A Simulation Model of IntraVascular UltraSound (IVUS)

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Abstract

The IVUS technique is continuously gaining its use due to multiple clinical advantages, however the technical process of IVUS image generation is not known by doctors and researchers. This fact leads to a simplified use, based only on the gray level values of the image pixels. In this article we present a simple IVUS simulation model that can be used to learn and to compare the influence of different physical parameters in the IVUS image formation.

Resumen

La técnica IVUS cada vez está ganando más uso debido a sus múltiples ventajas clínicas, sin embargo los procesos técnicos relacionados con la generación de la imagen no son bien conocidos por los médicos e investigadores. Este hecho tiende a limitar su uso basado solamente en los valores de los niveles de gris de los píxeles de la imagen. En este artículo presentamos un modelo simple de simulación, que puede ser usado para aprender y para comparar la influencia de los diferentes parámetros fiscos que contribuyen en la formación de una imagen IVUS.

Palabras Claves: / IVUS / Ultrasound / Intravascular / Medical imaging / Simulation /

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1 Introduction

The introduction in the field of the medical image of the IVUS exploratory technique has made a significant change to the understanding of the arterial diseases and individual patterns of diseases in the coronary arteries. The main roll of IVUS technique (Boston Scientific Corporation, 1998; Berry and et al, 2000; Hausmann and et al, 1998) is to serve as guide in the interventional procedures allowing to measure the cross-section of the artery. Imaging modeling is relatively new (Trobaugh, 2000; Rosales and Radeva, 2003), the approach requires a physically-based model for the image data. Existing applications for ultrasonics images employ data models using assumptions that significantly limit the general applicability of their results. Few works relative to the simulation of IVUS images really exist that take into account the visualization of the data in the format that doctors use. The article is organized as follows section: Section 2 discusses the formal exposition of the model, section 3 is devoted to the IVUS image generation, section 4 presents the results and the conclusions are presented in section 5.

2 Formal Exposition of the Model

Let us consider an ultrasound pulse P_0 that is emitted at time t_0 with speed V_0, from point with coordinates (r_0, θ_0, z_0) (See Fig. 1 (a)). Let it interact with the scatterer located at position (R, Θ, Z), with the spatial distribution of the differential backscattering cross-section $\sigma(R, \Theta, Z)$. The reflected pulse P_i for the i-th scatterer is an exact replica (Verhoef and et al, 1984) of the transmitted sound pulse P_0, that will return to the point (r_0, θ_0, z_0) at time (t_i - t_0). It will be out of phase temporarily with respect to the pulse P_0, by the time difference, δ between the emitted (t_i) and the received (t_0) ultrasound pulse. δ is given by:

$$\delta = \frac{2|\vec{R}|}{V_0}, \qquad \vec{R} = \vec{r} - \vec{r}_0 \tag{1}$$

where V_0 is the ultrasound speed. Assuming the Born approximation (Isabelle and Cloutier, 1999), the ultrasound reflected signal, $S(R, \Theta, Z, t, \tau)$ is given by:

$$S(R,\Theta,Z,t,\tau) = \sum_{i=1}^{N} \sigma_i(R,\Theta,Z) I_i(t,\tau) \tag{2}$$

Where N is a finite set of reflecting scatters with coordinates, (R, Θ, Z) contained in a simulated arterial structure (See Fig. 1 (b)), $\sigma_i(R, \Theta, Z)$ is the space distribution Differential Backscattering Cross Section (DBC) of the i-th scatterer localized in position (R, Θ, Z),

$I_i(t,\tau)$ is the transducer impulse function and τ is the delay time which leads to constructive and destructive contributions to the received signal. The impulse function $I(t,\tau)$ is generally approximated (Thijssen and Oosterveld, 1988) by a Gaussian which envelopes the high frequency pressure distribution. Hence Eq. (2) in the transducer coordinates system can be rewritten as:

$$S(R,\Theta,Z,t,\delta)=C_0\sum_{i=1}^{N}\frac{\sigma_i(R,\Theta,Z)}{|R|}\exp\left(-\frac{(t-\delta)^2}{2\xi^2}\right)\sin(\omega t-\delta) \quad (3)$$

where ξ is the gaussian standard deviation. Eq. (3) is based on a discrete representation of the tissue of individual scatters elements with given position and DBC with respect to the transducer coordinates (Trobaugh, 2000).

