Fusion of Magnetic Resonance and Ultrasound Images for Endometriosis Detection

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- **Background, Motivation and Objective**

Endometriosis is a benignant condition that typically affects women in their reproductive age. It is commonly associated with chronic pelvic pain and/or infertility. Endometriosis treatment often involves surgery. Preoperative workup is based on both magnetic resonance (MR) and ultrasound (US) images. These two imaging modalities have both advantages and drawbacks. MR images provide a wide field of view of patient's anatomy and good contrast but with a low spatial resolution. Hence, precise anatomic landmarks at the millimetric scale are underevaluated. In contrast, US imaging presents low signal to noise ratio and a reduced field of view but enables enhanced anatomic details. These complementary properties motivate our study whose objective is to fuse MR and US images, *i.e.*, generate one single image that takes advantage of both modalities.

- **Statement of Contribution/Methods**

The proposed MRI and US fusion is based on two image formation models adapted to each modality. The MR image formation model accounts for low spatial resolution of the observed image through a standard linear model formed by a blurring and a downsampling operator (1). The US image formation model takes into consideration the high amount of speckle noise, considered Rayleigh-distributed in this work (2). The correspondence between MR and US pixel gray levels is modelled using a polynomial function (3), estimated using the two observed MR and US images. This polynomial function induces a non-linear term in the fusion problem (4). A proximal alternating linearized minimization-based algorithm is investigated to solve the resulting nonconvex minimization problem.

- **Results/Discussion**

The proposed image fusion method is evaluated on experimental data acquired on a phantom with imaging characteristics close to endometriosis Fig. 1. This data corresponds to a beef steak on the top of which has been glued a structure made by PolyVinyl Alcohol (PVA). Both qualitative and quantitative results (see Fig. 1 and Tab.1) show the interest of fusing MR and US images. The MR, US and fused images are shown in Fig. 1(a-c). The fused image highlights the ability of the proposed algorithm to provide an image having the good spatial resolution of US and the good contrast of MRI. This observation is confirmed by the contrast to noise ratios in Tab. 1 and by the image profiles in Fig. 1(d).

Observation models

$$\mathbf{y_m} = \mathbf{S}\mathbf{H}\mathbf{x_m} + \mathbf{n_m} \quad (1)$$

$$\mathbf{y_u} = \mathbf{x_u} + \mathbf{n_u} \quad (2)$$

- $\mathbf{y_m}$: MRI image
- $\mathbf{x_m}$: HR-MRI
- $\mathbf{n_m}$: i.d.d additive white Gaussian noise
- $\mathbf{S}$: Decimation matrix
- $\mathbf{H}$: Blurring matrix
- $\mathbf{y_u}$: Ultrasound image
- $\mathbf{x_u}$: Despeckled ultrasound image
- $\mathbf{n_u}$: i.d.d additive log-Rayleigh noise

Relation between US and MR images

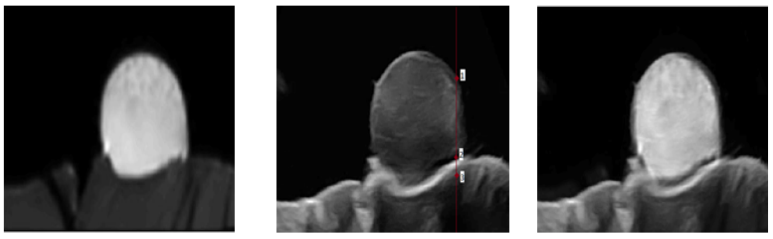
$$x_{u,i} = \sum_{p+q\leq 3} c_{pq} x_{m,i}^{p} (\nabla x_m^H u)_i^q \quad (3)$$

Fusion model

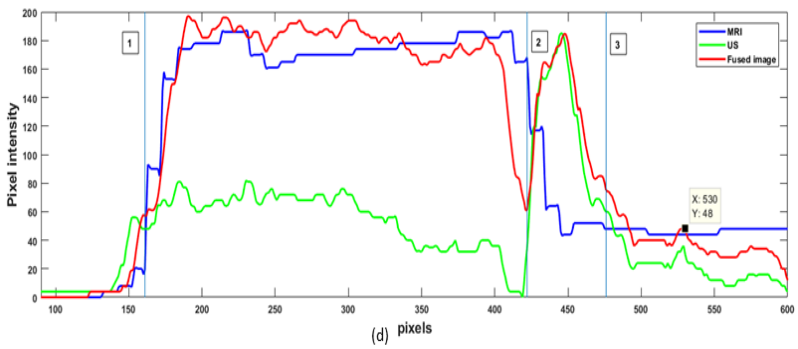
$$\hat{\mathbf{x}}_\mathbf{m} = \underset{x}{\operatorname{argmin}} \underbrace{\frac{1}{2}\left\|\mathbf{y_m} - \mathbf{S}\mathbf{H}\mathbf{x}\right\|^2}_{\text{MRI data fidelity}} + \underbrace{\tau_1 \left\|\nabla \mathbf{x}\right\|^2 + \tau_3 \left\|\nabla f(\mathbf{x}, \nabla \mathbf{x}^H \mathbf{u})\right\|^2}_{\text{regularization}}$$
$$\underbrace{+\tau_2 \sum_i \left[\exp\left(y_{u,i} - f_i(x, \nabla x^H u)\right) - \gamma\left(y_{u,i} - f_i(x, \nabla x^H u)\right)\right]}_{\text{US data fidelity}} \quad (4)$$

	MRI	US	Fused image
CNR	49,65 dB	19,65 dB	39,63 dB

Table 1: Contrast to noise ratios computed between two regions extracted from the beef steak and the PVA structure.



(a) MRI observation (b) US observation (c) Fused image



(d)

Fig. 1: (a) MR image, (b) US image, (c) fused MR and US image with the proposed algorithm, (d) normalized profiles corresponding to the vertical line in (b) extracted from the MR, US and fused images. Note that the three main visible structures, from top to bottom are, the PVA phantom, the glue and the beef steak. Because of the low resolution, the glue is not visible in the MR image. Because of the low contrast, the PVA and the beef steak have similar gray levels in the US image. The fused image achieves a good compromise between the observed MRI and US images.