Adaptation of Cardinal Points Symmetry Landmarks Distribution Model to *in-vivo* B-Mode Ultrasound Images of Transverse Cross-section of Carotid Arteries

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Abstract — The geometry of the imaged transverse cross-section of carotid arteries in *in-vivo* B-mode ultrasound images are most times irregular, unsymmetrical, full of speckles and usually non-uniform. We had earlier developed a technique of cardinal point symmetry landmark distribution model (CPS-LDM) to completely characterize the Region of Interest (ROI) of the geometric shape of thick-walled simulated B-mode ultrasound images of carotid artery imaged in the transverse plane, but this was based on the symmetric property of the image. In this paper, this developed technique was applied to completely characterize the region of interest of the geometric shape of *in-vivo* B-mode ultrasound images of non-uniform carotid artery imaged in the transverse plane. In order to adapt the CPS-LD Model to the *in-vivo* carotid artery images, the single VS-VS vertical symmetry line common to the four ROIs of the symmetric image is replaced with each ROI having its own VS-VS vertical symmetry line. This adjustment enables the *in-vivo* carotid artery images possess symmetric properties, hence, ensuring that all mathematical operations of the CPS-LD Model are conveniently applied to them. This adaptability was observed to work well in segmenting the *in-vivo* carotid artery images. This paper shows the adaptive ability of the developed CPS-LD Model to successfully annotate and segment *in-vivo* B-mode ultrasound images of carotid arteries in the transverse cross-sectional plane either they are symmetrical or unsymmetrical.

Keywords — Cardinal Points, *in-vivo* B-mode ultrasound, Landmarks, Carotid Artery, Shape Space Pattern.

I. INTRODUCTION

Oftentimes, strokes are caused when there is a blockage in an artery leading to the blood supply to the brain being restricted or cut off. Around 20% of all strokes are caused by carotid artery disease and is more common in older people who have stroke [1].

The carotid arteries are the large arteries which are located at both sides of the neck under the jaw as shown in Fig. 1. Their pulse can be felt as they are quite superficial (about 1 to 3cm away from the skin). The carotid artery is divided into three vessels: the common carotid artery (CCA), the external carotid artery (ECA) and the internal carotid artery (ICA). The CCA is the main vessel and bifurcates into two branches: the ICA, which supplies blood to the brain; and the ECA, which supplies blood to the neck and face. This bifurcation is called carotid bulb and it is characterized by an enlargement

of the vessel [2]. The differentiation of the ICA and ECA is based on their depth from the skin of the neck.

Fig. 1. The position of the Carotid Artery in the neck [3].

In this work, the main vessel which is the CCA is the region where segmentation is carried out. The typical arterial wall of the CCA consists of three layers: an innermost layer, “the intima”, a middle layer, “the media”, and an outer layer, “the adventitia”. The intima-media region of the artery is a useful place to examine in the diagnosis of atherosclerosis [4].

In-vivo ultrasound images of carotid arteries especially those in B-mode need the ‘eye’ of a trained expert to be able to interpret them correctly. The geometry of the carotid arteries in these images is most times irregular, non-uniform, unsymmetrical; and the images are usually full of noise called speckles. The degree of interpretation of these images determines to a large extent the health condition of the patient. The carotid artery imaged in the transverse plane in conjunction with that made in the longitudinal plane help to determine the intima-media thickness (IMT) of the arterial wall. The IMT is a very useful marker for the diagnosis of atherosclerosis especially at its early stage [5]. The transverse image of carotid artery can show to some extent the spread of the plaques in the artery wall, and other applications of it include patient management, genetic research, and therapy evaluation [6]. An *in-vivo* B-mode ultrasound image of the transverse cross-section of a carotid artery showing the three layers of the arterial wall in the posterior region is shown in Fig. 2.

