Skull outer contour extraction image using compass scanning

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Abstract. Skull outer contour extraction is an important step for craniofacial reconstruction. It useful for performing surface reconstruction. Skull outer contour obtained by three stages: thresholding, defining region of interest, and skull outer contour extraction. Compass scanning is used to this extraction. Scanning is performed using eight compass directions, four scanning are done from the four edges of ROI area, and the other four from corner of ROI area. This proposed method successfully extracts skull outer contour for four sample slices: upper temple, eye, nose, and mouth. Scanning from four corners of ROI area gives better result than four edges of ROI area, but using all eight scanings will give the best extraction performance.

Keywords: skull outer contour extraction, craniofacial reconstruction, compass scanning.

1. Introduction

Two common modalities used in neuroimaging are the MRI and the CT [1]. Due to MRI’s inherent weakness concerning hard tissue imaging; few works have been published so far on skull segmentation in newborns using MRI [2][3]. In all the proposed methods, the extracted skull models suffer from low accuracy and absence of any information about the location of fontanels.[1]

Unlike MRI, CT scanning has some limitations such as the need to expose the subject to ionizing radiation and the lack of good contrast for soft tissues. Nevertheless, since it provides the best contrast for bone definition, CT is a preferred modality in cranial studies.[1]

Some works has done using medical images. Galdames[4] using Simplex Mesh and Histogram Analysis Skull Stripping (SMHASS) to perform skull stripping methods that are designed to eliminate the non-brain tissue in magnetic resonance (MR) brain images. They get better accuracy compared to Brain Extraction Tool (BET), Brain Surface Extractor (BSE), and Hybrid Watershed Algorithm (HWA). Tilotta[5] uses curve evolution method to perform contour extraction and makes new public database which is compose of 85 CT-scans of healthy subjecy aged 20 to 65 years old. Foi[6] has presented a fully automatic method to compute the OFD and BDP measurements from fetal ultrasound images. The method is based on fitting an ellipse modelling the head contour of the fetus to the provided ultrasound images by minimizing a cost function with respect to the parameters of the ellipse. Dogdas[7] presents a new technique for segmentation of skull and scalp in T1-weighted magnetic resonance images (MRIs) of the human head. The method uses mathematical morphological operations to generate realistic models of the skull, scalp, and brain.
Craniofacial reconstruction is a useful tool in the identification of skeletal remains when there is a lack of other forensic evidence to suggest an identity. The aim of craniofacial reconstruction is to recreate a likeness of the real face using relationship between the soft tissues and the underlying skull.[8] With the development of computer science and medical imaging, many computer-aided methods have been proposed for craniofacial reconstruction.[9][10][11]

In craniofacial reconstruction, there is an important stage to do, it is extraction of the outer contour of the skull. To build a 3D model of the head, skull outer contour extraction must be performed first. Deng[8] shows two phases of his method framework, first is extraction of the relationship between skull and face regions, and it consists of six steps: 3D CT reconstruction, global coordinate adjustment, dense point registration, segmentation, local coordinate adjustment, and PCA and PLSR. The second phase is craniofacial reconstruction for a skull, and it consists of seven steps: global coordinate adjustment, dense point registration, segmentation, locale coordinate adjustment, facial regions reconstruction, local coordinate readjustment, and fusion. This proposed method is a sub-work of 3D CT reconstruction in first phase.

2. Method
According to a study [12], skull outer contour extraction is one of segmentation method. Segmentation being classified into three categories: structural techniques, stochastic techniques, and hybrid techniques. The classification is done based on the approach used for segmentation. Structural techniques utilize some information about the structure of the region in segmenting it. Stochastic techniques are the ones that are applied on discrete voxels without any consideration for the structure of the region. The final category is the hybrid methods which include those techniques which posses characteristics of both structural and stochastic techniques.

Structural techniques tries to find structural property from region that will be segmented. Intersection surface is one of that property and done by an edge between 2 slices. The outer contour from each slice will become an important information to form those edges.

