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Optimal *k*-space Sampling for Single Point Imaging of Transient Systems

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Abstract

A modification of the Single Point Imaging (SPI) is presented. The novel approach aims at increasing the sensitivity of the method and hence the resulting Signal-to-Noise ratio (*SNR*) for a given total time interval. With prior knowledge of the shape of the object under study, a selective sparse ***k***-space sampling can then be used to follow dynamic phenomena of transient systems, in this case the absorption of moisture by a cereal-based wafer material. Further improvement in the image quality is achieved when the un-sampled ***k***-space points are replaced by those of the initial dry or the final wet sample acquired at the beginning and the end of the acquisition respectively when there are no acquisition time limitations.

Keywords

k-space, SPI, selective sampling, rapid imaging

1. Method Development

1.1. SNR Optimisation for a Known Geometry

SPI [1] is a transient magnetisation imaging technique [2].Consequently each point in ***k***-space is sampled with a different amount of magnetisation. The SNR ratio for an image is predominantly determined by points acquired at low ***k*** values (corresponding to lower spatial frequencies [3]) .Hence more optimal use of the available magnetisation, before it reaches its equilibrium value, is achieved via sampling trajectories that are initiated at the ***k***-space origin. In the work presented here, an alternative way of sampling ***k***-space is proposed that is suitable when prior knowledge of the system shape exists. Instead of a general geometric ***k***-space trajectory [4], a trajectory that maximises the SNR is implemented. The relatively simple principle employed is that ***k***-space points with the highest probable modulus signal intensity are acquired with the highest value of magnetisation [5].

1.2. Selective Sparse *k*-space Sampling

SPI compared to frequency encode techniques has, in general, longer acquisition times. To follow dynamic changes in transient systems an attempt is made to accelerate acquisition. Geometric knowledge of the object of interest enables via inverse Fourier Transform (e.g Figure 1) a rank order of importance to be assigned to the ***k***-space points based on their modulus signal intensity. Hence, by sorting them one can decide to omit a significant amount of points that will contribute least in the final image. Finally, the ***k***-space points with the least information can either be zero-filled prior to Fourier transform, or can be replaced by ***k***-space points acquired for the same sample at the beginning or the end of acquisition consisting of a series of images tracking a transient phenomenon [5].

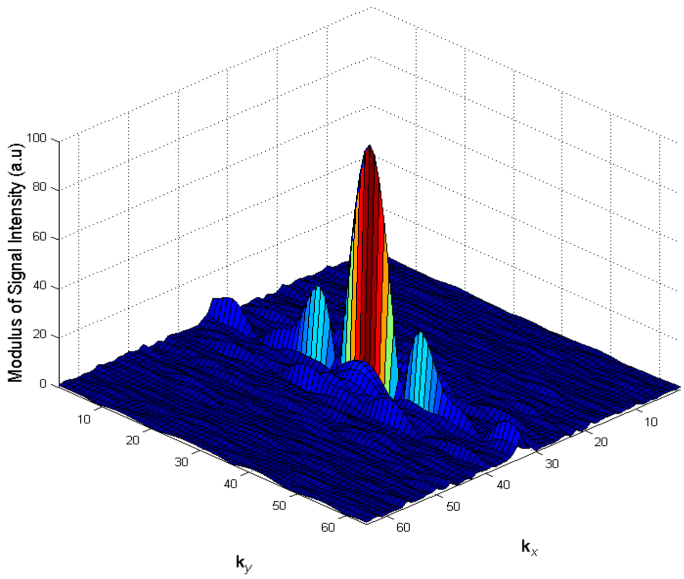

Fig. 1: Signal from the cross-sectional image shown on Fig 2. Lower spatial frequencies in general have a higher modulus. However, there are points further away from the origin with a significant amount of information.

