Workflow for the arterial diameter computation and maximum blood velocity extraction

Christophe Noël [1]*

Abstract
We detailed the procedure for the arterial diameter computation and maximum blood velocity extraction from DICOM® files. These files resulted from measurements carried out with an ultra-high ultrasound scanner (Vevo MD, Fujifilm VisualSonics) on proper volar digital arteries. Firstly, we implemented a DICOM® to MAT (Matlab® storage file) translator. Secondly, we defined a five-stage procedure to compute the artery diameter by using Otsu's image segmentation technique and a Euclidean distance transform. Finally, the maximum blood velocity was captured using an RGB to HSV colour space convertor.

Keywords
DICOM® format – despeckling filter – segmentation algorithm – Otsu's method – proper volar artery.

[1] *Electromagnetism, Vibration, Optics laboratory, French National Research and Safety Institute for the Prevention of Occupational Accidents and Diseases (INRS), Vandœuvre-lès-Nancy, France*
***Corresponding author**: Christophe Noël, Institut national de recherche et de sécurité (INRS), 1 rue du Morvan, CS 60027 - F-54519 Vandœuvre cedex, France; Email, christophe.noel@inrs.fr; Phone, +33 383 50 21 12

Contents

1. Postprocessing DICOM® files

Firstly, the B-mode images and blood velocities measured by Pulsed Wave Doppler (figure 1, B-mode cineloop and Pulsed Wave Doppler of the proper volar digital artery) were recorded in DICOM® (Digital Imaging and Communications in Medicine) format [1].
Secondly, these DICOM® files were processed by Matlab® (The MathWorks, Natick, MA, USA) to extract, among the full ultrasound data, only information needed for the next computing step (e.g., the number of frames, the physical units, the physical value increments per positive pixel increment, etc.). Our DICOM® to MAT (i.e. Matlab® storage file) translator dramatically reduced the size of the initial raw DICOM® files. This was necessary owing the large number of tests to be performed. Hence without such a procedure, all these measurements would have generated a huge amount of digital data rather complicated to manage.

2. Arterial diameter computation

Starting from the MAT files stored previously, we implemented five stages in Matlab® to assess the artery diameter of the proper volar digital artery (figure 2).
In the first stage and for the first frame of the cineloop, the experimenter picked out the region of interest (ROI) where the artery diameter had to be computed. Afterwards, a despeckling filter was applied to reduce the ultrasound speckle noise and so foster the next computation steps. Ten filters (table 1) proposed by Loizou and co-authors [2, 3] were taken into account in the second stage. This denoised ROI image was then segmented in the third step. A number of computational approaches were determined for image processing field to address the issue of image segmentation [4, 5, 6, 7, 8, 9]. In this study, we applied Otsu's segmentation method which proved its relevance and accuracy regarding ultrasound im-

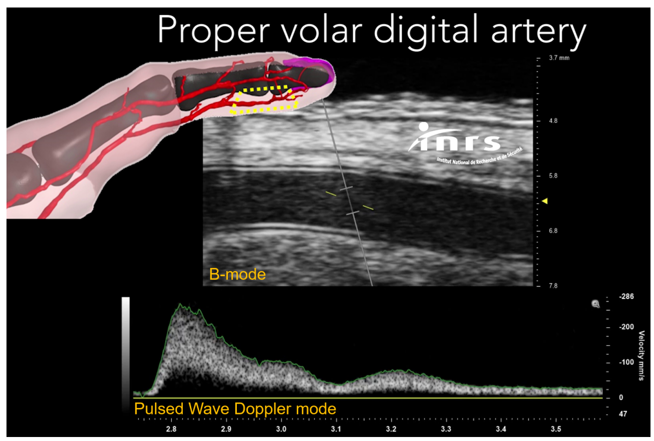

Figure S1. *B-mode image and velocity measured by pulsed wave Doppler mode for a 21-year-old male volunteer.*