Several researchers have presented several models and algorithms that can detect and segment the cross-section of the carotid artery in ultrasound images. Some of the works of these researchers are presented as follows: A detection method was developed by [7] for the detection of artery

section area in its perpendicular cut. In their method, the Hough transformation was used for the detection of initial circle parameters while a discrimination-based artificial immune system was used for the classification of pixels located inside and outside of the artery. The main goal of their work was to find the curve of the heart cycle of blood pressure in an ultrasound video-sequence which contains a short sample of pulsating geometric dimensions of the carotid artery in time.

Fig. 2. The arterial wall layers of an *in-vivo* B-mode ultrasound image of the transverse cross-section of a carotid artery.

A reliable detection of sectional area of an artery during a time in the B-mode ultrasound video sequence frames by automatic monitoring of artery border tissue movement using the Lucas-Canade optical flow technique was developed by [8]. In their method, invariant features that are uniformly selected in the artery border area are tracked in the whole video sequence. Volume cut is then estimated by using fitted ellipse from set of these points so that the most suitable artery shape is denoted in every frame. [9] developed a method for the detection of pulsative circular objects in a medical video sequence. Their motivation for investigating this method was that a circular object is not very apparent in medical images and its detection in such frame is inaccurate. Their proposed method starts from an analysis of movement using optical flow estimation. This was followed by another main processing step; the Hough transform for the circular position estimation. Circles with expected properties are selected using the Bayes classifier and finally, the circle position in a single frame was adapted using the analysis of average pixel intensity in the directions starting from the circle center. A grammar-guided genetic programming (GGGP) automatic localization of common carotid artery (CCA) in ultrasound images was developed by [10]. In their method, the GGGP searches for the best possible combination of simple image processing tasks. The best possible solution is represented with the highest detection precision. The resulting success rate of this method was 82% which was 4% higher than the state-of-the-art at that time. [11] developed a method which employed a Viola-Jones detector for efficient detection of transverse sections of the carotid artery. Their algorithm was trained on a set of labelled images using AdaBoost algorithm, Haar-like features, and the Matthews coefficient. Their method had a high success rate, approximately 97%. However, the method was not based on the geometrical description of the object sought.

We had earlier developed the cardinal point symmetry landmark distribution model (CPS-LDM) to completely

characterize the ROI of the geometric shape of a transverse cross-section of simulated B-mode ultrasound images of carotid arteries in [12]. We proceeded to apply this developed model on the geometric shape of transverse cross-section of thin-walled phantom carotid arteries in B-mode ultrasound images [13]. In this paper, we model the unsymmetrical *in-vivo* arterial wall as a thick-wall and then applied the technique developed in [12], [13] on it to obtain its complete characterization. The model consists of the following components: (1) Cardinal point and inter-cardinal point symmetry description; (2) Fixed landmarks (FLs) equation, movable landmarks (MLs) equation, and the total landmarks (TLs) equation to yield the CPS-LDM equation; and (3) Shape Space Pattern (SSP) of the carotid artery based on the developed CPS-LDM equation.

II. CARDINAL POINT SYMMETRY (CPS) MODEL FOR *IN-VIVO* CAROTID ARTERY IMAGE

A. Data Acquisition

Real B-mode *in-vivo* ultrasound images of transverse cross-section of carotid artery of human patients were obtained from the Department of Telecommunication database known as ARTERY_TRANSVERSAL database [7]-[11]. The images have no symmetry at all. Fig. 3 shows a sample of the *in-vivo* B-mode ultrasound image of transverse cross-section of a carotid artery.

Fig. 3. *In-vivo* B-mode ultrasound image of a carotid artery in the transverse plane obtained from [11].

