Application of Cardinal Points Symmetry Landmarks Distribution Model to B-Mode Ultrasound Images of Transverse Cross-section of Thin-walled Phantom Carotid Arteries

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Abstract—We had earlier developed a technique based on 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. In this paper, this developed technique was applied to completely characterize the region of interest of the geometric shape of B-mode ultrasound images of thin-walled phantom carotid artery imaged in the transverse plane. The developed model employs a combination of fixed landmarks (FLs) and movable landmarks (MLs) to obtain the total landmarks (TLs) that can sufficiently segment the shape of the ROI of the carotid artery. For the phantom carotid arteries, three FLs are fixed on each of the four ROIs determined by the cardinal points North (N), South (S), East (E) and West (W) drawn on the ROIs of the phantom carotid artery. The MLs are determined by the inter-cardinal directions such as North-East (NE), North-West (NW) and so on. The obtained CPS-LDM equation developed allows graphical visualization the optimum number of points that can sufficiently segment the ROIs. ImageJ2 software was used to generate the Cartesian coordinates for each landmark which were then used to generate the Shape Space Pattern (SSP) of the phantom carotid artery ready for further statistical analysis. The results showed that the CPS-LD model is generic and adaptable to a variety of transverse cross-sectional B-mode ultrasound images of thin-walled phantom carotid artery.

Index Terms—Cardinal Points, Phantom Carotid Artery, Landmarks, Region of Interest, Ultrasound.

I. INTRODUCTION

Cardiovascular disease (CVD) is the first leading cause of death and adult disability in the industrial world [1]. Arteries are the blood vessels transporting blood from the heart out to the body. The arteries are elastic and they move when the heart is pumping. The arteries widen due to the incoming blood, but the arterial wall also moves along the blood flow back and forth. A very important artery in the human body is the carotid artery [2]. The carotid arteries are the main blood vessels that carry blood and oxygen to the brain. When these arteries become narrowed, it is called carotid artery disease. It may also be called carotid artery stenosis. The narrowing is caused by atherosclerosis which is the buildup of fatty substances, calcium, and other waste products inside the artery lining. Carotid artery disease reduces the flow of oxygen to the brain. If the narrowing of the carotid arteries becomes severe enough that blood flow is blocked, it can cause a stroke.

The typical arterial wall consists of three layers: an innermost layer, “the intima”, a middle layer, “the media”, and an outer layer, “the adventitia”. This is illustrated in Fig. 1. The intima-media region of the artery is a useful place to probe the diagnosis of atherosclerosis [3].

A large variety of imaging modalities are being used to study the carotid artery. Examples are X-rays, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Fluoroscopy, Ultrasound, etc. [5]. Compared to other prominent methods of medical imaging, ultrasound has several advantages: It provides images in real-time, it is portable and can be brought to the bedside, it is substantially lower in cost, can be battery operated and it does not use harmful ionizing radiation. Drawbacks of ultrasonography include various limits on its field of view including patient cooperation and physique, difficulty in imaging structures behind bone and air, and its dependence on a skilled operator [6]. Variability in in-vivo B-mode images of real carotid does also exist [7], [8], [9]. Sources of variability are outlined below:

1) Geometrical and diffraction effects, where spatial compound imaging may be employed to correct the image [10].
2) Inter-patient variation due to depth dependence and inhomogeneous intervening tissue, where normalization techniques may be applied to standardize the image [11].
3) Speckle which is an important factor affecting the quality of ultrasound B-mode imaging. It is described as an ultrasound textural pattern that varies depending on the type of biological tissue. The
presence of speckle, which is difficult to suppress may obscure small structures thus degrading the spatial resolution of an ultrasonic image.

4) The IMT and plaque borders generally have a very low contrast and a small thin size, which makes it more difficult to interpret.

5) Inter observer variability in which ultrasound images inspected by two or more experts will be seen to be different, as each expert will interpret a specific tissue differently [6].