3 IVUS image generation

Using the ultrasound reflected signal $S(R, \Theta, Z, t, \tau)$ (Eq. 2) for a finite set of N reflecting scatters with coordinates (R, Θ, Z), and space distribution of the DBD, $\sigma(R, \Theta, Z)$, the 2D echo temporal signal generated by a set of N_R scatterers which are localized between the angular position $\theta_a \leq \Theta \leq \theta_a$ can be rewritten as:

$$S(t,\delta,\Theta)=\sum_{i=1}^{N_R}\sum_{j=1}^{N_{\theta_i}}\sigma(R_i,\Theta\pm\theta_j)I(t,\delta_i) \quad (4)$$

where $N_{\theta i}$ are the scatterers number only localized on the ultrasound way beam line (See Fig. 2 (a)). The procedure to obtain the ***2D IVUS simulated echogram*** is the following: A rotatory transducer at angular velocity ω is located at the center of the simulated arterial configuration (See Fig. 2 (a)). The transducer emits an ultrasound pulse at frequency, f_0 at angular direction, θ_1 that is radially focused. The pulse progressively penetrates in each one of the layers of the simulated arterial structure (See Fig. 1 (b)). Each one of the layers generates a profile of amplitude or echoes (See Eq. 4) in the time that can be transformed into a profile of amplitude as a function of the penetration depth (See Fig 2 (b)). As the penetration depth is coincident with the axial beam direction, the radial coordinate *R* is thus determined. This procedure is made n-times for angles, ($\theta_1, \ldots, \theta_n$) and the 2D image is generated (See Fig 2 (c)). The empty pixels are filled in a recursive way form, using for this a bi-linear interpolation (See Fig. 2 (d)).

4 Results

This investigation is found in a preliminary phase, the major emphasis has been carried out trying to obtain simulated images and comparing them to the real images, according to the expert opinion. Figure 3 (a) shows an IVUS real image of right coronary artery, obtained by a 40 MHz Boston Sci. equipment (Boston Scientific Corporation, 1998). Figure 3 (b) shows a simulated image obtained at the same frequency. The global appearance of each image region and their corresponding interface transitions are visually well contrasted, compared to the real image. Figure 3 ((c) and (d)) show two selected regions of interest of the real (Fig. 3 (a)) and simulated (Fig. 3 (b)) image. We can see a good grey level distribution and a soft grey level decay from the center to the peripheries of the IVUS image, produced by the inverse relation between the ultrasound intensity and the penetration depth (See Eq. 3). The average grey level projection gives a global measure of similarity between real and simulated images. In this way, grey level average projection, correlation coefficients for the simulated versus real images were analyzed. The linear correlation coefficients, m and b (Fig. 4) for the grey level average projection in the horizontal direction (m = 0.87; b = 4.91) and vertical direction (m = 0.85; b = 5.79), show a significant grey level correspondence between the real and simulated Region Of Interest

(ROIs) of the image.

5 Conclusions

The aim of this work is to give an insight on 2D IVUS image formation and to development an IVUS simulating model. The obtained results yield a good approximation to the main objective of this work. The 2D IVUS images show a good correspondence between the arterial structures that generate the image structures and their gray level values. The simulations of the regions and tissue transitions of interest such as: lumen, lumen/intima, intima/media, media/adventitia and adventitia, have been achieved in satisfactory degree. Our IVUS image generation model, provides of a basic methodology that allows the most important real image emulation aspect. Interested readers are invited to check the generation model in (http://www.webdelprofesor.ula.ve/misael).