B. Arterial Wall Modelling of *in-vivo* Carotid Arteries

Due to limitations of *in-vivo* ultrasound discussed in [13], clearly imaged arterial wall shape in these kind of ultrasound images are not always symmetrical, and this makes it challenging to apply the CPS-LD Model on them. One way this problem was overcome was to 'force' the CPS-LD model developed in [12] on the *in-vivo* carotid artery images i.e., adapting the *in-vivo* carotid artery images to possess symmetry such that when the CPS-LD model developed in [12] was used for the segmentation of the ROI on these images, they were found to perform satisfactorily. In order to achieve this, the ROIs in these images were first identified which is the encircled portion shown in Fig. 4 for example. Due to the unsymmetrical nature of the *in-vivo* carotid artery images, instead of a single VS-VS vertical symmetry line used in [12], each ROI in the *in-vivo* carotid artery image has its own VS-VS vertical symmetry line drawn as much as possible from the midpoint of each ROI. This is shown in Fig. 5.

annotate the ROI boundaries of the carotid artery image, the ML equation as developed in [12] is given as (2):

$$MLS = n(K_{WNE}^{1,4}) + n(K_{WSE}^{1,4}) + n(K_{WNE}^{2,3}) + n(K_{WSE}^{2,3}) \quad (2)$$

Equation (2) is a series expansion of the notation $n(K_{CP}^{ROI})$ where $n(K)$ is the number of integer points on the wall boundaries of the ROIs, the superscript ROI is the position of the ROI under consideration where the ROI positions could be 1, 2, 3, or 4; and the subscript CP is the cardinal point region under consideration where CP could be NW, NE, SW, SE, ..., etc.).

In matrix-like form, equation (2) becomes (3):

$$MLS = \begin{bmatrix} K_{WNE}^{1,4} & K_{WNE}^{2,3} \\ K_{WSE}^{1,4} & K_{WSE}^{2,3} \end{bmatrix} \quad (3)$$

The Total Landmarks (TLs) that can completely annotate the geometry of the in-vivo carotid artery image is governed by equation (4).

$$TLs = FLs + MLs \quad (4)$$

Combining equation (1) and (3), equation (4) becomes (5):

$$TLs = 4U_M + \begin{bmatrix} K_{WNE}^{1,4} & K_{WNE}^{2,3} \\ K_{WSE}^{1,4} & K_{WSE}^{2,3} \end{bmatrix} \quad (5)$$

IV. APPLICABILITY OF THE CPS-LD MODEL TO *IN-VIVO* B-MODE CAROTID ARTERY IMAGED IN THE TRANSVERSE PLANE

A. Example 1

Assuming we want to completely annotate a given in-vivo carotid artery image with 80 landmarks, we want to show how equation (5) can help to accomplish the distribution of landmarks on the in-vivo carotid artery image for annotation which will enable its segmentation.

The Fixed Landmarks FLs are given as equation (1), where $M = 1 : 4$ [12]; and ROI 1, 2, 3 and 4 are to be annotated. Hence,

$$FLs = 4 \times 4 = 16 \text{ landmarks}$$

Fig. 9 shows the position of the FLs on the in-vivo carotid artery image. ImageJ2 [14] software was used to generate the coordinates of the FLs which was then used to obtain the Shape Space Pattern (SSP) of the image as shown in Fig. 10.

Considering equation (4), subtracting the 16 landmarks used for the FLs from the total 80 landmarks to be used for annotation, we are left with 64 landmarks. The MLs equation of (3) was used to distribute this remaining 64 landmarks.

Since the MLs are at the user's discretion, we assigned the matrix values as follows:

$$n(K_{WNE}^{1,4}) = 12, \quad n(K_{WSE}^{1,4}) = 12,$$

$$n(K_{WNE}^{2,3}) = 4, \quad n(K_{WSE}^{2,3}) = 4$$

So that $12 + 12 + 4 + 4 = 64$ MLs as required.

Fig. 9. Positions of the FLs on the *in-vivo* B-mode ultrasound image of carotid artery in transverse plane based on equation (1).

Fig. 10. The SSP for the FLs annotated on the unsymmetrical *in-vivo* carotid artery image.