It is these limitations of ultrasound images of in-vivo carotid arteries that necessitated the use of phantom carotid artery images in this research.

Accurate segmentation of the region of interest (ROI) of the phantom carotid artery image is very important for proper carotid atherosclerosis assessment and management [12]. The desired segmentation can be addressed by two main steps: (i) the definition or estimation of a region of interest (ROI) of the carotid artery in the B-mode ultrasound image and (ii) the delineation of the boundaries of the structure desired, which depends on the ROI defined and can be the artery lumen, intima or adventitia. For this reason, the two steps are considered not to be independent of each other, since the correct delineation of the arterial wall in the segmentation algorithm is strictly connected to the right definition of the ROI [13].

We had earlier developed a technique of CPS-LDM to completely characterize the ROI of geometric shape of transverse cross-section of simulated B-mode ultrasound images of carotid arteries [14]. In this paper, the technique was applied to thin-walled phantom carotid artery B-mode ultrasound images in the transverse plane (short axis plane) to obtain its complete characterization. The model consists of the following components. (1) Cardinal point and inter-cardinal point symmetry description of the simulated carotid artery. (2) Fixed landmarks (FLs) equation, movable landmarks (MLs) equation, and the total landmarks (TLS) equation to yield the CPS-LDM equation. (3) Shape Space Pattern (SSP) of the carotid artery based on the CPS-LDM equation developed.

The remainder of this paper is organized as follows. Section II describes the Cardinal Point Symmetry (CPS) of the phantom carotid artery geometry used in deriving its CPS-LDM model. Section III derives the fixed, movable and total landmarks on the CPS carotid artery. Section IV shows the results obtained from the developed equations. Conclusions are drawn in Section V and an appendix showing how the developed model can be used for landmark distribution on phantom carotid artery images is shown.

II. CARDINAL POINT SYMMETRY (CPS) MODEL FOR PHANTOM CAROTID ARTERY IMAGE

This section discusses how the CPS-LD Model we had earlier developed in [14] was adapted in segmenting the Region of Interest (ROI) of the imaged region of the transverse cross-section of phantom carotid artery B-mode ultrasound image. The phantom used is silicone-rubber tube dipped in water were obtained from [3]. The images were highly symmetrical with clear wall outline, hence, they were well suited for this work. Fig. 2 shows a sample of the transverse cross-sectional B-mode ultrasound image of the phantom. Each landmark was registered and digitized using ImageJ2 software [15].

![Fig. 2. B-mode ultrasound image of phantom carotid artery in the transverse plane obtained from [3].](image)

B. Arterial Wall Modellings of Phantom Carotid Arteries

We had earlier developed a Landmark Distribution Model for segmenting the arterial wall of simulated B-mode ultrasound images of carotid artery in the transverse plane [14]. The Region of Interest (ROI) of the simulated B-mode ultrasound carotid artery images used in the development of the CPS-LDM were modelled as thick-walled images, hence the images were landmarked with double arc points. However due to variability in B-mode images of in-vivo carotid artery for reasons stated earlier, it is possible for the arterial wall to be imaged as thin walls instead of thick walls, hence the silicone-rubber tube phantom carotid artery images used in this research are thin-walled. The adapted Cardinal Point Symmetry Landmark Distribution Model (CPS-LDM) used for capturing the geometric shape of the thin-walled silicon-tube phantom ultrasound carotid artery images are discussed in the subsequent sections in this paper.

C. CPS Model Description

The cardinal and inter-cardinal points used to develop the CPS-LDM for the phantom image are discussed in [14]. The cardinal points concept was then used to describe and label strategic points on the phantom image which subsequently led to the full description of the image. This is shown in Fig. 3 and Fig. 4.
The first two ROI (ROI [1] and ROI [2]) occupy the AR while the last two (ROI [3] and ROI [4]) occupy the PR. The leftmost tip of ROI 1 is marked by equation (1) [14].

