Suitable Image Intensity Normalization for Arterial Visualization

Yara Omran, Radek Benes, Kamil Riha

***Abstract*—Ultrasonic imaging is a widely used non-invasive medical imaging procedure since it is economical, comparatively safe, portable and adaptable. However, one of its main weaknesses is the poor quality of images, which makes the enhancement of image quality an important issue in order to have a more accurate diagnose of the disease, or for the transformation of the image through telemedicine channel and in many other image processing tasks [1]. The purpose of this paper is to automatically enhance the image quality after the automatic detection of the artery wall. This step is essential before subsequent measurements of arterial parameters [9]. This was performed automatically by applying linear normalization, where results showed that normalization of ultra sound images is an important step in enhancing the image quality for later processing. In comparison with other methods, our method is automatic. The evaluation of image quality was done mathematically by comparing pixel intensities of images before and after enhancement, in addition to a visual evaluation.**

I. Introduction

Ultrasound imaging (sonography) uses high-frequency sound waves to view soft tissues such as muscles and internal organs. Since ultrasound images are captured in real-time, they can show movement of the body's internal organs as well as blood flowing through blood vessels. But the complex nature of sound transmission and reflection in anatomical structures causes the medical ultrasound images to contain many artifacts. We can mention the most common artifact such as:

- speckle noise: which results in image degredation and reduction in contrast resolution.
- Shadowing: when the beam encounters an interface of highly different acoustic impedance, a large proportion of it is even reflected or absorbed, so only little remains to travel into deeper tissues and produce echos, this reduction in the beam's intensity appears as shadow in the image.
- Scattering: Scattering happens especially when the beam meets a very small object or a rough surface, so the echos are scattered in all directions in a non-uniform manner instead of being reflected back to the probe.
- Blood backscattering: The flow of blood in arteries causes aggregation of blood cells moving in the lumen following the bloodstream. Blood clots would be detectable as hyper-echogenic fixed spots in the ever moving bloodstream which makes the lumen appear brighter than it should be (ideally, the artery should appear as a black strip (the lumen) surrounded by bright lines (the walls)). this artifact puts a big challange on the measuring of the LI boundary. Normalization is a good way for reducing the problem of backscattering [4].

These drawbacks and many others the improvement of ultrasound iamges'quality an important need. The goal is to achieve an image with a good quality that allow to take measurements of static and dynamic parameters of the artery, such as lumen diameter LD, artery stiffness (AS), intima media thickness IMT, the results of such measurements can be used for the prediction of patient's risk of cardio-vascular events. These days the measurements are still performed manually by experts and main efforts are paid to atomize them.

A. Anatomy of the artery

Blood vessels are usually composed of three layers: the tunica intima, tunica media, and tunica adventitia [3]. The outermost layer is known as the tunica externa formerly known as "tunica adventitia" and is composed of connective tissue and elastic fibers. Inside this layer there is the tunica media, which is made up of smooth muscle cells and elastic tissue. The innermost layer, which is in direct contact with the flow of blood, is the tunica intima, commonly called the intima. This layer is made up of mainly endothelial cells. The hollow internal cavity in which the blood flows is called the lumen [3]. Segmentation of the artery wall means automatically tracing the profiles of the most important interfaces: Lumen-Intima (LI), media-adventitia (MA) interface. For the measuring of IMT the longitudinal view is required [4] (for automatic measuring see [9]).

II. Related work

Much effort has been devoted to enhance the quality of ultrasound images, due to the importance of image quality in making later measurements of the artery more effective and robust. In [1], [2] manual algebraic normalization was used by linearly adjusting the image so the average gray level of the blood was 0-5 inside the lumen, and the average gray level of pixels on the artery wall was 180-190, in this work linear normalization and speckle reduction proved their efficiency [1]. However, this was all done manually. In our work, after the automatic detection of the artery, linear normalization was performed also automatically by automatic selection of a reference point inside the lumen and of another point on the adventitia, then applying linear remapping of intensity values between these two values following the same procedure mentioned above.

