the femur. Some improvements have been made to the existing algorithm but the main thrust of incorporating *a priori* knowledge has been suggested for future research.

Some assumption of shape variation, slice thickness and availability of transverse slices have been made in this investigation. Future research will attempt to relax some of the assumptions and efforts will be made to incorporate thinner slices (1.5mm), coronal and sagittal slices.

Currently, much research work has been done involving the production of bone anatomy RP models from CT images [20]. The gold standard for biomodelling is CT images [116]. MRI focuses less on hard tissue like the bone [14] hence are in general less suited for bone anatomy modelling. Excellent hard tissue rendition in CT images comes with the price of exposure to radiation. Hence, MRI scans are preferred in spite of the blurring of the image and the presence of noise. There are no known risks on patient's health or well being in exposing a patient to high magnetic field [13][27][31].

Using MRI image instead of CT scan is a trade-off between image quality which means less accurate classification of the slices and the potential health hazard.