As repeated in [14], the CPS model describes the geometric shape of the carotid arteries by two set of landmarks; The Fixed Landmarks (FLs) and the Movable Landmarks (MLs). The Total Landmarks (TLs) which completely describe the shape of the carotid arteries is given by equation (1) [14].

\[ \text{TLs} = \text{FLs} + \text{MLs} \] (1)

### A. Fixed landmarks (FLs) equation

Figure 5 shows the FLs on the phantom image, there are...
three FLs on each ROI which are the North (N), the East (E) and the West (W). For example, ROI 1 has points on N₁, E₁, and W₁. These FLs are the red points marked on the ROIs of Fig 5. If the number of ROI(s) desired to be described is represented by \( K \), then the number of FLs on any desired ROI is given by equation (2).

\[
\text{FLs} = 3U_M
\]  

(2)

Equation (2) governs the annotating of fixed landmarks on the phantom image. The rules followed in selecting the index \( M \) remains as described in [14].

The fixed landmarks (FLs) are not sufficient to fully capture the geometry of the phantom carotid artery image, hence the need for the movable landmarks (MLs).

![Fig. 5. Positions of the FLs on the phantom carotid artery image.](image)

**B. Movable landmarks (MLs) equation**

In developing the MLs equation, the symmetry of the phantom carotid artery shape shown in Figure 5 is utilized to develop symmetry equations. Symmetry equations for each ROI given in equation (3-10) were developed.

**ROI 1**

\[
N_W = NE_1
\]

(3)

\[
N_W + NE_1 = WNE_1
\]

(4)

**ROI 2**

\[
N_W = NE_2
\]

(5)

\[
N_W + NE_2 = WNE_2
\]

(6)

**ROI 3**

\[
N_W = NE_3
\]

(7)

\[
N_W + NE_3 = WNE_3
\]

(8)

**ROI 4**

\[
N_W = NE_4
\]

(9)

\[
N_W + NE_4 = WNE_4
\]

(10)

Let \( n(K_{CP}^{ROI}) \) notation represent the number of integer points on the ROIs, ROI (superscript) is the position of the ROI under consideration (ROI = 1, 2, 3, 4) and CP (subscript) is the cardinal point under consideration (CP = NW, NE, etc.)

The MLs equation is then given as;

\[
MLs = n(K_{NW}^1) + n(K_{NE}^1) + n(K_{W}^2) + n(K_{NW}^1) + n(K_{NE}^3) + n(K_{W}^4)
\]

(11)

Applying the symmetry equations (3) to (10) into equation (11) yield equation (12)

\[
MLs = n(K_{WNE}^1) + n(K_{WNE}^2) + n(K_{WNE}^3) + n(K_{WNE}^4)
\]

(12)

Applying the mirror-image condition [14] to (12), the equation for MLs becomes;

\[
MLs = n(K_{WNE}^{1,4}) + n(K_{WNE}^{2,3})
\]

(13)

Equation (13) can be written in a matrix-like form as shown in (14).

\[
MLs = \begin{bmatrix}
K_{WNE}^{1,4} \\
K_{WNE}^{2,3}
\end{bmatrix}
\]

(14)

Equation (14) governs the landmarking of movable points on the simulated carotid artery image.

**C. Total landmarks (TLs) equation**

The total number of landmarks that can be annotated on the transverse section of phantom carotid artery images to govern its complete shape characterization is given in equation (1) which is repeated below.

\[
\text{TLs} = \text{FLs} + \text{MLs}
\]

From equation (2) and equation (14), TLs becomes

\[
\text{TLs} = 3U_M + \begin{bmatrix}
K_{WNE}^{1,4} \\
K_{WNE}^{2,3}
\end{bmatrix}
\]

(15)

Equation (15) is the Cardinal Point Symmetry Landmark Distribution Model (CPS-LDM) Equation for the phantom image which completely characterizes the geometric shape of thin-walled phantom B-mode ultrasound carotid arteries imaged in the transverse cross-sectional plane.