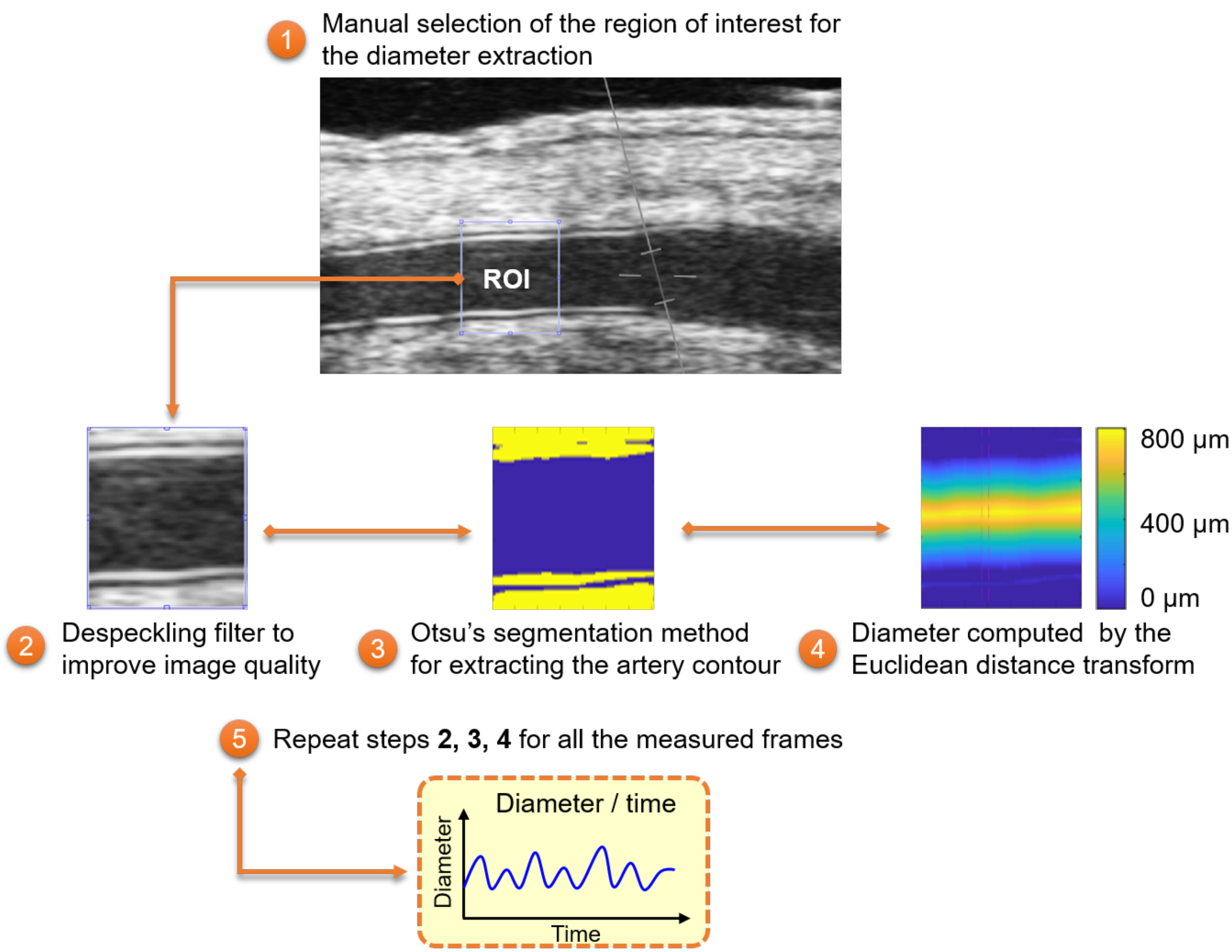

Figure S2. *Synoptic chart of the procedure for the artery diameter assessment.*

ages [10]. This method had already been implemented in the `imbinarize` function from the Matlab® Image Processing Toolbox. The binary image resulting from that segmentation procedure was subsequently used to work out the artery diameter in the fourth stage. To this end, we computed the Euclidean distance transform of the previous binary image by applying the `bwdist` function from the Matlab® Image Processing Toolbox. For each pixel in the binary image, the Euclidean distance transform assigned a number that is the distance between that pixel and the nearest nonzero pixel of the binary image. Afterwards, the mean artery diameter in ROI resulted in averaging the maximal values of the Euclidean distance transform. Instead of computing the mean diameter for the whole ROI, the experimenter could also pick out a sub-part of the ROI by placing (figure 2 stage 4) two segments on the image to delimit the desired sub-area. This sub-area could also be only an artery slice. Further information about using the Euclidean distance transform in artery diameter computing with Matlab® may be found here: Help in measuring vessel diameter and How to calculate the diameter of a vessel.

Finally, steps 2,3 and 4 were repeated for all the frames of the recorder cineloop. Hence, the mean diameter of the whole ROI or selected sub-area was evaluated as exemplified in figure 3. The systolic diastolic-pulsatile cardiac cycle resulted in oscillating the artery diameter roughly between 775 to 790 μm for this particular volunteer.

3. Maximum blood velocity extraction

The pulsed wave Doppler mode of our ultrasound scanner (Vevo MD, Fujifilm VisualSonics) may provide the blood flow velocities in the ultrasound probe steering direction and enables drawing the maximum blood velocity in this measuring section in green (the colour can also be orange depending of the software update). The DICOM® files recorded were processed by converting the raw pulsed wave Doppler images from the classical RGB to HSV (Hue, Saturation, Value) colour system. Indeed, in the HSV colour space the hue (or the colour) of each pixel was easily distinguishable by examining the first channel of the matrix representation of the image.

Table S1. *Despeckling filters [2] used in step 2 of the procedure for computing the artery diameter.*

Type	***General name***	***Algorithm name***
Linear	First-Order Statistics Filtering	`DsFlsmv`
	First-Order Statistics Filtering	`DsFwiener`
	Homogeneous Mask Area Filtering	`DsFlsminsc`
Non-Linear	Median Filtering	`DsFmedian`
	Linear Scaling Filter	`DsFls`
	Linear Scaling Filter	`DsFlecasort`
	Maximum Homogeneity Over Pixel Neighborhood Filtering	`DsFhomog`
	Geometric Filtering	`DsFgf4d`
	Homomorphic Filtering	`DsFhomo`
Image analysis	Wavelet filtering	`DsFwaveltc`

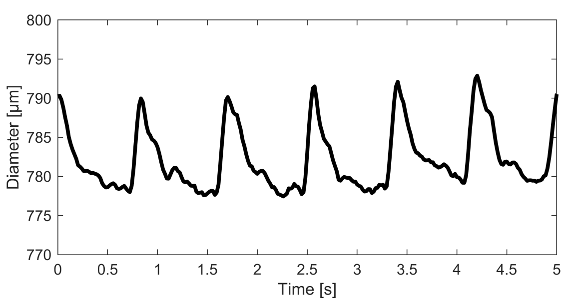

Figure S3. *Diameter as a function of time computed from an ultrasound B-mode cineloop recorded on the proper volar artery of a 39-year-old male volunteer.*

More details of this method are available here: Matlab - How to detect green color on an image? The procedure was then reiterated among the full frames of the cineloop. Information on physical units and pixel scales provided by the DICOM® files were then used to format the data. The blood velocity capture algorithm was included in the DICOM® to MAT translator described in section 1.

Acknowledgments

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