A Review on Edge Detection on Osteogenesis Imperfecta (OI) Image using Fuzzy Logic

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Abstract. Osteogenesis Imperfecta (OI) is a bone disorder that causes bone to be brittle and easy to fracture. The patient suffered from this disease will have poor quality of life. Simulation on the bone fracture risk would help medical doctors to make decision in their diagnosis. Detection of edges from the OI images is very important as it helps radiologist to segmentize cortical and cancellous bone to make a good 3D bone model for analysis. The purpose of this paper is to review the fundamentals of fuzzy logic in edge detection of OI bone as it is yet to be implemented. Several fuzzy logic concepts are reviewed by previous studies which include fuzziness, membership functions and fuzzy sets regarding digital images. The OI images were produced by modalities such as Magnetic Resonance Imaging (MRI), Ultrasound, or Computed Tomography (CT). In summary, researchers from the reviewed papers concluded that fuzzy logic can be implemented to detect edges in noisy clinical images.

1. Introduction

Osteogenesis imperfecta (OI) is a type of bone disease caused by defects in Collagen [1]. Prediction of bone fracture due to brittleness of OI bone has become one of the important issues for this disease. Image processing and analysis is the key to get a good quality of bone modelling. Due to abnormal shape of bone, makes it difficult to segment most of current-existing medical images, getting a good visual quality of a bone edges and boundaries are proven to be complex and challenging [2]. Fuzzy logic methods are introduced as means to improve the quality of edge detection on noisy clinical images. The strength of fuzzy logic lies in handling vague information, imperfect knowledge, and ambiguity. Fuzzy logic in image processing functions by getting crisps values of an image and classifies the corresponding pixel intensity based on modified set of rules [3].

The main issue in segmenting OI bone is boundary detection. It is vital to determine the boundaries of the bone to differentiate between boundary of bone and surrounding muscle tissues. Due to the limitations of most of current-existing medical image processing techniques, getting a good visual quality of a bone image is proven to be complex and challenging. Several obstacles include: (a) bone
structures inhomogeneity, (b) low contrast edges producing non-sharp image, and (c) cancellous and cortical bone have overlapping intensity [4]. In addition, there is no study regarding implementation of fuzzy logic in detecting edges of OI images, this is crucial due to the imprecise knowledge of the image itself. Therefore, the edge detection using fuzzy logic of OI bone will give important enhancement for detecting edges, especially in differentiating the bone with soft tissue. The processed image will improve the accuracy for image segmentation and bone modelling which can be used for fracture risk prediction.

2. Osteogenesis Imperfecta

Osteogenesis imperfecta (OI) also known as brittle bone disease affects the human skeleton specifically by causing fractures and lowering bone mass [1]. This globalized, inherited, connective-tissue disease is known to be autosomal dominant albeit being identified several rare cases of recessive and X-chromosome linked forms [5]. The name osteogenesis imperfecta in Latin means imperfect bone formation, coined by Willem Vrolik describing a case of numerous fractures of a newborn in the 1840s [5]. Mutations in either of the type I collagen encoding genes Collagen type 1 Alpha (COL1A1) and Collagen type 2 Alpha (COL1A2) are known to be the causes of OI, affecting the main component of the extracellular matrix of bone and skin [7]. This causes and irregular or decreased in production of protein collagen [8]. This rare disease has a frequency of occurring in 1 in 15,000 to 20,000 births, causing patients to suffer from bone fracture throughout their lifetime [9].

The disease is divided into four different types based on severity and symptoms during clinical signs and practice [10]. Type I is identified as the least severe while type II is identified as the most severe. For patient suffering from type I OI, they appear to be stable at birth with no fractures recorded. However, fracture rate increased as they aged and decreases as they hit puberty. Patient may appear to have symptoms such as abnormal thinness, double-jointedness, broken teeth and bluish sclerae of the eye which is caused by pigmentation from the choroid. Deformity of the skull and inner ear caused by type I OI will cause hearing impairment towards the patients. For type II OI, patient may have cases of fractures before birth. Chances of survival decrease during adulthood, and they may experience extreme paralysis. Type III and IV OI level of severity lies between type I and II [11].

The main cause of OI is due to interruption in osteoblast production and continuous assembly of collagen type I which is found in most tissues [1]. Hence, all of tissues including human bone is affected the mutation in genes caused by COL1A1 and COL1A2. Bone matrix and bone architecture composition are the two mostly affected by mutation caused by OI. Patients with OI are ranged widely in terms of medical outcome, from mild symptoms of normal life expectancy to intrauterine death.