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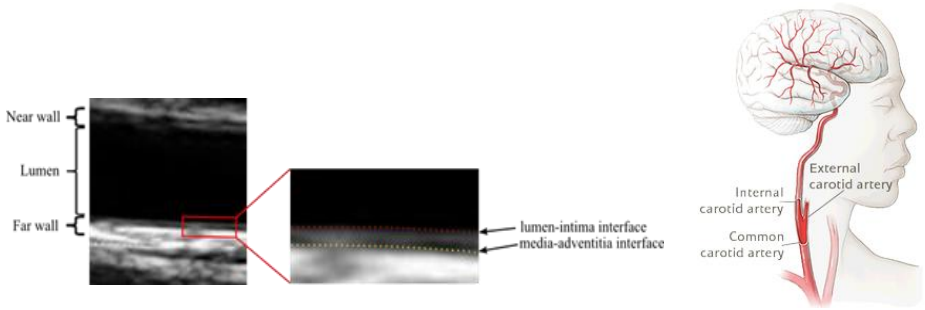

Fig. 1: (a) B-mode common carotid artery ultrasound image (b) Anatomy of CA

III. Materials and Method

Our data base consists of 84 B-mode ultrasound images of the longitudinal view of the CCA (common carotid artery). CCA images were obtained with the patient lying down with the neck turned to the side. Images were acquired from 10 volunteers, with 8 images from each one with Sonix OP ultrasound scanner with deferent set-up of depth, gain, time gain compensation(TGC) curve, and deferent linear array transducers (frequencies 10MHzand, 14MHz). Images were not zoomed during scanning and also they were not cropped after the capturing.

After automatically detecting the arterial wall [9] and by analyzing pixels we can find two sets of points, points inside thumen $l(i)$ and points that are on the arterial wall $w(i)$. These sets of points were analyzied in order to find a suitable remapping function that will transfer the intensities into an appropriate interval. Intervals were chosen in similar way described in [1], [2], which implies that pixels' intensities inside the lumen will be transferred into the interval $\langle 0, 5\rangle$, and those on the arterial wall should be in the range $\langle 180, 255\rangle$. The intensity remapping was done by applying the so called look-up-table, this table matches each intensity value with appropriate value using linear remapping, the look up table is graphically depicted in Fig. 2.

The structure of look-up-table:

- Inside the lumen:
  Pixel intensities inside the limen fall into the interval $\langle \max(l(i)), \min(l(i))\rangle$, where min($l(i)$) is almost 0 in all cases. What we want is to remap these values into the interval $\langle 0, 5\rangle$. However, max(l(i)) can be - due to artifacts, noise and other factors - corrupted, therefor we take a quantile of 80% of $l(i)$ (we assume that 20% of points can be corrupted). This quantile value was marked as $Q_{0.8}(l(i))$. The mapping of points inside artery can be defined as:
  $$\left.\begin{array}{l} 0 \rightarrow 0 \\ Q_{0.8}(l(i)) \rightarrow 5 \end{array}\right\}$$
- On the arterial wall:
  Points on the arterial wall have a mean value of intensity mean($w(i)$), we know that this value should be transfered to 180. In similar way we can define the mapping of pixels on the arterial wall as:
  $$\left.\begin{array}{l} \text{mean}(w(i)) \rightarrow 180 \\ 255 \rightarrow 255 \end{array}\right\}$$
  The points in LUT are approximated by lines. The final LUT is depicted on Fig. 2.

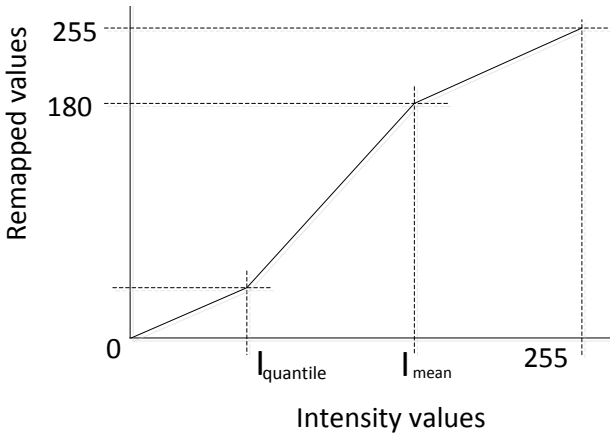

Fig. 2: Remapping Function

IV. Results

We tested our method on 84 ultrasound images, the evaluation was done mathematically by comparing the values of pixels in both areas inside the lumen and on the arterial border as shown in Fig. 3, where we can see the two box plots representing the intensity values inside the lumen and on the arterial wall respectively, before and after the normalization procedure was applied, in Fig. 3(a) we notice that most of pixels inside the lumen had the values 0-20 before normalization, but after normalization these pixels had the values 0-5. In similar way pixels on the arterial wall were remapped to have intensity values 150-200 (which are around the wanted value 180) as shown in Fig. 3(b).

