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Declaration of Relevant Financial Interests or Relationships

Poster Presenter: Mike Smith

I have no relevant financial interest or relationship(s) to disclose with regard to the subject matter of this presentation.

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Overcoming the Image Position-Dependent Resolution Inherent in DFT and CS Reconstruction

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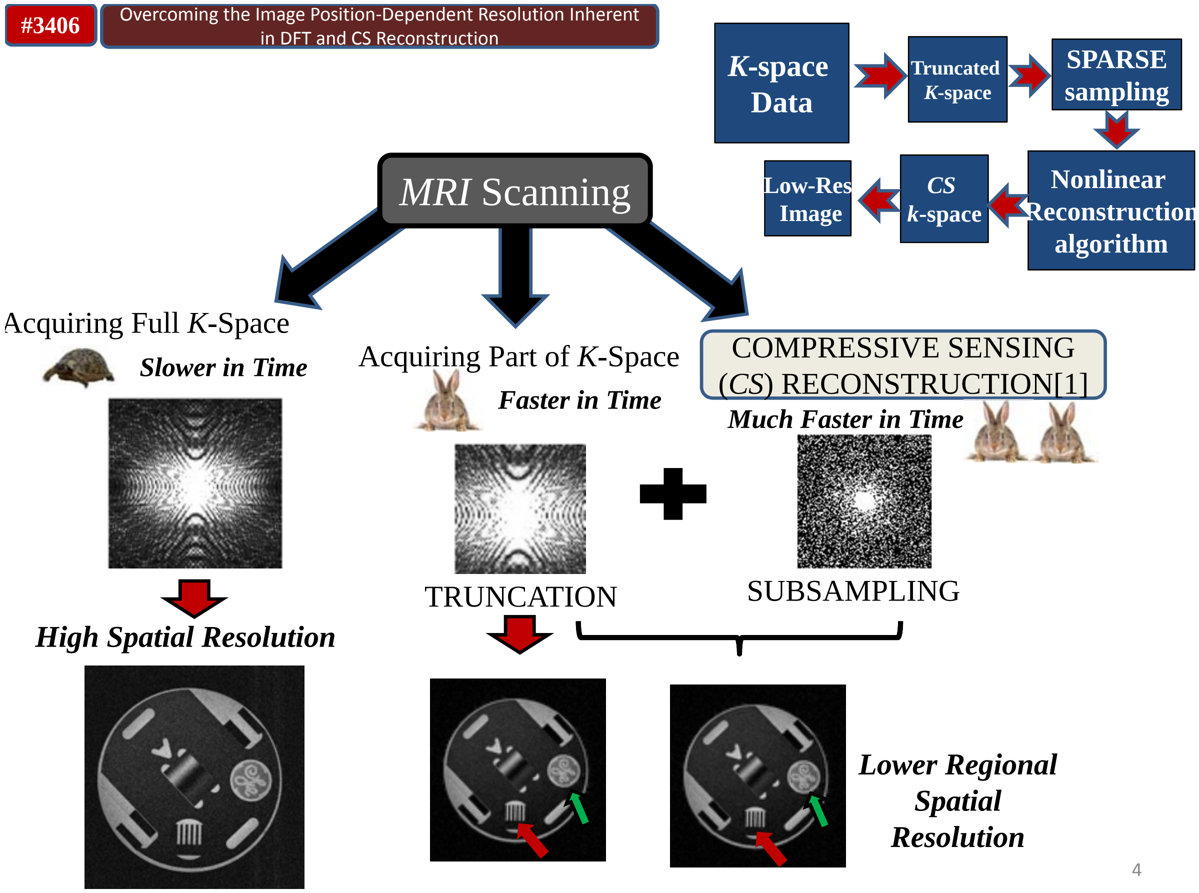
#3406 Overcoming the Image Position-Dependent Resolution Inherent in DFT and CS Reconstruction