Treatment of OI patient focuses on developing bone mass, controlling symptoms and prevention of fractures. There is no cure for OI, hence the best approach is by undergoing treatment process. One of the methods in preventing fractures and correcting deformities is by insertion of metal rods into patient’s bones [10]. The brittleness and low bone mass of the OI bone is caused by uneven distribution of material and minimal bone mineral density in bone biopsies [12].

3. Edge Detection

Edges in an image occur due to abrupt or sudden change on any of the pixel level characteristics. Edges can be identified due to variation in light absorption, colour, texture or shade and is vital in determining the picture’s surface features, size, orientation, and depth [13]. There are several techniques available for developing an optimum edge detection algorithm. Prewitt, Kirsch, Canny, Sobel are few of the computationally efficient and well-established techniques used for edge detection [14]. However, these filtering techniques are sensitive to noise despite being able to process data in relatively short time.

Medical image analysis, robotics, geographical science, military technology, and pattern recognition are few of the fields which applies edge detection technique [15]. Edge detection plays an important role in detecting anomalies and structure in MRI, X-rays, CT scans and PET scans [16]. Problems in image analysis arise when detecting continuous edge points due to irrelevant data or high frequency noises [17]. Edges are also considered as high frequency data, thus disrupting the image analysis. The known algorithms for detecting edges often generates false flags where it represents the noises as an edge.
Jiang and Bunke [18] proposed an edge detection method using scan lines estimation. Compared to other edge detection techniques, the achieved outcomes were significantly precise and sufficient. Genming and Bouzong [19] developed a 5x5 kernel with fixed threshold level based for detecting edges. However, using fixed threshold point causes inadaptability to regions with varying grayscale. It is important for adaptability techniques due to different conditions of noise in medical images. There are several recent studies in edge detection which implement the techniques for genetic algorithms with particle swarm optimization, ant colony optimization and artificial neural networks [17, 20].

4. Fuzzy Logic in Edge Detection
The first presentation of fuzzy set is introduced by Zadeh [21] in 1965. The fuzzy sets are the extension of classical crisp sets, which restricts its Membership Function (MF) to \{0, 1\}. Using fuzzy sets, the MF elements is expanded beyond zero or one using a matter of grade value. Fuzziness, which is the linguistic variable in fuzzy logic is built upon two key systems: membership grade and MFs. The theory of applying fuzzy sets into digital image was first discovered by Prewitt [22].

There are several terms used in fuzzy logic, one of them is fuzzy sets. Fuzzy set, \(A\) can be categorized by a MF, \(\mu_A(x)\). The MF assigns each variable \(x \in X\) with a number ranging from zero to unity. The Equation (1) expresses fuzzy set as:

\[
A = \{(x, \mu_A(x))|x \in X\} \quad \text{where } \mu_A(x): X \to [0,1] \tag{1}
\]

The MF indicates the range of values which belongs to \(A\) which is contrary to binary MF used by crisps set [23]. There are different MFs such as second-order polynomials, trigonometric functions or piecewise linear functions. These varying MFs allow for adaptability of usage depending on application [24].

Edge detection can also be implemented using Fuzzy Set theory [25]. Instead of using crisps values, the method performs logical and mathematical reasoning based on approximations. This proves to be an advantage by significantly reducing the complexity of problems caused by data that cannot be classified or obtained using real values. Kim et al. [26] proposed the usage of look up table by employing a 3x3 kernel. However, the methodology requires manual tuning and configuration, making it impossible to adapt to challenging tests. Another study developed by Kaur et al. [27], conducted a study by defining several fuzzy rules for edge detection. This study was significant in detecting edges for images with low noise but distorts when high noise is present.

There are several studies which incorporates the usage of fuzzy type-2, which is a higher form of fuzzy logic [28]. Greater uncertainties can be effectively resolved by using fuzzy type-2. Nevertheless, the complexity ceiling for representation of model using fuzzy type-2 increases exponentially.

Haq et al. [29] proposed an edge detection using fuzzy logic in noisy and smooth clinical images. For noisy clinical images, a 3x3 window mask is employed using fuzzy rule set to allow tracing of edges. The mask will store the pixel and the surrounding neighborhood pixels values as input and detects the changes of pixel value. From these changes it can recognize whether the consequent pixels act as an edge or not. The study uses trapezoidal membership function as an input while using gaussian membership function as an output.