**IV. CONCLUSION**

In this paper, the new Cardinal Point Symmetry Landmark Distribution Model (CPS-LDM) we developed was adapted to sufficiently segment the ROIs of B-mode ultrasound image of phantom carotid artery imaged in the transverse plane. The model is generic enough and adaptable to varieties of images of thin-walled phantom B-mode ultrasound carotid arteries imaged under various scenarios.

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APPENDIX

In this section, an example is shown on how to use CPS-LD Model to landmark and segment B-mode ultrasound images of thin-walled phantom carotid artery in the transverse plane. The shape space pattern for various transverse cross-section of phantom carotid artery images obtained using the adapted CPS-LDM are also shown.

A. Example

Given the equation:

$$TLs = 3U_M + \begin{bmatrix} 6 \\ 4 \end{bmatrix}$$  \hspace{1cm} (16)$$

Where $U = 4$ and $M = 1-4$. Calculate the TLs required to fully annotate the carotid artery and show its Shape Space Pattern (SSP).

$$TLs = 3 \times 4 = 12 \text{ landmarks}$$

$$(M = 1-4; \text{ROIs 1, 2, 3 and 4 are required to be described})$.

Fig. 6 shows how the FLs were annotated on the phantom carotid artery image.

$$\begin{align*}
\text{MLs} &= 6 + 6 + 4 + 4 \\
\text{MLs} &= 20 \text{ landmarks}
\end{align*}$$

$$\text{TLs} = \text{FLs} + \text{MLs}$$

$$\text{TLs} = 16 + 20$$

$$\text{TLs} = 32 \text{ Landmarks.}$$

Fig. 7 shows how the TLs were annotated on the phantom carotid artery image.

Also comparing the given equation (16) with the CPS-LDM equation given in (15), equation (14) is used to obtain the MLs where

$$n(K_{WNE}^{1,4}) = 6 \text{ implies that ROIs 1 and 4 is divided equally into NW and NE respectively. The integer 6 is arbitrary, chosen by the user and it can be changed at the user’s discretion. The underlying principle in the MLs equation is that the integer 6 is divided also into two equal integers. These equal integers in this case will be landmarked on the NW and NE of ROIs considered at that point, in this case, ROIs 1 and 4. This procedure applies to all other terms and integers in the MLs equation. This operation is captured mathematically below.}$$

$$\begin{align*}
\text{MLs} &= \begin{bmatrix}
\text{ROI 1, 4} : [WNE] = 6 \\
\text{ROI 1, 4} : [WNE] = 4
\end{bmatrix} \\
\text{MLs} &= \begin{bmatrix}
\text{ROI 2, 3} : [NW] = 3 \\
\text{ROI 2, 3} : [NE] = 3
\end{bmatrix} \\
\text{MLs} &= \begin{bmatrix}
\text{ROI 2, 3} : [NW] = 2 \\
\text{ROI 2, 3} : [NE] = 2
\end{bmatrix}
\end{align*}$$

$$\text{MLs} = 6 + 6 + 4 + 4$$

$$\text{MLs} = 20 \text{ landmarks}$$

The total landmarks (TLs) that fully describe the geometry of the phantom carotid artery based on equation (16) was calculated using equation (1),

$$\text{TLs} = \text{FLs} + \text{MLs}$$

$$\text{TLs} = 16 + 20$$

$$\text{TLs} = 32 \text{ Landmarks.}$$

The imageJ2 [15] software was used to generate the coordinates for all the 32 landmarks, the generated coordinates are shown in Table 3.

Fig. 7. Landmark Distribution for both the FLs and MLs on the Phantom Carotid Artery (32 landmarks)
Fig. 8 shows the complete shape space pattern (SSP) of the phantom carotid artery image.

![CA PHANTOM TRAINING IMAGE 1](image)

Fig. 8. The complete SSP of the phantom carotid artery image of Fig.7.

### References

[1] American Heart Association, Heart disease and stroke statistics, Available web page, www.americanheart.org/presenter.html. Date accessed, 16th of August, 2019.