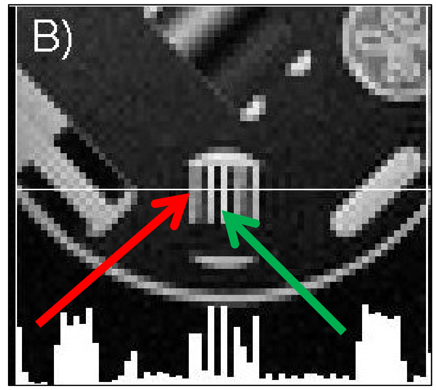


Position Dependent Resolution in GE Phantom after *k*-space truncation

Hi-Resolution (512 x 512) DFT Reconstruction

All Comb tines have EQUAL HIGH RESOLUTION

Low Resolution (128 x 128) DFT Reconstruction



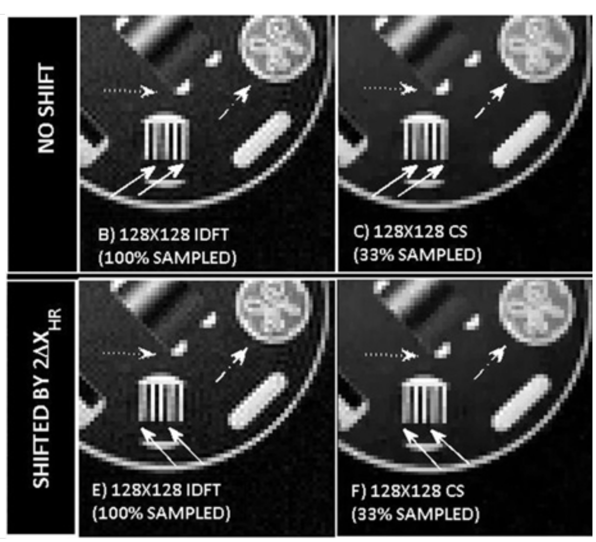
Tines 1 and 4 have LOWER RESOLUTION than Tines 2, 3 and 4

Resolution changes with FOV position occur in *both* DFT and CS reconstructions

Field of view (FOV) shift distance to change resolution is equivalent to

2 high resolution (512 x 512) voxel widths

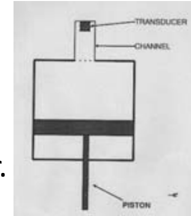
20 cm / 256 < 0.1 cm



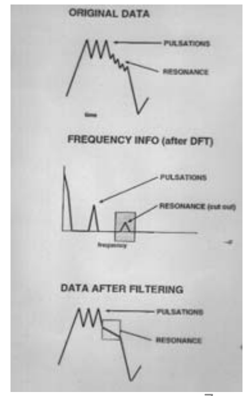
Adipour and Smith, "*Overcoming Field of View Position-dependent Image Quality Exhibited in DFT and Compressed Sensing Reconstructions of Truncated Magnetic Resonance k-space Data Sets*", submitted MRI, May 2015

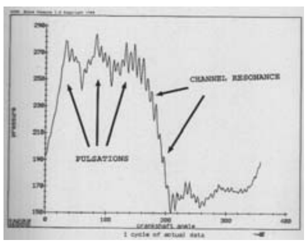
Hint on solving MR problem

- Smith (1993) investigated industrial signals from a rotating gas compressor
  - Need to measure compressor *P-V curve* to calculate efficiency. Added pressure sensor to compression chamber. Volume determined by position of piston driven by rotating engine



- Time domain signal is noisy with certain dominant frequencies caused by compressor and pressure monitor channel resonances



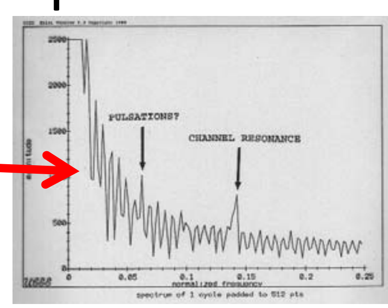


- **Theoretical solution:** Re-analyse *PV-curve* after frequency domain filtering