Skull outer contour extraction has three stages: thresholding, finding region of interest (ROI), and compass scanning. Fig 1 shows the stages of this work. This research is using head CT image as data, we already set some rules to meet the data, specially on stage ROI. We may try to use this extraction method on other part of body with some rule adjustments.

![Fig 1 The stages of research](image)

2.1. Thresholding
In thresholding, one assumes that the foreground can be characterized by its brightness [13]. One selects a value \( \theta \), \( \min(x(f(x))) \leq \theta \leq \max(x(f(x))) \), and sets foreground voxels, accordingly.
\[ g(x) = \begin{cases} 1 & \text{if } f(x) \geq \theta \\ 0 & \text{else} \end{cases} \tag{1} \]

In this research, we set the value of \( \theta \) manually to satisfy with the data characteristic. Its value is 0.518.

### 2.2. Finding ROI

This stage tries to keep the important region and erase the other region. Our focus is skull outer contour, we will keep everything inside the skull and remove everything outside the skull. We use ellipse to select the important region. The most important information in the CT image is slice of skull and its form is ellipse as well. The position and the size of ellipse are set manually. After we adjust ellipse and agree with its position and size, we can make the ellipse become the valid ROI.

The result of this ellipse is a binary mask. The area inside the ellipse will have logical value 1 and the outside will have logical value 0. We operate this mask with binary image produced by thresholding stage with logical operator AND. AND operator will make region inside ellipse area still remain like what they are, but changes area outside ellipse to logical value 0. After this stage we successfully clear some objects outside the ellipse.

![Fig 2 Region of interest stage; (a) Blue ellipse, (b) After clearing, (c) Minimize the computational area](image)

The other advantage of this ellipse is its position. We can use its position to minimize the computational area. We wish we can save a little computational time. Fig 2 show the result of stage ROI, Fig 1a shows the adjustable blue ellipse, we can move or resize it. Fig 1b show the result after being operated with the mask. Fig 1c show the position of the ellipse after being converted to a rectangle.

### 2.3. Compass scanning

After stage ROI, we get clear binary image with smaller area, and we run compass scanning within this area. The concepts of compass scanning is simple, de do the scanning activity according to eight direction of wind. We can have 4 scanning groups, horizontal, vertical, and two diagonals. Horizontal scanning covers west and east, vertical scanning covers north and south, primary diagonal covers north west and south east, and secondary diagonal covers north east and south west. Scanning on a certain direction, actually the same as running multiple line using linier equation.

| Direction                  | Equation                | Constraints              |
|----------------------------|-------------------------|--------------------------|
| Horizontal                 | \( y = c \), with: \( y_{\text{min}} \leq c \leq y_{\text{max}} \) | (2)                      |
| Vertical                   | \( x = c \), with: \( x_{\text{min}} \leq c \leq x_{\text{max}} \) | (3)                      |
| Primary Diagonal           | \( y = x + c \), with: \( y_{\text{min}} \leq c \leq y_{\text{max}} \) | (4)                      |
form top left and bottom right \[ x = y + c, \text{ with: } \text{xmin} \leq c \leq \text{xmax} \] \text{(5)}

Secondary Diagonal \[ y = -x + c, \text{ with: } \text{ymin} \leq c \leq \text{ymax} \] \text{(6)}

from top right and bottom left \[ x = -y + c, \text{ with: } \text{xmin} \leq c \leq \text{xmax} \] \text{(7)}

Each scanning through a certain line will search the first white pixel and stop, save the pixel, then continue to next line. That white pixel represent the outer contour of the skull. We have four scanning groups, as the result, we will have four results as well. We count the number of white pixel to determine which scanning is more effective.

3. Result and Discussion
We have done some experiment using those stages to four samples area, upper temple, eye, nose, and mouth. Each location has ten samples. Fig 3 shows result image on eye location. Fig 4 shows result image on upper temple location.