References

Berry E, Kelly S, Hutton J, Lindsay HS, Blaxill JM, Evans JA, Connelly J, Tisch J, Walker GC, Sivananthan UM, Smith MA. (2000) *Intravascular ultrasound-guided interventions in coronary artery disease*, Technical report, Healt Technology.

Scimed division Boston Scientific Corporation. (1998) *The ABCs of IVUS*.

Verhoef C, Cloostermans W and Thijssen J, (1984) *The impulse response of a focused source with an arbitrary axisymmetric surface velocity distribution*, The Journal of the Acoustical Society of America, 75:1717-1721.

Hausmann D, Lundkvist AJ, Friedrich GJ, Mullen WL, Heart J, (1998) *Intracoronary ultrasound imaging, intraobserver and interobserver variability of morphometric measumrements*, In Beyond Angiography, Intra Vascular Ultrasound, state of the art, vol. XX Congress of the ESC Viena-Austria, Stanford University School of Medicine, California, USA.

Isabelle F and Cloutier G, (1999) *A system-based approach to modeling the ultrasound* *signal backscattered by red blood cells*, Biophysical journal. 77:2387-2399.

Rosales M and Radeva P, (2003) *Empirical simulation model of intravascular ultrasound*, Master's thesis, Centre de Visió per Computador, Universitat Autonoma de Barcelona. España,

Thijssen J and Oosterveld B, (1998) *Perfomance of echographic equipment and potentials for tissue characterization*, NATO ASI Series, page 455.

Trobaugh J, (2000) *An image model for ultrasound incorporating surface shape and microstructure and characteristics of imaging system*, Technical report, Washington University, Sever Institute of Technology, Department of Electrical Engineering, Doctoral thesis.