The superscript 1, 4 and subscript WNE of the term $n(K_{WNE}^{1,4}) = 12$ implies that ROIs 1 and 4 are divided equally into NW and NE respectively so that along the NW direction, 6 landmarks will be annotated on it and the remaining 6 landmarks will be annotated along the NE direction. This procedure which is applied to the other terms is captured mathematically as given in equations (6) and (7).

$$MLS = \begin{bmatrix} ROI\ 1, 4 : [WNE] = 12 & ROI\ 2, 3 : [WNE] = 4 \\ ROI\ 1, 4 : [WSE] = 12 & ROI\ 2, 3 : [WSE] = 4 \end{bmatrix} \quad (6)$$

$$MLS = \begin{bmatrix} ROI\ 1, 4 : NW = 6 & ROI\ 2, 3 : NW = 2 \\ ROI\ 1, 4 : NE = 6 & ROI\ 2, 3 : NE = 2 \\ ROI\ 1, 4 : SW = 6 & ROI\ 2, 3 : SW = 2 \\ ROI\ 1, 4 : SE = 6 & ROI\ 2, 3 : SE = 2 \end{bmatrix} \quad (7)$$

Fig. 11 shows the distribution of the FLs and MLs on the image using the Image J2 software.

Fig. 11. Landmark distribution for both the FLs and MLs on the *in-vivo* Carotid Artery Image in transverse plane of Figure 9 (80 landmarks).

The coordinates of the landmarks were also generated from ImageJ2. The generated values are shown in Table I.

TABLE I: COORDINATES GENERATED BY IMAGEJ2 FOR FIG. 10

Label	Land-mark	Xcor	Ycor	Label	Land-mark	Xcor	Ycor
1	FL	30.0	38.0	41	FL	57.5	92.3
2	ML	33.3	31.5	42	ML	61.8	94.3
3	ML	39.3	27.3	43	ML	66.8	94.5
4	ML	45.5	24.0	44	FL	72.3	94.8
5	ML	52.8	22.0	45	ML	78.3	94.5
6	ML	66.8	20.3	46	ML	83.3	93.8
7	ML	74.3	20.0	47	FL	88.0	91.8
8	FL	59.8	20.8	48	ML	83.3	91.0
9	ML	80.8	20.3	49	ML	78.3	91.3
10	ML	87.3	21.0	50	FL	72.3	91.3
11	ML	94.0	22.5	51	ML	67.0	91.3
12	ML	100.0	24.5	52	ML	61.5	91.5
13	ML	105.8	26.8	53	FL	46.0	94.8
14	ML	112.0	29.8	54	ML	47.0	98.3
15	FL	114.0	35.3	55	ML	50.5	100.8
16	ML	110.5	34.5	56	ML	54.3	102.5
17	ML	105.0	32.0	57	ML	58.8	103.8
18	ML	99.2	29.8	58	ML	63.3	104.0
19	ML	93.3	35.3	59	FL	67.5	104.0
20	ML	87.3	26.3	60	ML	72.0	104.3
21	ML	80.8	25.3	61	ML	76.8	104.3
22	FL	74.5	24.8	62	ML	80.8	104.0
23	ML	67.0	25.3	63	ML	84.5	103.5
24	ML	60.3	26.0	64	ML	89.0	102.3
25	ML	53.8	28.0	65	M	92.5	100.5
26	ML	47.3	30.8	66	ML	95.3	98.3
27	ML	41.5	33.5	67	FL	96.5	95.3
28	ML	36.5	37.5	68	ML	92.3	95.3
29	FL	68.3	31.5	69	ML	89.3	96.8
30	ML	70.8	30.0	70	ML	87.3	98.3
31	ML	74.8	29.3	71	ML	83.5	98.8
32	FL	78.0	29.0	72	ML	80.0	99.0
33	ML	82.0	29.5	73	ML	76.5	99.0
34	ML	85.5	30.3	74	FL	71.6	98.8
35	FL	87.3	32.5	75	ML	67.0	98.8
36	ML	85.5	32.3	76	ML	63.5	98.8
37	ML	82.0	32.3	77	ML	59.5	98.3
38	FL	78.3	32.3	78	ML	55.8	97.8
39	ML	74.8	32.3	79	ML	52.0	96.0
40	ML	71.0	32.3	80	ML	49.0	94.3

From the generated coordinates of the landmarks shown in Table I, the complete Shape Space Pattern (SSP) of the carotid artery image is shown in Fig. 12.

