Automatic Gradient Delay Correction Using Center-Acquisition-at-Partial-Ramp Imaging (CAPRI)

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Purpose: In conventional UTE imaging the k-space center is acquired during ramp-up of the read-out gradient. Accurate knowledge of the gradient delay and the associated shift of the echo top of the k-space signal is mandatory, demanding additional reference scans[1,2]. In this abstract CAPRI is applied for automatic correction of gradient delays without requiring additional reference scans. CAPRI allows direct measurement of the location of the echo top and system delays can be corrected without any additional scans.

Methods and Materials: In CAPRI the dead time t_{dead} required for switching the front end from transmit to receive mode is used for playing out an additional small pre-phasing gradient shifting the acquisition of the k-space center towards the flat region of the readout gradient (figure 1). Accepting some signal intensity reduction due to slightly increased echo time (TE), a partial echo is acquired by starting signal acquisition prior to the k-space center (figure 2). TE depends on the rise-time of the gradient (t_{slope}) and the CAPRI-factor (cf) which describes the relative position of k-space center (k_0; TE = t_{k0} = cf*t_{slope}) on the gradient slope (UTE: cf=0; flat top: cf=1):

$$\text{TE}_{min} = \max(t_{dead}, (1+\sqrt{2}) * cf * t_{slope})$$

<u>Algorithm for automatic delay correction:</u>

1.) interpolation of the k-space data along the raw data profile
2.) detection of echo peak time ($t_{peak} = t_{acq}(I_{max})$) by identification of the maximum value (I_{max}) along the single k-space data profiles
3.) determination of k_0-position (t_{k0}) in the estimated trajectory profile (waveform approximated / no delay correction)
4.) calculation of delay for every single k-space profile by determinate the time difference between k_0 and data maximum ($delay_{single} = t_{k0} - t_{peak}$)
5.) calculation of mean delay for opposite profiles ($delay_{opp}$) to eliminate off-resonance related shifts.

Two different approaches were investigated. a) calculation of the gradient delay for the three main axes only, with calculation of the delays for the kooshball trajectory by tri-linear interpolation, and b) calculation of the off-resonance corrected delay for each profile ($delay_{3axes}$) individually.
For evaluation of image quality improvement a 3T whole body imaging MRI (Achieva, Philips Medical, Netherlands) with maximum gradient amplitude (ga) of 31mT/m and maximum slew rate (sr) of 200mT/m/s and different sets of scan parameters (FOV / resolution / cf (0.25/ 0.5/ 1)) were used. Echo time varied between 80µs (c = 0.25; sr = 150mT/m/s; ga = 20mT/m) and 500µs (c = 1; sr = 150mT/m/s; ga = 30mT/m).

Results: Delay detection worked for the investgated CAPRI factors. Results are shown for a knee scan with TE = 365µs; cf = 1; sr = 200mT/m/s; ga = 30mT/m. Figure 3 shows the delays along one kooshball interleave, comparing the detected delays without correction ($delay_{single}$: blue) with the off-resonance-corrected ($delay_{opp}$: red) delays. Differences up to 3µs between the methods were observed. Comparing the three-axes method ($delay_{3axes}$) to full compensation ($delay_{opp}$) (fig. 4) revealed a maximum difference of the resulting delays of 0.5µs. Without correction of the system delay the reconstructed data suffers from severe image degradation (fig. 5a). Differences between the reconstructed images using detected (fig. 5b) and calculated (fig. 5c) off-resonance-corrected delays appear negligible.

Discussion: Automatic delay detection is possible with the CAPRI method. Using a linear combination of the detected delays of the three main gradient axes appears sufficient for providing excellent image quality. A slight increase in echo time is inevitable, but can be controlled by a proper combination of slewrate, gradient amplitude and CAPRI-factor

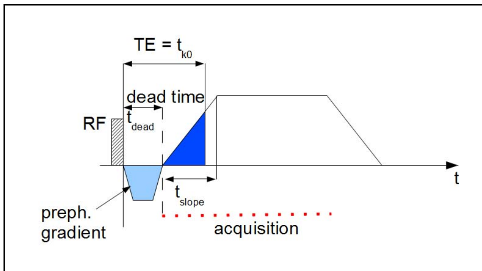


Fig.1: CAPRI: shift k_0 and acquire partial echo

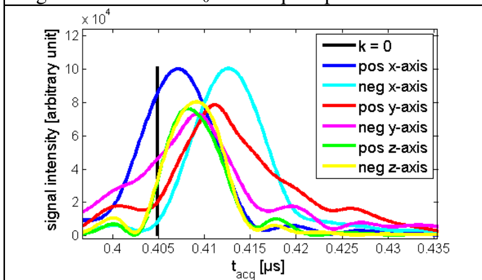


Fig.2: k-space data along the main axes (x,y,z)

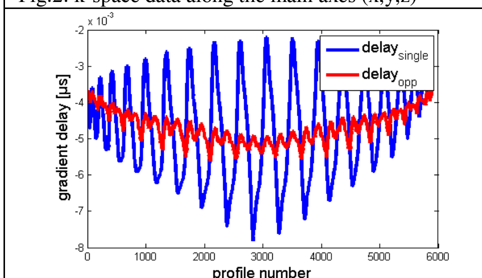


Fig.3: detected delays over kooshball interleave

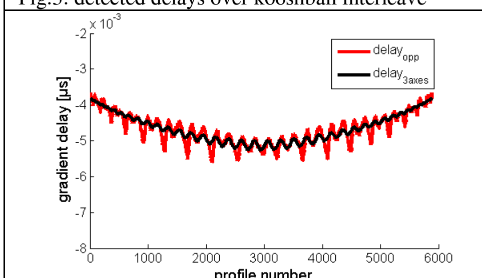


Fig.4: detected delays over interleave vs. calculated delays (using diff. delays for x, y, z)

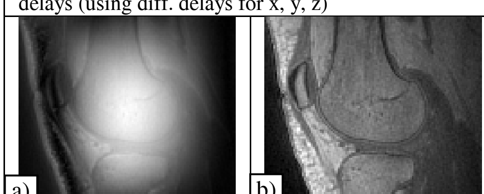
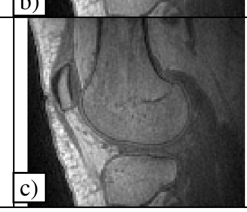


Fig.5: CAPRI Image
a) no delay correction,
b) detected delays $delay_{opp}$
c) calculated delays (diff. delays for x,y,z)



References: 1. Takizawa M: Proc. Intl. Soc. Mag. Reson. Med. 20:2496 (2012); 2. Atkinson I. Mag. Reson. Med 62:532-537 (2009); 3. Bracher AK. Proc. Intl. Soc. Mag. Reson. Med. 20:3741 (2012).