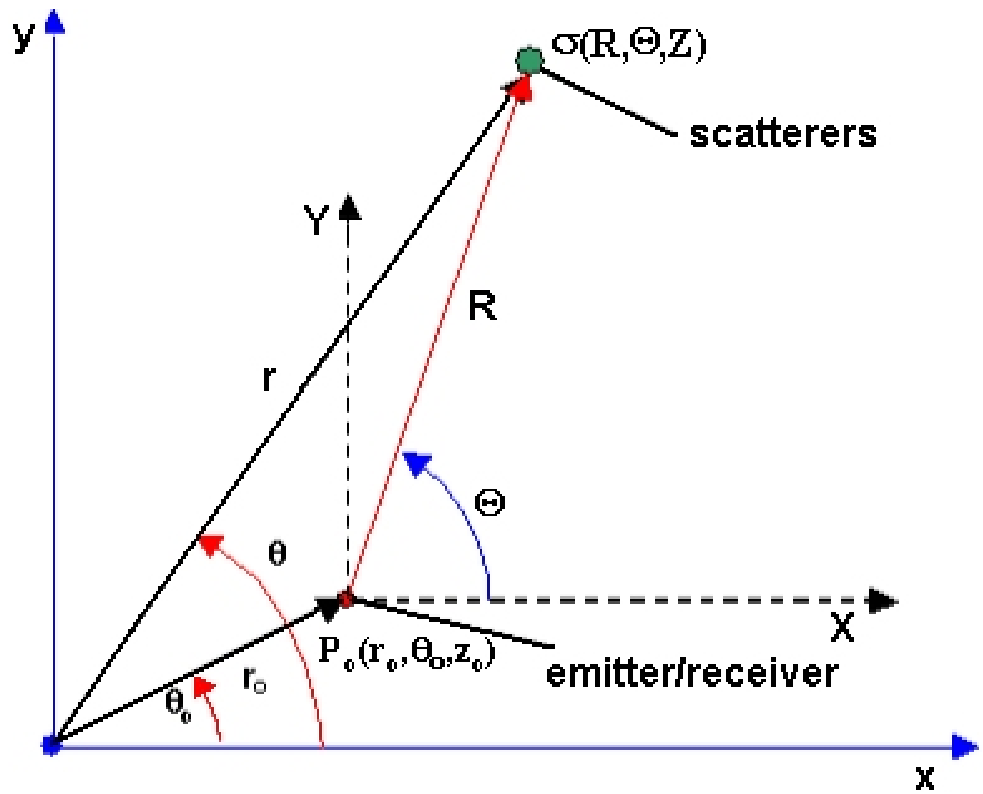


Figure 1a

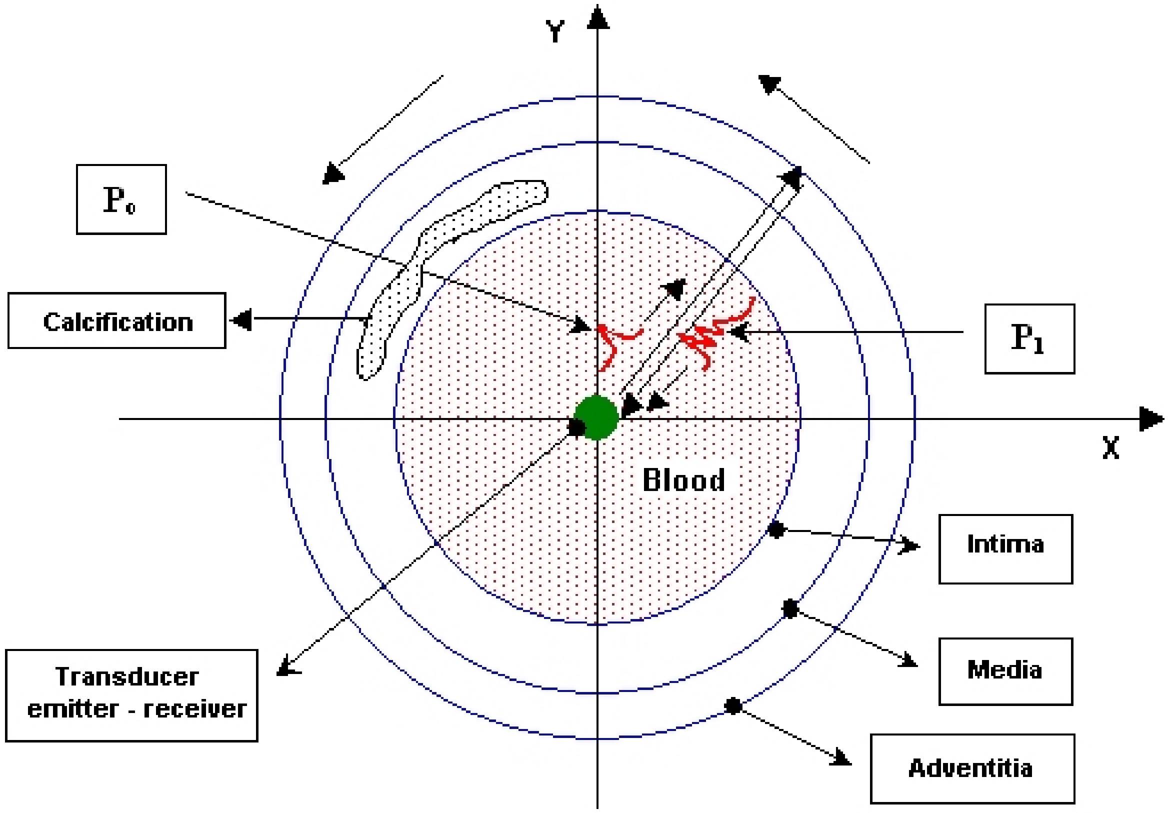

Y
P₀
Calcification
P₁
X
Blood
Intima
Media
Transducer
emitter - receiver
Adventitia

