White Paper

AM-FM: Enabling New Possibilities in CAD for Medical Imaging

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SIGNIFICANCE

Amplitude-Modulation Frequency-Modulation (AM-FM) demodulation represents images using spatially-varying sinusoidal waves and their spatially-varying amplitudes. The model uses different frequency scales and bandpass filters to characterize the wide range of frequencies that may be present in an image.

Multi-dimensional AM-FM methods provide us with powerful image and video decompositions that can effectively describe non-stationary content. They represent an extension to standard Fourier analysis, where we allow both the amplitude and the phase functions to vary spatially over the support of the image, following changes in local texture and brightness.

Introduction to AM-FM

In the field of computer-aided detection and diagnostics (CAD), recent advances in image processing techniques have brought a wide array of applications into the field. Many existing CAD methods rely on fixed basis functions based on Wavelet decompositions, Fourier analysis, or Gabor filters. Amplitude-Modulation Frequency-Modulation (AM-FM) methods[1] represent an emerging technique that shows great promise in this area.

In the past few years, as the understanding of its theory advanced, AM-FM has been used on a variety of medical imaging problems ranging from ultrasound to retinal image analysis, yielding excellent results. Some applications of the use of AM-FM in medical imaging are carotid artery ultrasound, pneumoconiosis, diabetic retinopathy, and age-related macular degeneration.

In the simplest definition, the basic AM-FM model is represented by demodulating and input signal (N-dimensional) into a sum of AM-FM estimates using: $f(x) = AM(x)FM(x)$, where x represents the N-dimensional space. For example, for a digital image, $(x) = (k_1, k_2)$, where k_1 and k_2 represent the rows and columns of the image. The third AM-FM estimate, considering the AM and the FM as the first two estimates, is defined as the instantaneous frequency (IF), which is defined as the gradient of the instantaneous phase (IP) presented in the $FM(x) = \cos(IP(x))$

AM-FM decompositions provide for physically meaningful texture measurements. Usually, significant texture variations are captured in the frequency components. For single component cases, IF vectors are orthogonal to equi-intensity lines of an image, while the IF magnitude provides a measure of local frequency content. Also, by using AM-FM components from different scales, we can produce IF vectors from different scales, at a pixel-level resolution.

Our Product

AM-FM demodulation methods[2] represent a different approach compared to Wavelets, Fourier and Gabor. Wavelets methods look for the representation of an input signal in different frequencies. However, it does not produce information of the instantaneous frequency of every sample in the signal. AM-FM methods are derived from the Fourier analysis. Nevertheless, Fourier spectrum analysis changes the signal from the 'local' space (by 'local', we mean 'time' for 1D signals, 'space' for 2D signals, 'space-time' for 3D signals, etc.) to the frequency space. It does not analyze the signal in the original space. Fourier series describe the input signal as a sum of fixed sine and cosine functions. They are not instantaneous at every sample. Finally, Gabor analysis uses a frequency analysis with no full coverage of the frequency spectrum. Thus, amplitudes and frequencies located at not covered frequencies in the spectrum are lost or confused with different ones.

The advantages of our AM-FM methods[3]: (i) they provide for a large number of physically meaningful texture features, over multiple scales, at a pixel-level resolution, (ii) we can reconstruct the image from the AM-FM decompositions, (iii) based on the target application, we can design for different AM-FM decompositions using different frequency coverage and (iv) we have the recent development of very robust methods for AM-FM demodulation.

Table 1. AM-FM based medical applications. VisionQuest Bio. applications in highlight.

Author	AM-FM method	Medical Application
Pattichis et al. 2000	Quasi-Eigenfunction Approximation (QEA).	Electron microscopy image segmentation.
Maragos et al. 2002	Energy Separation Algorithm (ESA).	Doppler ultrasound spectroscopy resolution.
Elshinawy et al. 2004	QEA and continuous- space demodulation.	Demonstrated AM-FM reconstructions of breast cancer images.
Boudraa et al. 2006	Cross energy operator.	Nuclear cardiac sequences for one normal and four abnormal cases.
Alexandratou et al. 2006	Vector-valued ESA for color images.	Ploidy image analysis (cancer).
Murray et al. 2007	QEA + new AM and FM motion estimation.	Motion Estimation for Atherosclerotic Plaque videos compared against other Phased-based method.
Murray et al. 2008, Agurto et al. 2008-2011 and Barriga et al.	New variable spacing, local linear phase (VS-LLP) method.	Retinal image analysis.
Pitris et al. 2009	QEA.	Optical coherence tomography.
Rodriguez et al. 2002- 2006	QEA implementation using SIMD.	Cardiac applications including Wireless Transmission.
Gill et al. 2005	1-D monocomponent AM- FM.	Detection and identification of heart sounds.
Ramachandran et al. 2001, Pattichis et al. 2002 and Murray et al. 2009	Hilbert-based AM-FM.	Analysis of pneumoconiosis X-Ray images.
Nguyen et al. 2008	1-D Hilbert based AM-FM.	Analysis of Electroencephalography.
Christodoulou et al. 2009 and Loizou et al. 2009	New VS-LLP method.	Segmentation and classification in the carotid artery.

Medical Applications of AM-FM

We present in Table 1 a list of medical applications using AM-FM demodulation methods. The applications produced at VisionQuest Biomedical are highlighted.

THE FUTURE

Our AM-FM demodulation methods are always improved in the basic formulation and design. In the future we will have, for example, directional and multi scale analysis (see Figure 1 for an example)[4] and real time motion AM-FM-based motion estimation.

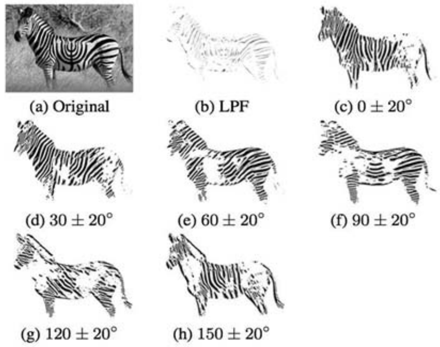

Figure 1. Analysis of a zebra using 3 scales and 6 directions[4].

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[1] Murray, V., Rodriguez, P. and Pattichis, M.S., "Multi-scale AM-FM Demodulation and Reconstruction Methods with Improved Accuracy," IEEE Transactions on Image Processing, vol.19, no.5, pp.1138-1152, May 2010.

[2] "Robust, Multi-scale, Adaptive-Spacing Amplitude-Modulation Frequency-Modulation (AM-FM) Methods with Applications in Digital Images and Digital Video," Inventors: Victor Manuel Murray Herrera, Marios S. Pattichis, Peter Soliz, Carla Paola Agurto Rios and Herbert T. Davis III, Patent App. Serial No. 12/586,276. Filed Sept. 18, 2008.

[3] V. Murray, E.S. Barriga, M.S. Pattichis, and P. Soliz, "A Survey of AM-FM methods for Applications in Medical Imaging," submitted to EURASIP Journal on Advances in Signal Processing, 2011.

[4] Murray, V., Pattichis, M., and Soliz, P., "'Multiscale Directional AM-FM Demodulation of Images Using a 2D Optimized Method," to be presented at International Conference on Image Processing (ICIP), 2011.