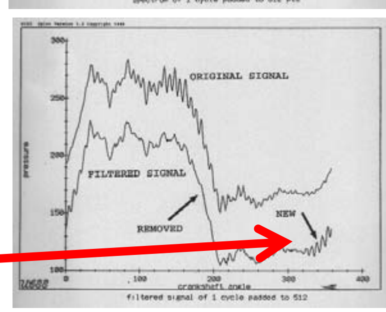
M. R. Smith, "FFT - fRISCy Fourier transforms," Microprocessors and Microsystems, Vol. 17:9, pp.507 - 521, 1993

Frequency domain filtering is not as straight forward in practice

- Various characteristics of time domain signal means that frequency domain signal was "Not clean" after "Bull-at-gate" DFT application.



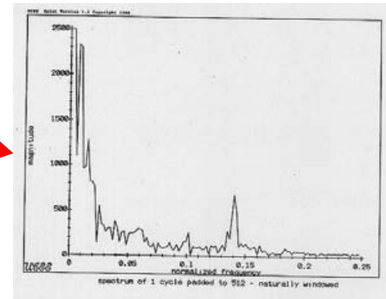
- Filtering (removing) channel resonance in frequency domain also cuts out more than channel resonance signals.
- New distortions introduced after frequency domain filtering.



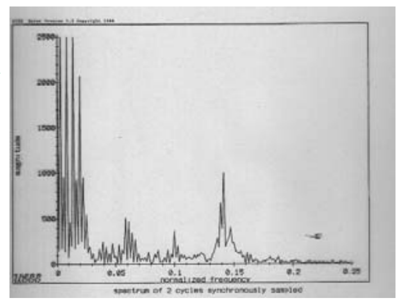
M. R. Smith, "FFT - fRISCy Fourier transforms," Microprocessors and Microsystems, Vol. 17:9, pp.507 - 521, 1993

Improved frequency spectra if take into account signal DSP characteristics

- Frequency domain signal after DC offset removal and applying window in time domain



- Significantly higher resolution in frequency domain signal after "synchronous sampling" (SS)
- Synchronous sampling involved taking into account specific underlying DSP characteristics of the rotating compressor signal.
  - Rotating signal samples were obtained at 1 degree intervals around 360 degree rotating engine motion.
  - Smith performed custom 720-pt DFT



M. R. Smith, "FFT - fRISCy Fourier transforms," Microprocessors and Microsystems, Vol. 17:9, pp.507 - 521, 1993

Synchronous Sampling Reconstruction of MRI data

- Compressor signals and MRI *k*-space data are different.
  - Compressor signals were infinitely long and easy to manipulate to provide Synchronous Sampling conditions.
- **How can we use Synchronous Sampling characteristics to improve the resolution of DFT reconstructions from truncated MRI *k*-space data?**
- **We have identified that**

  MRI Synchronous Sampling Reconstruction (SSR)

  can improve resolution by deliberately manipulating the *k*-space data characteristics through pre- and post-processing approaches

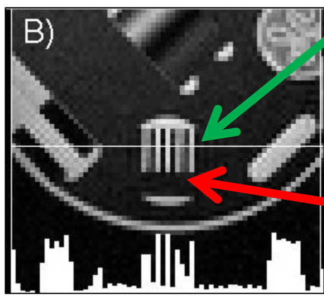
  to maximize the number of basis functions present in the truncated data.

Adipour and Smith, "*Overcoming Field of View Position-dependent Image Quality Exhibited in DFT and Compressed Sensing Reconstructions of Truncated Magnetic Resonance k-space Data Sets*", submitted MRI, May 2015

Signal types present after truncating *k*-space from *512x512* to *128 x 128*

Broad signals in the image domain which are narrow in k-space domain

- No resolution change as these signals are not "truncated" at *128 x 128* size.