Figure 1b

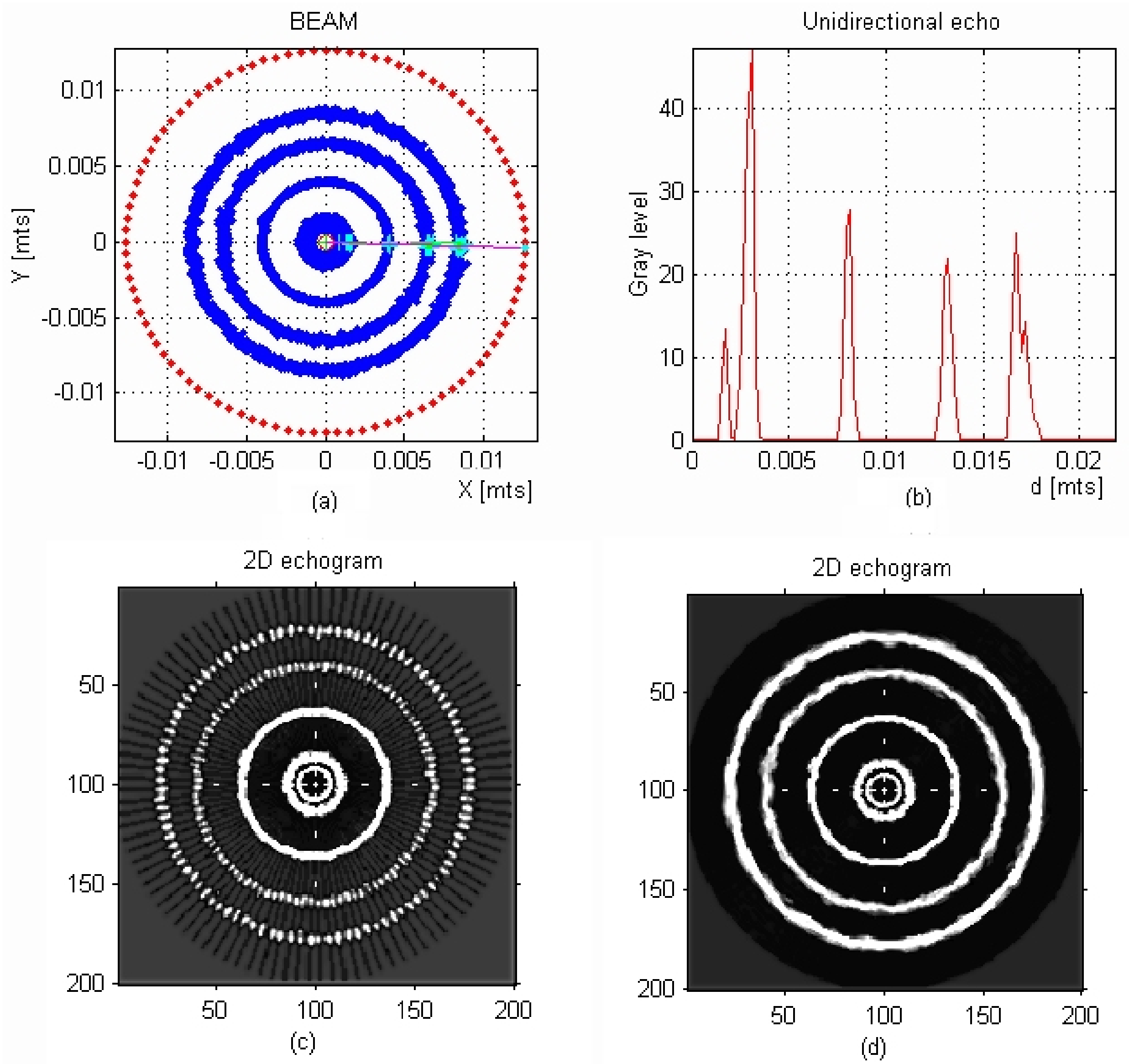


Figure 2(a,b,c y d)