[2] C. Loizou, C. Pattichis, R. Istepanian M. Pantziaris and A. Nicolaides, “Atherosclerotic carotid plaque segmentation,” *Proc. of the 26th Annual Int. Conf. IEEE EMBS*, San Francisco, California, USA, Sept. 1-5, pp. 1403-1406, 2004.

[3] A. Ponnle, A., H. Hasegawa, and H. Kanai, “Multi element diverging beam from a linear array transducer for transverse cross sectional imaging of carotid artery: simulations and phantom vessel validation,” *Japanese Journal of Applied Physics (JJAP)*, Japan, Vol. 50(7), pp. HF051 – HF0510, 2011.

[4] M. Brewin, “Carotid atherosclerotic plaque characterization by measurement of ultrasound sound speed in vitro at high frequency, 20 MHz,” *Stroke*, vol 3, pp. 29-45, 2010.

[5] I. Bankman, “Handbook of Medical Image Processing and Analysis”, 2nd Ed. Academic Press, New York, ISBN: 0-12-739047-7, 2008

[6] V. Chan and A. Perlas, “Basics of Ultrasound Imaging”, Department of Anesthesiology, University of Toronto, Toronto Western Hospital, 399 Bathurst Street MP 2-405, Toronto, ON, Canada Springer Science, 2011.

[7] J. Gill, H. Ladak, D. Steinman, and A. Fenster, “Accuracy and variability assessment of a semi-automatic technique for segmentation of the carotid arteries from three-dimensional ultrasound images,” *Medical Physiology*, vol. 27, no. 6, pp.1333-1342, 2000.

[8] J. Wilhjelm, M. Gronholm, B. Wiebe, S. Jespersen, L. Hansen, and H. Sillesen, “Quantitative analysis of ultrasound B-Mode images of carotid atherosclerotic plaque: Correlation with visual classification and histological examination,” *IEEE Transaction on Medical Imaging*, vol. 17, no. 6, pp. 910-922, 1998.

[9] I. Wendelhag, Q. Liang, T. Gustavsson, and J. Wikstrand, “A new automated computerized analyzing System simplifies reading and reduces the variability in ultrasound measurement of intima media thickness,” *Stroke*, vol. 28, pp. 2195-2200, 1997.

[10] A. Wahle, P. Pauze, S. Dejong, and M. Sonka, “Geometrically correct 3D reconstruction of Intra Vascular ultrasound images by fusion with biplane angiography-methods and validation,” in *IEEE Transaction of Medical Imaging*, vol. 98, pp.1-14, 1999.

[11] T. Elatrozy, A. Nicolaides, T. Tegos, A. Zarka, M. Griffin, and M. Sabetai, “The effect of B-mode ultrasonic image standardization of the echodensity of symptomatic and asymptomatic carotid bifurcation plaque,” *International Angiology*, vol.17, no.3, pp.179-186, 1998.

[12] A. Fenster, G. Parraga, A. Landry, B. Chiu, M. Egger, and J. Spence, “3D US imaging of the carotid arteries,” *in Advances in Diagnostic and Therapeutic Ultrasound Imaging*, Artech House, 1st ed. pp. 67–92, 2008.

[13] F. Miguel, A. Tavares, J. Sousa, L. Santos, R. Castro, P. Azvedo and T. Elsa, “Automatic segmentation of the lumen of the carotid artery in ultrasound B-mode images,” *Expert Systems Biomedical Journal*, vol. 40, pp. 117-122, 2013.

[14] C. Udekwu, and A. Ponnle, “Cardinal Points Symmetry Landmarks Distribution Model for Segmentation of Region of Interest in Simulated B-Mode Ultrasound Carotid Artery Images”, *EJERS, European Journal of Engineering Research and Science*, Vol. 4, No. 5, May 2019.

[15] C. Rueden, J. Schindelin, and M. Hiner, “ImageJ2: ImageJ for the next generation of scientific image data,” *BMC Bioinformatics*, vol. 18, pp. 529, PMID 29187165, 2017.

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