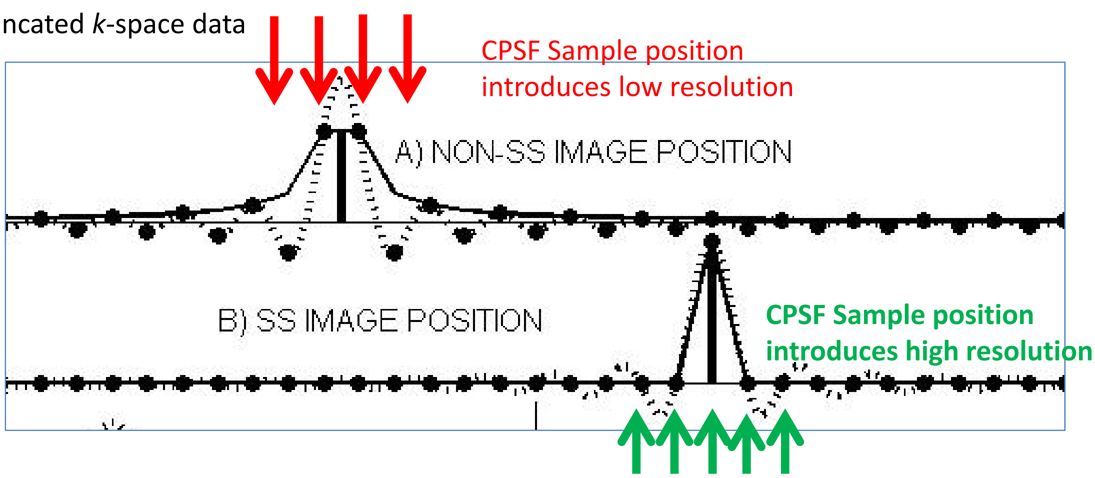
Narrow signals in the image domain which are wide in k-space domain

- **HIGHER** image resolution for *k*-space data components
  "Close to being 128 x 128 basis functions"
- **LOWER** image resolution for *k*-space data components
  "Not close to being 128 x 128 basis functions"

Resolution Changes are a "Sampling Artifact" of 128 x 128 Point Spread Function

ALL 512 x 512 sharp features have "identical" continuous point spread function (CPSF) (dashed line) when reconstructed from 128 x 128 truncated *k*-space data

However the **apparent resolution of the sharp feature depends on where that "identical" continuous point spread function is sampled** in the 128 x 128 image



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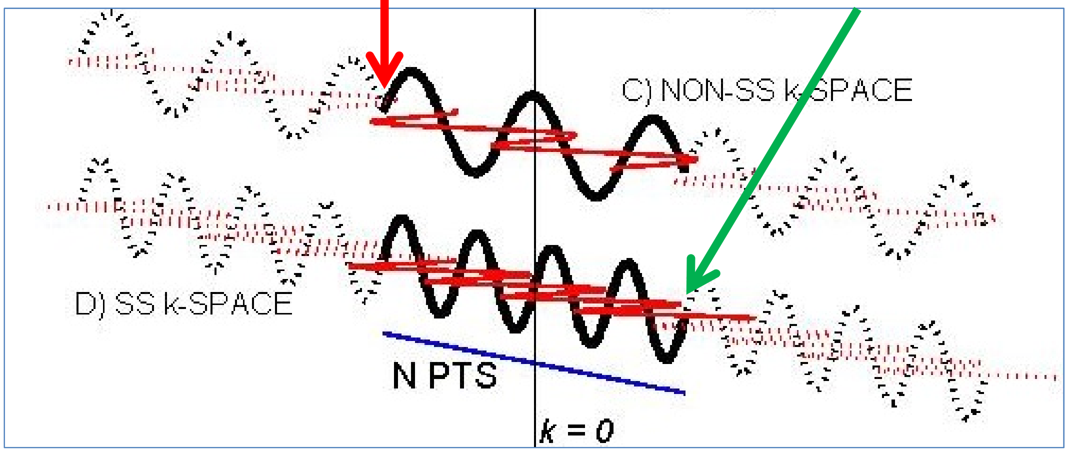
Resolution Changes are a "Sampling Artifact" of 128 x 128 Point Spread Function