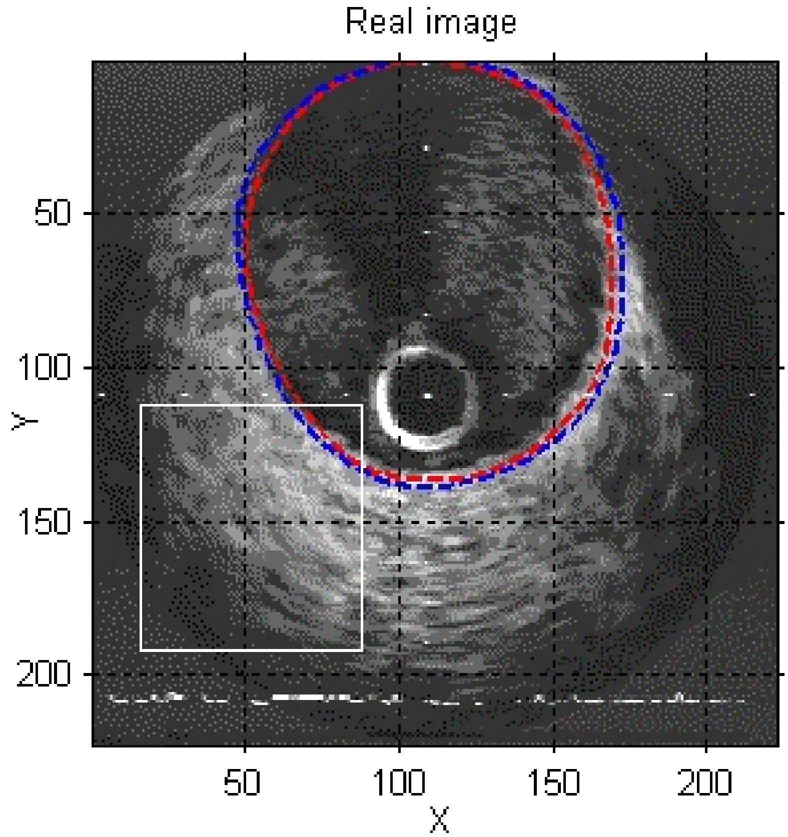


Figure 3a

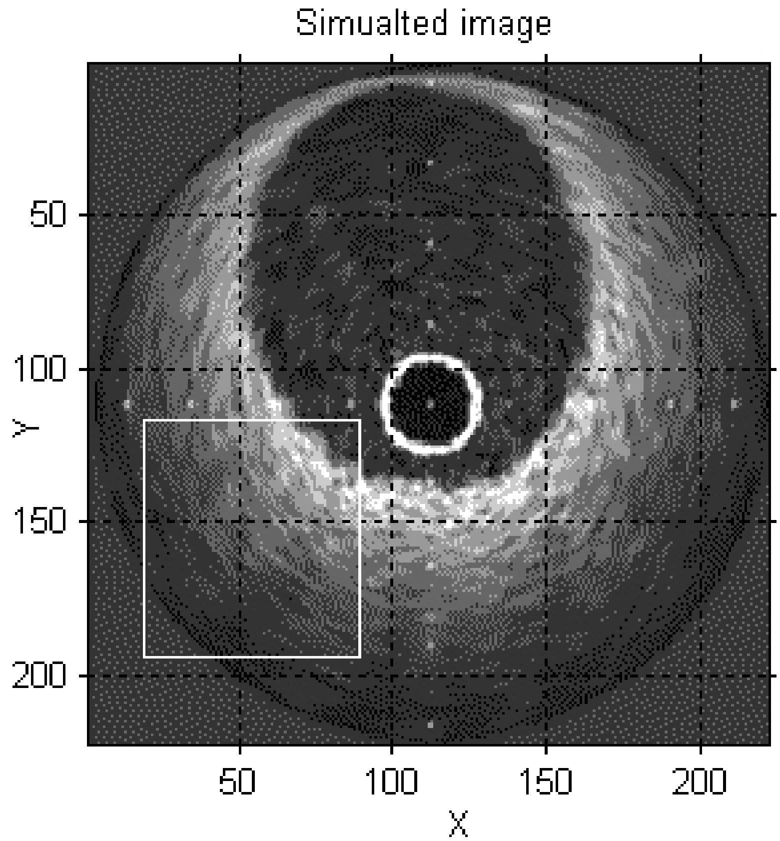