Fig. 12. The complete SSP of the *in-vivo* Carotid Artery Image of Fig. 10.

B. Example 2

Given the following equation for another *in-vivo* B-mode ultrasound image of a carotid artery in the transverse plane;

$$TLs = 4U_M + \begin{bmatrix} 12 & 4 \\ 11 & 3 \end{bmatrix} \quad (8)$$

Calculate the TLs required to fully annotate the carotid artery and show its Shape Space Pattern (SSP).

a) Calculations, Results and Discussion

From equation (1), the fixed landmarks are:

$$FLs = 4 \times 4 = 16 \text{ landmarks}$$

To obtain the movable landmarks, we have that

$$n(K_{WNE}^{1,4}) = 12, n(K_{WSE}^{1,4}) = 11, \\ n(K_{WNE}^{2,3}) = 4, n(K_{WSE}^{2,3}) = 3$$

Then

$$MLs = \begin{bmatrix} ROI 1, 4: [WNE] = 12 & ROI 2, 3: [WNE] = 4 \\ ROI 1, 4: [WSE] = 11 & ROI 2, 3: [WSE] = 3 \end{bmatrix} \quad (9)$$

For $n(K_{WSE}^{1,4}) = 11$, symmetry equation demands that SE = 5.5, and SW = 5.5 [12]. However, the number of points must be an integer; hence the symmetry equations are modified to make one side greater than the other side by one integer. For the example above, the following choices can be made

$$(1) SE = 5 \text{ and } SW = 6 \quad (10)$$

or

$$(2) SE = 6 \text{ and } SW = 5. \quad (11)$$

Once any of the choice is chosen, it must be consistently maintained for all set of the *in-vivo* carotid artery images.

Going for the choice of (11), and making similar procedure and choice for $n(K_{WSE}^{1,4}) = 3$, the MLs equation becomes:

$$MLs = \begin{bmatrix} ROI\ 1, 4 : NW = 6 & ROI\ 2, 3 : NW = 2 \\ ROI\ 1, 4 : NE = 6 & ROI\ 2, 3 : NE = 2 \\ ROI\ 1, 4 : SW = 6 & ROI\ 2, 3 : SW = 2 \\ ROI\ 1, 4 : SE = 5 & ROI\ 2, 3 : SE = 1 \end{bmatrix}$$

$$MLs = (2 \times 6) + (2 \times 6) + (2 \times 2) + (2 \times 2) + (2 \times 6) + (2 \times 5) + (2 \times 2) + (2 \times 1)$$

$$MLs = 12 + 12 + 4 + 4 + 12 + 10 + 4 + 2$$

$$MLs = 60 \text{ landmarks.}$$

The total landmarks (TLs) that fully describe the geometry of the *in-vivo* carotid artery image is calculated thus:

$$TLs = FLs + MLs$$

$$TLs = 16 + 60$$

$$TLs = 76 \text{ landmarks}$$

Fig. 13 shows the complete SSP obtained for the *in-vivo* B-mode ultrasound carotid artery image.

Fig. 13. The complete SSP for the *in-vivo* B-mode Carotid Artery Image.

V. CONCLUSION

In this paper, the Cardinal Point Symmetry Landmark Distribution Model (CPS-LDM) we developed in [12], applied in [13], was adapted to sufficiently segment the ROIs of *in-vivo* B-mode ultrasound image of thick-walled unsymmetrical carotid artery imaged in the transverse plane by replacing the VS-VS vertical symmetry line to enable it to possess symmetric properties despite that they are unsymmetrical images. This work shows that the CPS-LD model is adaptable to fully annotate both symmetrical and unsymmetrical carotid arteries images in the transverse plane for segmentation.

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