C) After 128 x 128 truncation
NON-SS k-space data
LOSES CYCLIC CONTINUITY
across *k*-space boundaries

D) After 128 x 128 truncation
SS k-space data
RETAINS CYCLIC CONTINUITY
across *k*-space boundaries

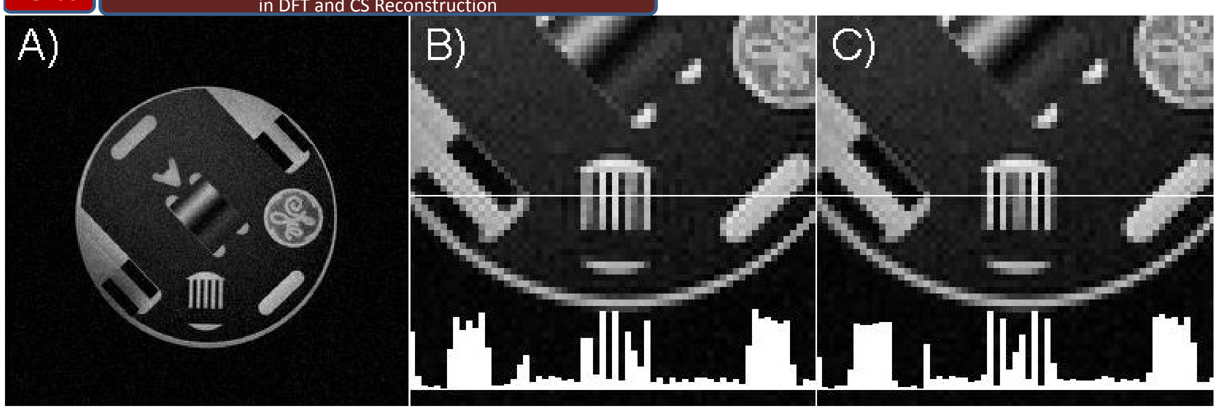


Adipour and Smith, "*Overcoming Field of View Position-dependent Image Quality Exhibited in DFT and Compressed Sensing Reconstructions of Truncated Magnetic Resonance k-space Data Sets*", submitted MRI, May 2015

Approaches to fix problem

- **SS - Plan Ahead Image Domain (SS-PAID):**
  Ensure SS conditions by ***PHYSICALLY ADJUSTING FOV*** so that fine detail of interest is placed at the centre of 128 x 128 voxel
- ***SS - K*-space Fourier Shift Reconstruction (SS-FSR):** Ensure SS conditions by ***POST-PROCESSING FOV ADJUSTMENT*** so that fine detail of interest is placed at the centre of 128 x 128 voxel.
  – Fourier relationship -- *x*-direction spatial shift of *p*% of the FOV equivalent to multiplying the *k*-space data by exp($-j2\pi\, pk / N$)
- **SS - Targeted K-space Re-truncation (SS-TRT):**
  POSTPROCESSING TO RE-TRUNCATE *K*-SPACE to ensure that texture pattern or fine detail will *become described* by *k*-space basis functions