Fig. 3(c) shows mean values computed from all images inside the artery, where mean values were between 2-4 before normalization but after normalization they were moved to the range 4-6. In similar way mean values on the arterial wall were moved from the range 80-100 to the range 140-160 as shown in Fig. 3(d).

By plotting the mean values calculated for each image inside the lumen as showed in Fig. 3(e),(f) we notice that mean

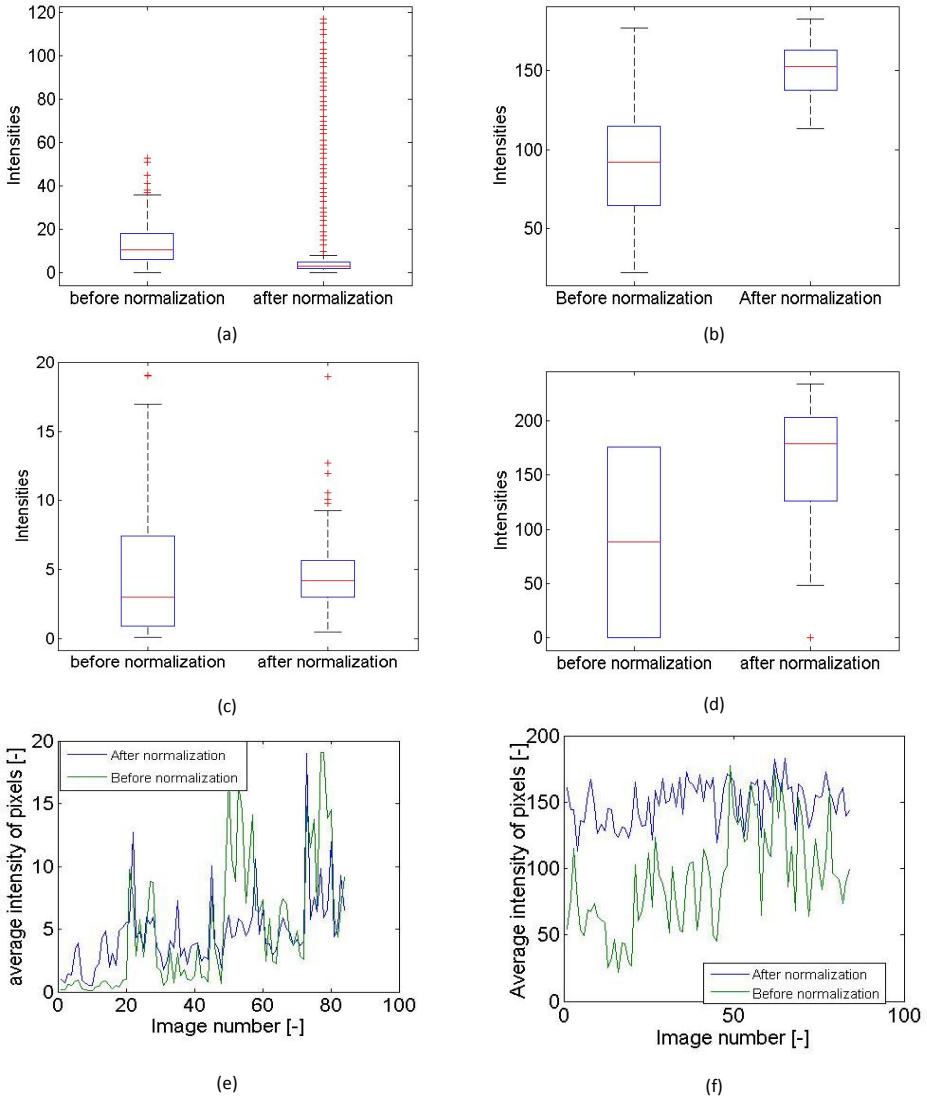

Fig. 3: (a) pixels' intensity values inside the lumen (b) pixels' intensity values on the arterial wall (c) Box plot of mean values of pixels inside the lumen computed from all images (d) Box plot of mean values of pixels on the arterial wall computed from all images (e) mean value of each image inside the lumen (f) mean value of each image on the arterial wall

