



**HAL**  
open science

## Ultrafast Radial Modulation Imaging

Pauline Muleki Seya, Kailiang Xu, Mickaël Tanter, Olivier Couture

► **To cite this version:**

Pauline Muleki Seya, Kailiang Xu, Mickaël Tanter, Olivier Couture. Ultrafast Radial Modulation Imaging. Forum Acusticum, Dec 2020, Lyon, France. pp.1057-1058, <10.48465/fa.2020.0232>. <hal-03240235>

**HAL Id: hal-03240235**

**<https://hal.science/hal-03240235v1>**

Submitted on 29 May 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

# ULTRAFAST RADIAL MODULATION IMAGING

P. Muleki-Seya<sup>1</sup>

K. Xu<sup>1</sup>

M. Tanter<sup>1</sup>

O. Couture<sup>1</sup>

<sup>1</sup> Physics for Medicine Paris, Inserm, ESPCI Paris, CNRS, PSL University, Paris, France

Correspondence pauline@muleki@creatis.insa-lyon.fr

## Introduction

Radial modulation imaging improves the detection of microbubbles at high frequency [1-4], where other nonlinear techniques, as pulse inversion and amplitude modulation, often lock the emission pulse frequency close to the bubble resonance frequency (below 10 MHz), and consequently limit image resolution. Radial modulation imaging uses two ultrasonics excitations: a low-frequency excitation to manipulate microbubbles diameter and a higher frequency excitation to image them. The synchronization between the imaging pulses in RMI is non-trivial because microbubbles need to be interrogated in the compression and in the rarefaction phase and not between them (ie, in nodes of the modulation pressure) and the time-delay difference corresponding to the dispersion of the imaging pulse by the modulation pulse have to be corrected [2, 5]. We propose to simplify RMI by sampling the oscillations of microbubbles induced by the modulation pulse with ultrafast imaging. Ultrafast nonlinear imaging allows to increase microbubbles contrast when compared to conventional ultrasound imaging [6-7]. For radial modulation imaging, we suggest that the modulation frequency can be filtered more efficiently, in the slow-time, on long ensembles of images comparably to ultrasensitive Doppler [8]. We describe an implementation of ultrafast RMI (uRMI) where a beat frequency between the modulation pulse and the ultrafast pulse-repetition frequency is exploited to separate microbubbles from tissue phantom *in vitro*. In this way, recording microbubbles in different states of the modulation period translates to a modulated images set in the spectral domain of the slow-time. The microbubbles images may then be evaluated by demodulation of the images through a lock-in-amplifier.