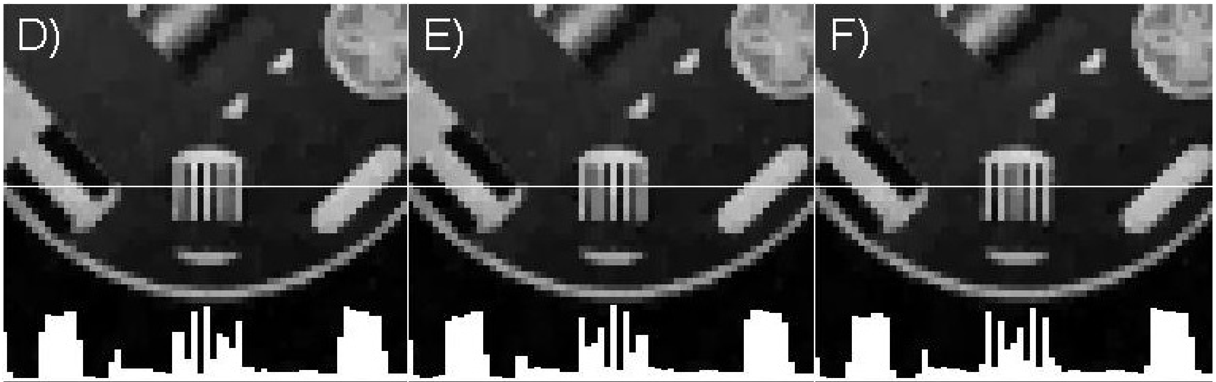
RESULTS



A) Original *512 x 512* DFT reconstruction.

128 x 128 DFT reconstruction resolution changes between B) Original and C) *0.40%* FOV shift (0.1 cm).

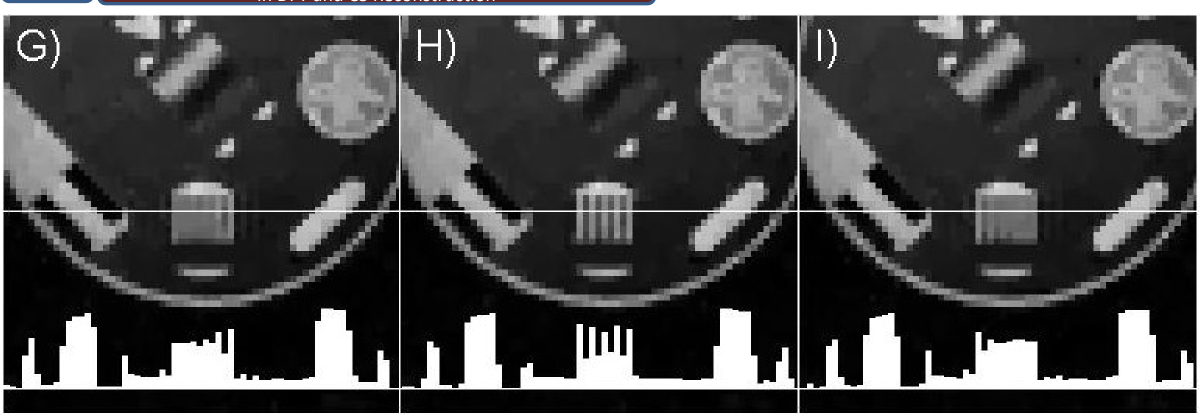
The bar plots are the intensities of the cross-section through the GE phantom tines marked by the thin white line.



DCT compressed sensing reconstructions also show position resolution changes.

D) Original, E) *0.20%* and F) *0.40%* FOV shifts across *128 x 128* images.

The bar plots are the intensities of the cross-section through the GE phantom tines marked by the thin white line.



DCT compressed sensing reconstructions combined with SS-TRT to 108 x 108

G) Original, H) *0.34%* and I) *0.50%* FOV shifts across *128 x 128* images.

The bar plots are the intensities of the cross-section through the GE phantom tines marked by the thin white line.

Conclusion

- Both *DFT* and *Compressed Sensing (CS)* reconstructions of truncated *k*-space data exhibit resolution that depends on the position of fine detail within the field of view.
- *Synchronous Sampling Reconstruction (SSR)* is an approach to manipulate truncated *NxN k*-space to maximize the number of fine detail image components that can be described by *NxN* k-space basis functions.
- Techniques and examples to achieve *DFT-SSR* and *CS-SSR* reconstructions were provided.
- The SSR implications associated with 3D reconstructions and characteristics of CS sampling schemes are under investigation.

- Theoretical explanation and additional SSR techniques detailed in

  P. Adipour and M. R. Smith, "*Overcoming Field of View Position-dependent Image Quality Exhibited in DFT and Compressed Sensing Reconstructions of Truncated Magnetic Resonance k-space Data Sets*", submitted MRI, May 2015.

- Contact Mike.Smith @ ucalgary.ca for more information