5. Image Segmentation
The edge detection method is designed to help recognize the boundaries of the edge, previous research regarding Osteogenesis Imperfecta image analysis required manual tracing of bone boundaries for all available Computed Tomography images [30]. Thus, making the process tedious and time-consuming. To measure the strength of fuzzy logic edge detection method, the image must be segmented according to tibial and fibular bone parts corresponding to the previous research.

Segmentation is one of the steps in image processing. It helps to differentiate object from background, thus providing necessary information for understanding object behaviour that is limited by human visual perception [31]. Dividing an image into several parts or segments with corresponding
attributes and identical features are the main objective of image segmentation. The divided parts of an image which contains useful characteristics and properties are used for further analysis [32].

The evolution of technology in medical fields allows for better data acquisition and higher resolution images in medical analysis. Thus, image segmentation has become ever more important in providing the necessary tools for diagnosis of illness, surgical preparations, simulation of surgery, minimally invasive surgery, and radiotherapy. Segmentation of image is carried out by radiologists on medical images provided by CT scans, X-rays, ultrasound, or MRI [33]. Several difficulties faced by segmentation algorithm in image processing is due to the variation of anatomical structures and pathological deformation [34].

Watershed segmentation is one of the segmentation methods which may be used to assist in getting tibial region of the OI bone. Watershed segmentation uses the analogy of valleys and ridges which is defined by variation of pixels in a greyscale image. Watershed segmentation separates the boundaries of detected regions; however, noisy clinical images will produce numerous small regions. Hence, the fuzzy logic method used will eliminate the false edges and help separate the tibial and fibular region of bone [35].

6. Image Validation

Image validation is the process to verify and test the performance of edge detection method. Comparison between different validation method can done through validation process, which allows better understanding of inherent characteristics and behavior of a system [36]. The purpose of validation is to ensure that related measurements in the future can be reliable and trusted. Precision of segmentation method plays and important role in image analysis [37]. By using ground truth image from previous studies, the segmented image can be compared and validated. Ground-based truth image is referred to as gold standard as it segmentize the region of interest (ROI) in an expert-like manual segmentation.

Confusion matrix or error matrix consists of four basic cardinalities which is used in validation measurements [37]. Confusion matrix is a specific table layout which consists of four sub-regions: True Positive (TP), False Positive (FP), True Negative (TN) and False Negative (FN). TP indicates the pixels correctly segmented as foreground while FP indicates the pixels falsely segmented as foreground. TN indicates pixels correctly detected as background and FN indicates pixels falsely detected as background. The confusion matrix is shown in Figure 1.

![Confusion Matrix](image.png)

**Figure 1.** Confusion Matrix

There are several terms which can be derived from the components of the confusion matrix. One of the terms is sensitivity. Sensitivity is also known as True Positive Rate (TPR) which indicates portion of pixels which matches the ground truth segmented object image. The second term is specificity. Specificity can be named as True Negative Rate (TNR) which is used to determine negative pixels that contrasts [38]. Another term is accuracy, which identifies as the precise predictions out of the total predictions.
The value of sensitivity and specificity measures the quality and perfection of segmentation. The higher the sensitivity and specificity, the better the segmented image is. These terms will be used in calculating Dice Coefficient (DC) or Dice Similarity Index (DSI), which is a type of overlap index [39]. DSI is a widely known tool used to verify medical image segmentation based on ground truth. The measurement is taken between the range of 0 to 1; where 0 indicates no similarity and 1 indicates total similarity between segmented and ground truth images [40]. Hence, the segmented image is said to have better results if the DSI value approaches 1.

To access the validity of segmented image, multiple measurement metric may be used to increase the reliability of image analysis [41]. Hence calculating DSI, accuracy, specificity and sensitivity is important to ensure quantification of the proposed algorithm.

7. Conclusion
This paper discussed the methods to corporate fuzzy logic-based methods in determining the edges of OI image. The slight malformation of bones caused by OI can limit the performance of detecting edges, causing inaccuracy in bone modelling, thus impairing fracture risk analysis. Moreover, the similarity of contrast between the cortical and cancellous OI bone makes it hard to determine the difference of contrast. Fuzzy logic excels in dealing with ambiguity and imprecise data, which is present in the noisy image of OI patient’s bone. Therefore, utilizing fuzzy logic for edge detection on OI image would be meaningful as it would enhance the process of developing a patient’s bone model used for analysis of bone fracture.

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