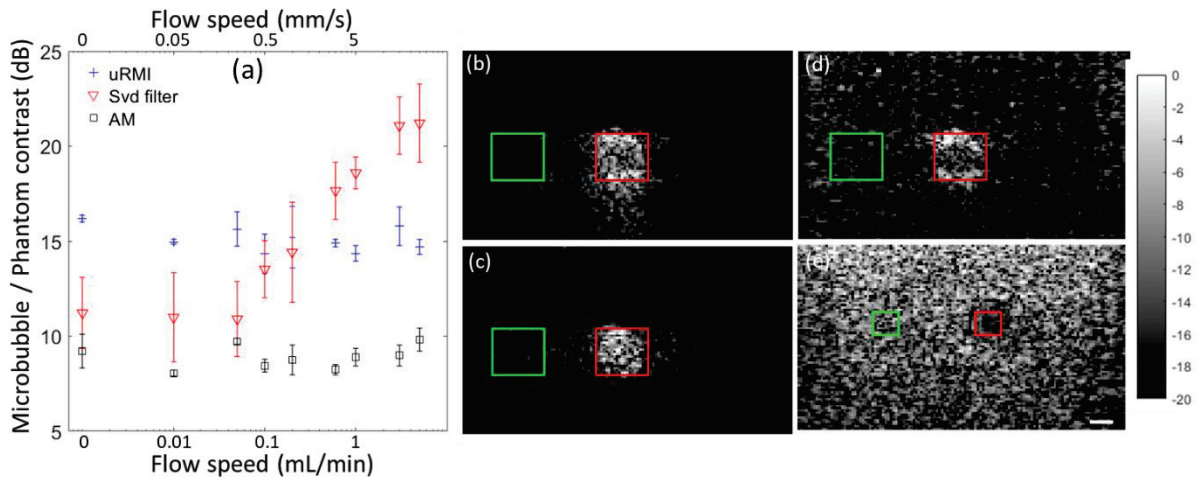
## Methods

Diluted Sonovue (1/3000) was injected in a flow phantom with a flow speed from 0 to 20 mL/min. It was insonified by two confocal transducers, one array at 15MHz and a single element at 1 MHz. The 1-MHz transducer generated a continuous excitation close to 1 MHz (10-35 kPa) using a function generator. The 15-MHz probe was connected to a Verasonics Vantage and performed ultrafast imaging with plane waves (300 kPa, 1 cycle, PRF 1/60  $\mu$ s). One thousand images were acquired for each acquisition, with a varying number of compounding angles. Ultrafast radial-modulation imaging consisted in addressing the microbubbles at different stage of their oscillations. The 1-MHz modulation wave was modulated in frequency so that high-frequency pulses reached microbubble at 3, 4, 5 or 10 modulation-states. Radio-frequency data were beamformed and filtered by a lock-in-amplifier in the slow time. Reconstruction of images was performed by combining coherently the compounding angles. The contrast-to-tissue ratio (CTR) was estimated for the sum in intensity of the 1000 processed images. Acquisitions were repeated 3 times to study the effect of the number of sampled modulation states, the number of angles of imaging plane waves acquisitions, the amplitude of the modulation pulse and the flow speed. The uRMI technique was also compared to other techniques to detect microbubbles: amplitude modulation at 15 MHz, microbubble disruption and SVD filter.

## Results

In our experimental conditions, a CTR from 7.2 to 14.8 dB was obtained with uRMI at 15 MHz. This CTR was stable with the number compounding angles. It increased with the amplitude of excitation of the low frequency and with the number of microbubbles modulation-states. It decreased with the flow speed. URMI provided the best CTRs without flow and for flow speed lower than 1 mm/s, higher than SVD filter, microbubbles disruption and amplitude modulation (Figure 1). For flows with higher velocities, SVD filter provided the best CTRs. The inherent limitation of uRMI and RMI techniques were the decorrelation of

microbubbles through a higher flow velocity or a lower frame rate. This shows the complementarity of uRMI and SVD filtering of ultrafast imaging of microbubbles, which works well in the presence of flow.



**Figure 1.** (a) CTR between microbubbles in the vessel and the phantom as a function of the flow speed for uRMI (3 angles, 4 modulation-states, 23 kPa low-frequency acquisition), SVD filtering and amplitude modulation (AM). Examples of images for uRMI (b), SVD filter (c), AM for a flow speed of 0.01 mL/min (d), and subtraction of an image with microbubbles to an image without microbubbles (e). The red and green rectangles correspond to the ROI of the vessel phantom and the agar, respectively. The scale bar represents 1 mm and the colorbar is in dB.

## Conclusion

In this study, we showed that RMI can be improved when combined to ultrafast imaging. This technique may then be suitable to improve the detection of targeted microbubbles in ultrasound molecular imaging applications. Moreover, it could be used to detect microbubbles moving extremely slowly in the finest vessels to improve ultrasound localization microscopy [9-11]. Furthermore, RMI may be less destructive than other nonlinear techniques as linear radial oscillations are enough to detect microbubbles whereas strong nonlinear oscillations (close from destruction regime) are needed for nonlinear contrast sequences.

## References

- [1] Shariff HH, Bevan PD, Karshafian R, Williams R and Burns PN, Radial Modulation Imaging: Raising the Frequency for Contrast Imaging, In *Ultrasonics Symposium*, 2006: 104-107, 2006.
- [2] Angelsen BA and Hansen R, SURF Imaging-A new method for ultrasound contrast agent imaging, In *Ultrasonics Symposium*, 2007: 531-541, 2007.
- [3] Chérin E, Brown J, Måsøy S-E, Shariff H, Karshafian R, Williams R, Burns PN and Foster FS, Radial modulation imaging of microbubble contrast agents at high frequency, *Ultrasound in medicine & biology*, 34(6): 949-962, 2008.
- [4] Masoy S-E, Standal O, Nasholm P, Johansen TF, Angelsen B and Hansen R, SURF imaging: In vivo demonstration of an ultrasound contrast agent detection technique, *IEEE UFFC*, 55(5): 1112-1121, 2008.
- [5] Hansen R and Angelsen BA, SURF imaging for contrast agent detection, *IEEE UFFC*. 56(2): 280-290. 2009.
- [6] Couture O, Bannouf S, Montaldo G, Aubry JF, Fink M, and Tanter M, Ultrafast imaging of ultrasound contrast agents, *Ultrasound in medicine & biology*, 35(11): 1908-1916, 2009.
- [7] Couture O, Fink M and Tanter M, Ultrasound Contrast Plane Wave Imaging, *IEEE UFFC*. 59(12): 2676-2683. 2012.
- [8] Bercoff J, Montaldo G, Loupas T, Savery D, Mézière F, Fink M and Tanter M, Ultrafast compound Doppler imaging: Providing full blood flow characterization, *IEEE UFFC*, 58(1): 134-147, 2011.
- [9] Couture O, Besson B, Montaldo G, Fink M and Tanter M, Microbubble ultrasound super-localization imaging (MUSLI), In *Ultrasonics Symposium*, 2011: 1285-1287, 2011.
- [10] Couture O, Hingot V, Heiles B, Muleki-Seya P and Tanter M, Ultrasound localization microscopy and super-resolution: A state of the art, *IEEE UFFC*, 65(8): 1304-1320 2018.
- [11] Errico C, Pierre J, Pezet S, Desailly Y, Lenkei Z, Couture O and Tanter M, Ultrafast ultrasound localization microscopy for deep super-resolution vascular imaging, *Nature*, 527(7579): 499, 2015.