Figure 3b

Real ROI

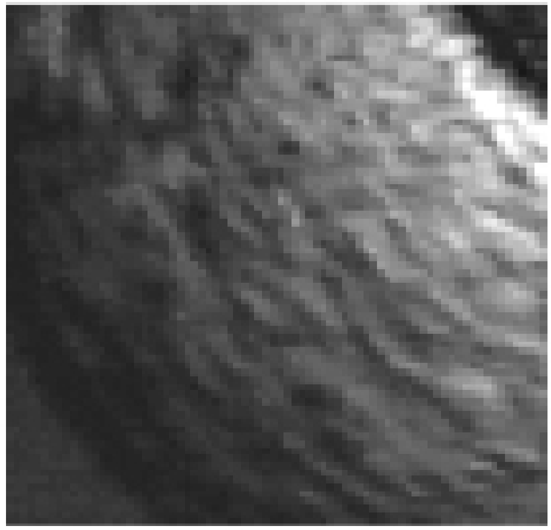
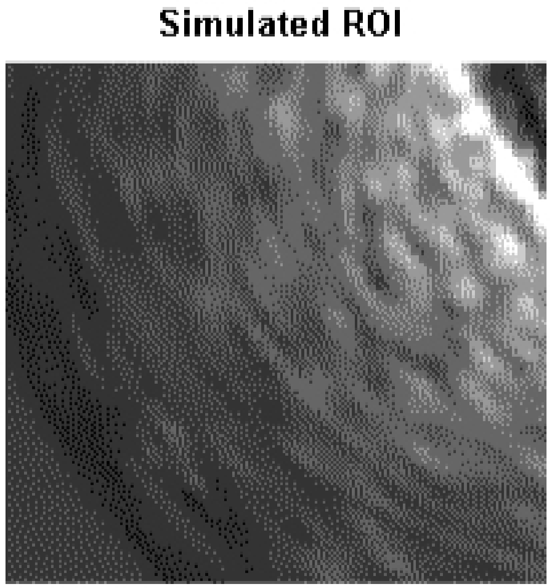


