Minimize the power of Variable-Rate Gradient Pulse using Conjugated Gradient Algorithm

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Introduction:

When RF pulse is applied most RF power is deposited into the imaging object. Therefore, Variable-Rate Gradient (VRG) pulse has been widely used in excitation to reduce the RF power. However, it is important to determine the variable gradient shape. In this work, Conjugated Gradient (CG) accompanied by piecewise cubic spline interpolation is applied to optimize the gradient of the VRG pulse in order to minimize the RF power without changing of excitation profile. Simulation results show that the RF power is reduced by 28% in excitation pulse.

Theory and method:

Normally, gradient waveform is composed of hundreds of discrete points, for example, 128 points. Here, only select 7 points are selected at equal interval to be adjusted by CG, and then the other points are interpolated by piecewise cubic spline interpolation. Thus, the variables vector is:

$g = [g_1, g_2, \cdots, g_8]$, (1) where g_i is the discrete point on the gradient waveform to be adjusted.

Given g, the variable rate gradient waveform $G_{VR}(t)$ can be obtained by interpolation. Then, the VRG RF pulse is designed according to following equation [1]:

$B_{1VR}(t) = \lambda(t) B_1(u(t))$, (2) where $B_{1VR}(t)$ and $B_1(t)$ are the VRG pulse and original RF pulse with constant gradient G_0 respectively; and

$u(t) = \int_0^t \lambda(t')dt'$, (3) where $\lambda(t) = \frac{G_{VR}(t)}{G_0}$.

The minimization target function is defined as:

$P = \int B_{1VR}^2(t)dt$, (4) where P is the power of VRG pulse.

Normally the varying of gradient waveform and RF pulse shape will change the excitation profile. Therefore it is necessary to monitor the error of excitation profile. For excitation pulse, the passband and stopband errors are defined as following:

$E_p = \max_{x \in VP}(|M_x| - 1)$ (5)

$E_s = \max_{x \in VS}(|M_x| - 0)$, (6) where VP and VS is the passband and stopband region respectively; M_x is the transverse magnetization after excitation. We calculate the errors after each iteration. Thus, the optimization constraints is the error of excitation profile no less than a given value, here we set it as 0.1. Then, the minimization problem becomes: Minimize P, subject to constrain E_p<0.1 and E_s<0.1. The method is depicted as following:

1) Initiate variable vector x, and calculate the power of VRG pulse;
2) Using CG to adjust the vector x;
3) Interpolate adjusted points to get new variable rate gradient, and design VRG pulse;
3) Evaluate the RF power;
4) Evaluate the excitation profile error, if it is not acceptable, restore the x value of previous step;
5) Goto step 2 and continue.

Simulation results:

In this work, we have designed a slice selection $\pi/2$ RF pulse. The desired excitation profile is a 0.9 cm slice, using a gradient system with 1G/cm amplitude.

Fig.1 (a) shows the original constant gradient waveform (blue) and optimized variable-rate gradient waveform (red), Fig.1 (b) shows the original RF pulse $B_1(t)$ (blue) and the VRG pulse $B_{1VR}(t)$ and optimized by CG (red). The VRG pulse amplitude at the central is reduced from 0.05 Gauss to 0.03 Gauss, which cause the RF power decreased by 28%. Fig.1 (c) shows that the excitation profile does not change due to the corresponding reduction of gradient waveform.

Conclusion:

In this work, CG has been applied to optimize the variable-rate gradient waveform to minimize the power of VRG pulse, while remaining the excitation profile unaffected. Simulation results have shown that the power is reduced by 28% after CG optimization with the same excitation profile as that of original pulse. Although this method is only applied to excitation pulse, it could also be applied to inversion pulse or refocusing pulse design.

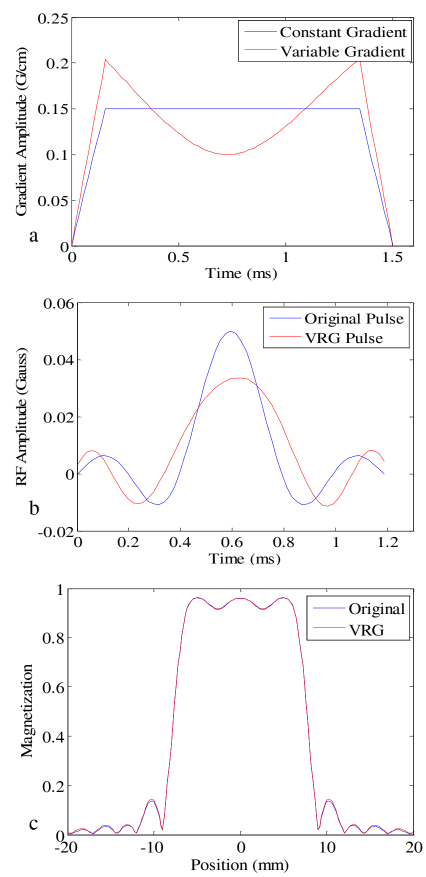

Fig.1 (a) Constant gradient (blue) and variable rate gradient (red); (b) Original pulse (blue) and Optimized VRG pulse (red); (c) Excitation profiles of the two pulses.

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References:

[1] M.A. Bernstein, K.F.King, X.J.Zhou: Handbook of MRI pulse sequence, Academic Press, Boston 2004.