values inside the lumen were even lower than 4 or higher than 8, but after normalization most of them fall into the range between 0 to 6 Fig. 3(e), while mean values on the arterials wall were less than 100 before normalization (Fig. 3(f)), but after normalization they were transfered to the range between 140 and 170. The main interest of experts when evaluating an ultrasound image is the ability to extract usefull information, they are primarily interested in differentiating blood from carotid wall, intima media, or plaque surface, which is very dependent on the image's quality. In Fig. 4 we can see the differences between ultrasound images before and after normalization especially inside the lumen area.

V. Conclusion

In this paper we have investigated the usefulness of normalization on the image quality as an important step for later processing of the image. Normalization was also proposed in other studies using blood echogenicity as a reference, and applied in carotid artery images [6]. In [7], [8], it was shown that normalization improves the image comparability by reducing the variability introduced by different gain settings, different operators and different equipment [1]. We tested our method on 84 ultrasound carotid images. Images were evaluated by comparing the pixel values in addition to mean values in each image, in the areas inside the lumen and on the arterial wall, before and after applying normalization. It can be seen in Fig. 3(a) that most of the pixels inside the lumen were remapped to the desirable range 0-5 after normalization, while they had the values 0-20 before normalization. In a similar way, as shown in Fig. 3(b), pixels on the arterial wall were remapped to have intensity values 150-200 (which are around the wanted value 180). Fig. 3(c) shows mean values

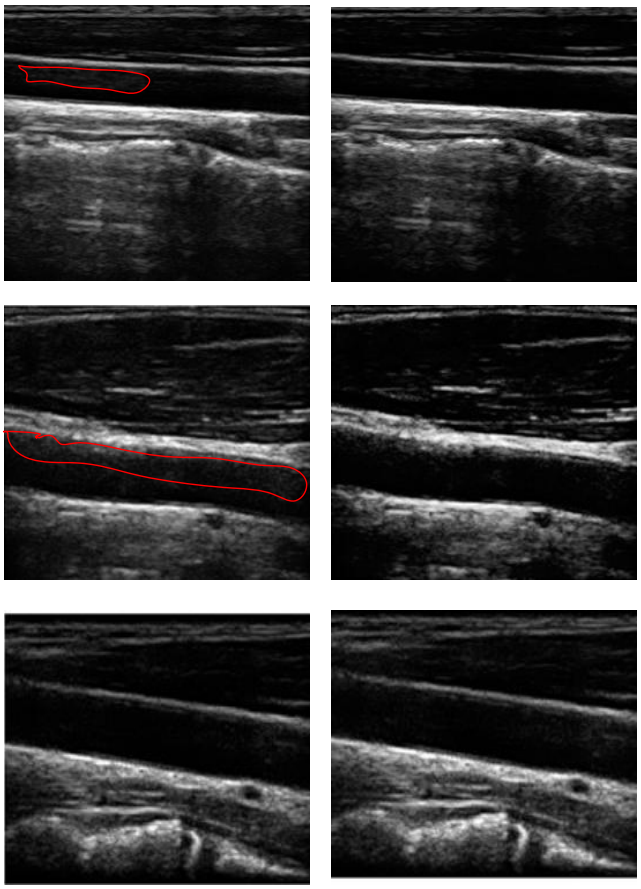

Fig. 4: (a), (c), (e) are images before normalization. (b), (d), (f) after normalization. We can see, For example in c, the normalization method decrease the echo artifacts in arterial lumen.

computed from all images inside the lumen, those values were between 2-4 before normalization but after normalization they were moved to the range 4-6. Mean values on the arterial wall were moved from the range 80-100 to the range 140-160 as can be seen in Fig. 3(d). Visual evaluation was also applied, results showed that the remapping of pixel intesities resulted in a better image quality, which is important for better analysis of the image. As it can be seen in Fig.4. Concluding results of this study showed that normalization is an important step in enhancing the quality of ultrasound images for the purpose of efficient segmentation or subsequent processing, the usefulness of this method in ultrasound systems needs to be more investigated.

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