2. Experimental Results

All experiments were conducted using a Bruker AV400 spectrometer equipped with a micro-imaging r.f. coil of 25 mm internal diameter. The samples were placed in a 17 mm internal diameter NMR tube featuring a glass sample holder and connected to a humidified air flow which ranged from 0 to 250 ml min^{-1}. The sample dimensions are shown in Figure 2. Images of the wafer were acquired whilst humid air was blown over it. Imaging of the wafer samples is very challenging as the porosity of the samples is typically 80-90 vol % and the absorbed moisture is typically only 2-7 wt % of the solid content. T_2* for water, is typically of the order of 50 µs. Imaging of this system with conventional frequency encode methods is not possible, hence the use of single point techniques is necessitated. The moisture signal is also, however, characterised by a relatively long longitudinal relaxation time, T_1 (~ 1s). A sample result is presented in Figure 3. In the above system a full acquisition of a 64 x 64 ***k***-space matrix with 16 signal averages requires 40 minutes. Acquisition time in the sparse imaging reduces proportionally to the percentage of acquired ***k***-space.

3. Conclusion

We have demonstrated that with prior knowledge of a general sample of interest's shape, a sparse ***k***-space sampling strategy in an SPI experiment can be optimised with respect to *SNR* for a given acquisition time interval. Furthermore, a full ***k***-space acquisition at the beginning and the end of the dynamic process can give information of the lower spatial frequencies that can be used to fill in the un-sampled points and give improved quality images.

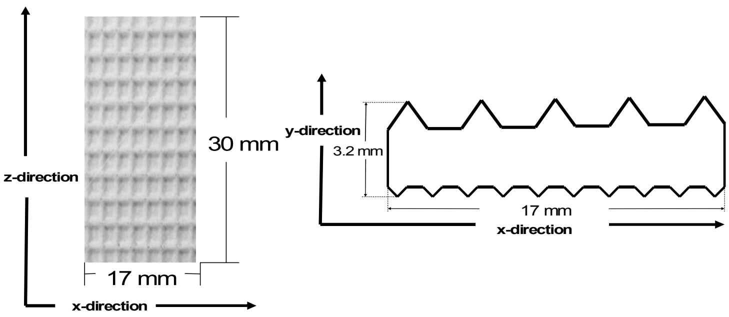

Fig. 2: Picture of a wafer sample (left) and schematic of its cross-section (right).

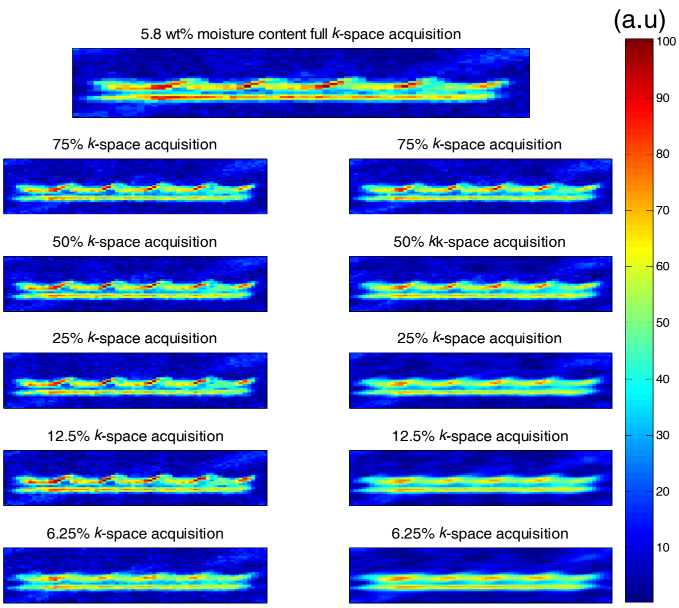

Fig. 3: Images of the sample with a moisture content of 5.8 wt %.The top image is with full *k*-space acquisition, the left column shows images acquired with 75, 50, 25, 12.5 and 6.25 % of *k*-space sampled respectively with un-sampled ***k***-space being filled with the values of the initial dry sample image (hybrid images). On the right, images with the same % of ***k***-space sampled, with un-sampled points filled with zeros. Hybrid images tend to reconstruct the original image more accurately even when a very small percentage of ***k***-space is sampled.

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