Figure 3c



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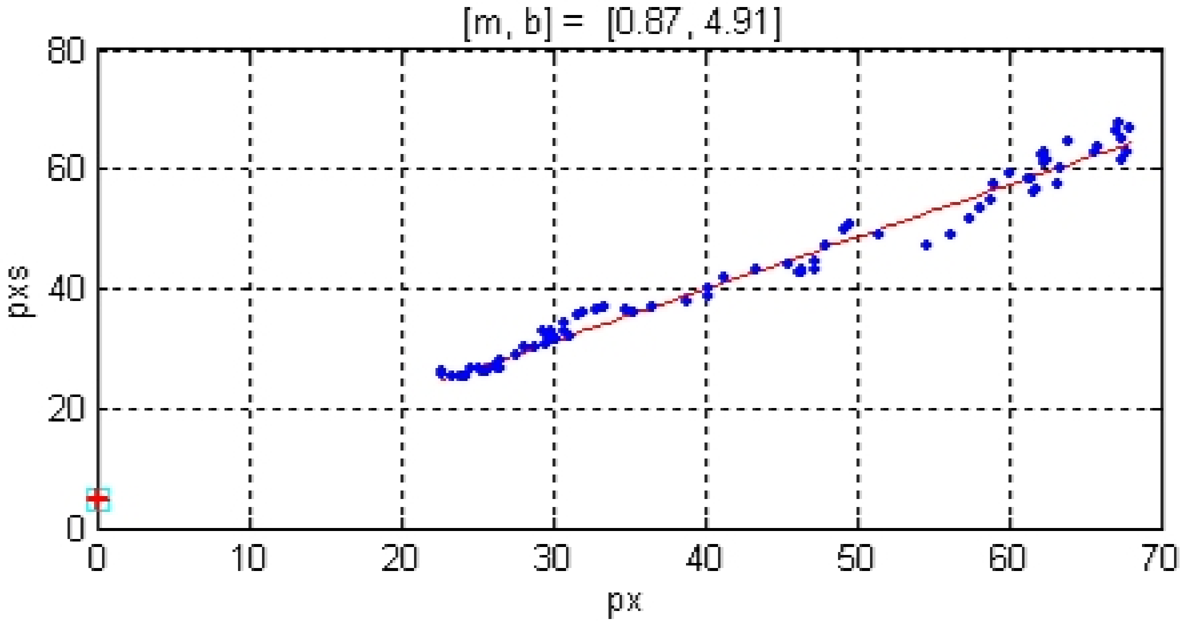

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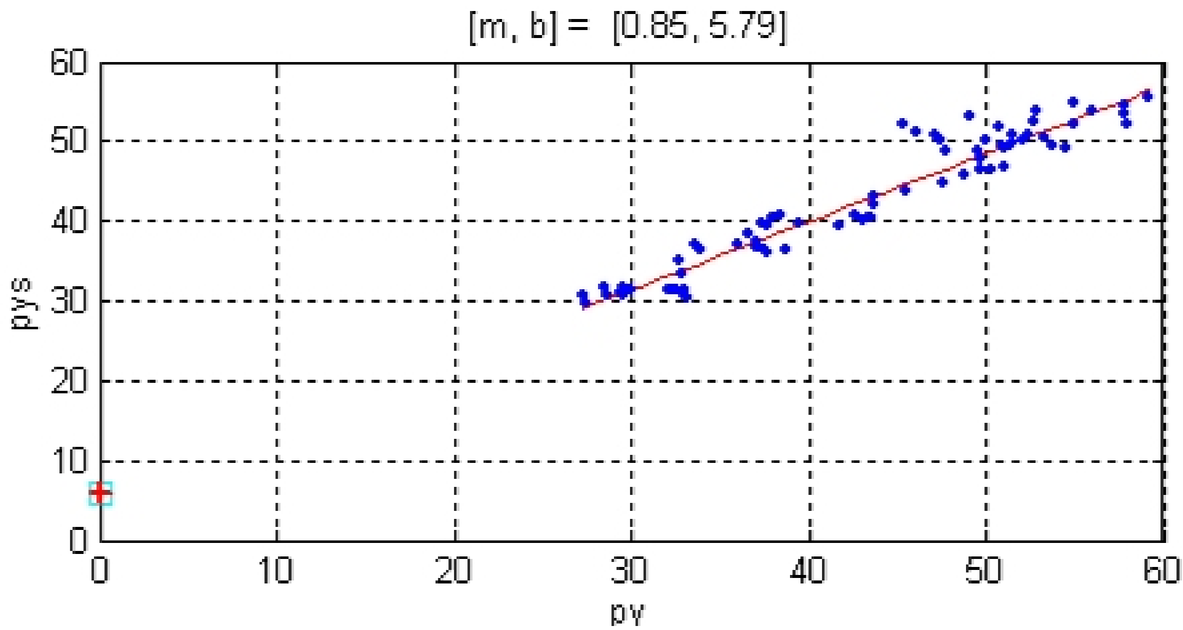

Figure 4b

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