From the result image we can say that when we working with hard tissue (Fig 4), this method can give us excellent result, but when there is much soft tissue in it we can have some false detection and that pixel become noise (Fig 3). The noise can be produced by some holes on outer contour of skull. When the scanning process is working and there is a hole on its path, the scanning will continue to working until it find the first white pixel. This white pixel will be a false pixel, because its location no longer serves as outer contour of skull.

Now we discuss the other result we have, the counter of white pixel for each scanning group. We record all counter for each experiments. Table 1 shows the record from nose locations. Table 2 shows the record from mouth location.

Fig 3 Result image from eye location; (a) ROI result, (b) Horizontal result, (c) Vertical result, (d) Primary diagonal result, (e) Secondary diagonal result, (f) Combine result
Fig 4 Result image from upper temple location; (a) ROI result, (b) Horizontal result, (c) Vertical result, (d) Primary diagonal result, (e) Secondary diagonal result, (f) Combine result.

Table 1 Counter record for nose location

| Hor | Ver | H+V | Dia1 | Dia2 | D1+2 | ALL |
|-----|-----|-----|------|------|------|-----|
| 488 | 528 | 844 | 776  | 786  | 1225 | 1448|
| 520 | 524 | 869 | 767  | 783  | 1239 | 1464|
| 530 | 520 | 869 | 749  | 780  | 1216 | 1444|
| 536 | 514 | 871 | 737  | 776  | 1193 | 1430|
| 539 | 504 | 859 | 728  | 774  | 1184 | 1424|
| 540 | 488 | 839 | 706  | 770  | 1181 | 1412|
| 540 | 486 | 831 | 698  | 766  | 1173 | 1415|
| 547 | 486 | 827 | 696  | 762  | 1181 | 1419|
| 555 | 486 | 819 | 696  | 756  | 1189 | 1420|
| 574 | 480 | 813 | 696  | 741  | 1181 | 1405|

Table 2 Counter record for mouth position

| Hor | Ver | H+V | Dia1 | Dia2 | D1+2 | ALL |
|-----|-----|-----|------|------|------|-----|
| 446 | 377 | 621 | 682  | 655  | 1088 | 1193|
| 446 | 374 | 620 | 680  | 656  | 1085 | 1183|
| 434 | 368 | 605 | 675  | 658  | 1075 | 1159|
| 439 | 364 | 607 | 667  | 659  | 1081 | 1157|
| 432 | 360 | 597 | 666  | 660  | 1098 | 1156|
| 429 | 354 | 592 | 670  | 664  | 1104 | 1169|
| 427 | 350 | 589 | 673  | 664  | 1102 | 1173|
| 421 | 344 | 581 | 673  | 664  | 1102 | 1172|
| 408 | 338 | 572 | 670  | 660  | 1099 | 1162|
| 390 | 334 | 559 | 654  | 656  | 1070 | 1134|

From the table we can see that D1+2 has better performance than H+V. We can have decision only to depend on D1+2 to scan the image, but it still has a disadvantage, it can not cover all outer contour. As a prove, we compare D1+2 and ALL. D1+2 is combining result from primary and secondary diagonal scanning, and ALL is combining result from D1+2 and H+V. We can see that ALL always greater than D1+2. It means that although D1+2 has better performance, it doesn’t mean that it can cover all skull outer contour. H+V can have many pixels that D1+2 doesn’t have. There is a possibility, if we only use D1+2 we may have some holes leaving by H+V. According to our discussion above, a hole can bring noise, and more holes can bring more noise as well.

We already discuss this research’s results. We have two bottom line, first is holes on skull outer contour can bring noise. As a further works, we have atleast two options to fix this, first after finding ROI we can use some particularly methods to close the hole, then perform the scanning. Second option
is we perform all proposed stages, then remove those noises using some particularly methods. Whatever option we choose, it need a lot of effort to do. But those are challenges to enhance this research.

Second bottom line is about scanning, we have some scanning groups, those group is not suppose to eliminate each other, but to take over other scanning weakness. Using all scanning groups together will give us better result.

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