Robust Detection of Contrast Bolus Arrival in Time-Resolved Magnetic Resonance Angiography

J. D. Trzasko[1], S. J. Riederer[2], and A. Manduca[1]

[1]Department of Physiology and Biomedical Engineering, Mayo Clinic College of Medicine, Rochester, MN, United States, [2]Department of Diagnostic Radiology, Mayo Clinic College of Medicine, Rochester, MN, United States

Introduction

Contemporary methods for automatically detecting bolus arrival in Contrast-Enhanced Magnetic Resonance Angiography (CE-MRA) typically rely on identification of a mean-signal rise within a user-defined search volume that closely encompasses a vessel of interest [1,2]. In practice, the presence of physiological motion such as that arising from the respiratory cycle can potentially shift the vessel partially outside of this static search volume and consequentially not initiate a net signal rise which exceeds the prescribed detection threshold. In this work, we propose a robust and fully-automated statistical framework for detecting bolus arrival events which is both robust to physiological motion and independent of *a priori* specification of vessel location. Following from techniques commonly employed in surveillance applications, a new probability density for spatio-temporal background noise in CE-MRA is first developed along with associated robust parameter estimators. Next, using a fluoroscopic image stream [3], an autoregressive likelihood model of the image background is generated and bolus arrival events are automatically detected in real-time as statistical outliers of this model. An example application of detection of cardiac bolus arrival is presented and compared to conventional manual fluoroscopic monitoring.

Methods

A bolus arrival event is marked by the simultaneous occurrence of a bright intensity and strong temporal change for a given spatial location. In the field of video surveillance, a commonly-employed tactic for automatically detecting change events is to develop a dynamic, statistical model of the scene background and, for each newly acquired image frame, identify regions which do not accord to the developed model [4]. Noise in MRI is well known to be governed by a Rician density [5]. In the background of a CE-MRA image, this model reduces to the Rayleigh Density, given by

$$f_R(v) = \frac{v}{\sigma^2} e^{-\frac{v^2}{2\sigma^2}} H(v), \qquad (1)$$

where v is the measured signal intensity, σ^2 is a scale parameter, and H is the Heaviside function. If the background of two sequential image frames can be modeled according to (1), i.e. $R_1, R_2 \sim R(\sigma)$, it can be shown that the background noise process of the difference image, $RD = R_2 - R_1$, is defined by

$$f_{RD}(v) = \frac{|v|}{4\sigma^2} e^{-\frac{v^2}{2\sigma^2}} + \frac{\sqrt{\pi}}{4\sigma} e^{-\frac{v^2}{4\sigma^2}} \cdot \left(1 - \frac{v^2}{2\sigma^2}\right) \cdot erfc\left(\frac{|v|}{2\sigma}\right), \qquad (2)$$

where *erfc* is the complementary error function. For both (1) and (2), σ can be robustly estimated using the median absolute deviation (MAD) operator, $\sigma \approx {}^{MAD}/_{\beta}$, where the density-specific bias, β, is approximately 0.4485 for (1) and 0.6130 for (2). A comparison between the described robust and conventional expectation-based estimators for background modeling by (1) and (2) is shown in Figure (1). Subsequently, the probability that a measured intensity/change pair from two sequential CE-MRA image frames did not arise from pure spatiotemporal background noise is

$$f_{Event}(u,v) = (1 - f_R(u)) \cdot (1 - f_{RD}(v)) \cdot \qquad (3)$$

In practice, the presence of physiological motion may potentially introduce spurious values into (3); however, as these events are generally temporally isolated, we employ a simple autoregressive (AR) likelihood estimate of the true background model, E,

$$E^{n+1} = (1 - \omega) \cdot E^n + \omega \cdot f_{Event}^n; \qquad (4)$$

ω is a tuning parameter to control the temporal reactivity of (4). Figure 2 depicts several generated background likelihood models at the detected time of bolus arrival time. At each given time point, the current background model can be thresholded by some predetermined likelihood value, τ, to determine regions of activity. As with any conventional binary surveillance application, the support of these events can be accumulated and processed morphologically if desired.

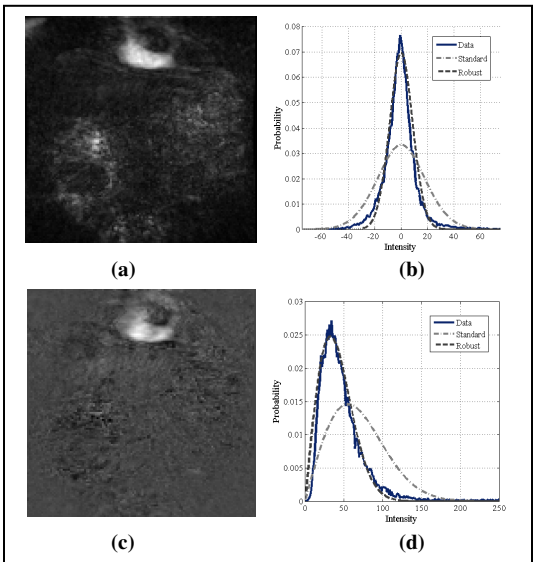

Fig 1. Standard vs Robust Background Modeling for CE-MRA Single Frame (a-b) and Temporal Difference (c-d) Image

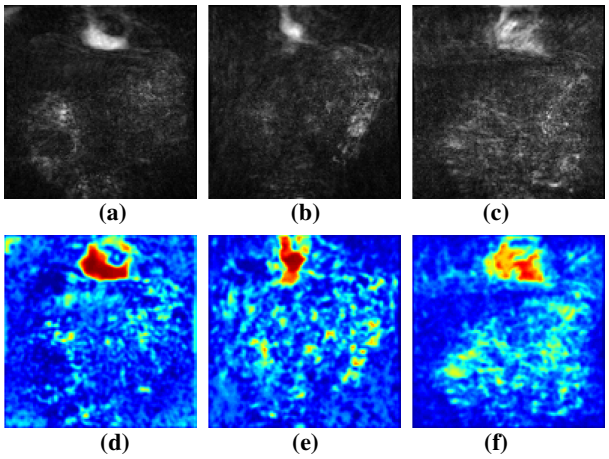

Fig 2. Example CE-MRA Images at Bolus Arrival Time (a-c) and Associated Background Likelihood Estimates (d-f)

Results

A comparison between the presented automated method and manual fluoroscopic monitoring for the detection of cardiac bolus arrival was made for 8 clinical examinations. In each case, a 128x128 maximum intensity projection (MIP) sequence with $\Delta x = \Delta y = 0.2$cm and $\Delta t = 0.6$s was used. For all experiments, $\omega = 0.33$ and $\tau = 0.67$ and bolus arrival was deemed as occurring when a 1cm^2 region of activity was detected. For the 8 test cases, a mean delay of only 0.3s and variance of 0.11s^2 between the manual and automated methods was measured along with a Pearson correlation of R = 0.9832.

Summary

We have developed a novel robust statistical framework for automatically detecting bolus arrival events in CE-MRA without any *a priori* knowledge of vessel location or contrast-based signal intensity levels that rivals the ability of fully manual detection. In addition to the presented full-scene cardiac bolus arrival detection example, this new framework could easily be incorporated into existing triggering methods for targeted arrival detection to significantly increase their robustness to motion.

References

[1] Foo et al., Radiology 203:275-280, 1997 [2] Farb et al, Radiology, 220:244-251, 2001 [3] Wilman et al, Radiology 205:137-146, 1997 [4] Aach et al, Signal Processing 31:165-180, 1993 [5] Gudbjartsson and Patz, MRM 34:910-914, 1995