# Performance Evaluation of F-K Kirchhoff Migration using Ultra-wideband Radar with Sparse Array

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***Abstract*—Recently, the authors proposed a fast high-resolution imaging algorithm, called frequency-wavenumber (F-K) Kirchhoff migration. It was developed by combining three algorithms: F-K migration, Kirchhoff migration and inverse boundary scattering transform. The F-K Kirchhoff migration is considered promising in improving the image resolution of images taken with airport security body scanners for which costs can be mitigated by introducing sparse arrays. We investigate the imaging performance of the F-K Kirchhoff migration using ultra-wideband radar with such sparse arrays.**

***Index Terms*—sparse array, radar imaging, F-K Kirchhoff migration**

## I. Introduction

In many airports worldwide, ultra-wideband radar-based body scanners are increasingly used to ensure the safety of passengers. Such systems use a 1-D antenna array with numerous ($\simeq$ 400) elements, making the system costly. To address this issue, the introduction of a sparse array is essential because it can significantly reduce the number of elements and the complexity of the system while maintaining the necessary quality of images [1], [2], [3], [4]. The quality of the images, however, depends on the adopted imaging algorithm. Thus, identifying the advantages and disadvantages of each imaging algorithm is important when applied to such sparse arrays.

Obtaining images of a higher resolution is desirable because they can provide more detailed information about concealed objects, and much effort has been made by many research groups to achieve this [5], [6], [7]. Moreover, fast imaging computation is also required to avoid queuing holdups for passengers at security checkpoints. The authors developed the frequency-wavenumber (F-K) Kirchhoff migration [8], which is an extension of the modified Kirchhoff migration [9] and combined it with F-K migration and inverse boundary scattering transform (IBST) to achieve fast computation and high resolution. In this paper, we apply the F-K Kirchhoff migration to sparse array radar measurements with various antenna spacings.

## II. System Model

The assumed measurement system is a bistatic radar configuration with transmitting and receiving antennas with a fixed at 5.0 cm in the horizontal direction; for convenience, their positioning defines the $z = 0$ plane. We measured a metallic target with the shape of the Siemens star (Fig. 1). The measurement was conducted in the frequency domain using a network analyzer to sweep 161 points at frequencies from 4.0 to 20 GHz.

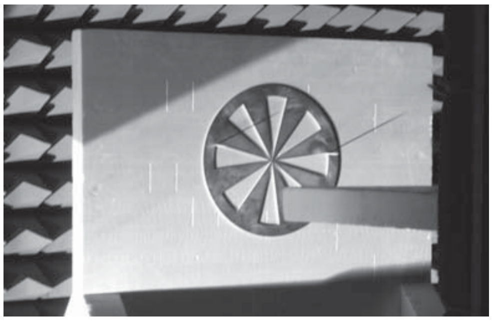

Fig. 1. A target with an eight-spoked Siemens star.

We used two Vivaldi antennas that are vertically polarized. The antenna pair scan in the $x$-$y$ plane ($z = 0$) over 75.0 cm$\times$ 75.0 cm at 1.0-cm intervals. This measurement corresponds to a $75 \times 75$ dense array. We selected signals every two and four vertical scan lines and virtually generated sparse array datasets for $38 \times 75$ and $20 \times 75$ arrays. The missing data were linearly interpolated to restore 75 full data, which were processed using the F-K Kirchhoff migration to produce images.

## III. F-K Kirchhoff Migration and Sparse Arrays

We apply F-K Kirchhoff migration [8] to radar data measured using the sparse arrays. First, an approximate target image is calculated using the texture angle [10] and IBST. The approximate shape of the target allows us to determine the integrand of the Kirchhoff integral [9]. Next, the time-domain calculation of the Kirchhoff integral is replaced by the application of the F-K migration to the pre-calculated Kirchhoff integrand to form a high-resolution image. This method combines the F-K migration, Kirchhoff migration, and IBST to obtain a high-resolution image within a short time.

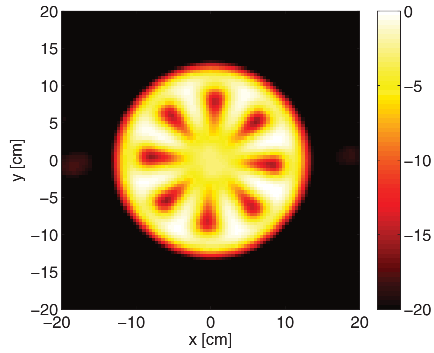


Fig. 2. Image obtained with the F-K Kirchhoff migration for 38 × 75 sparse array (horizontal and vertical antenna spacings: 2.0 cm and 1.0 cm, respectively).

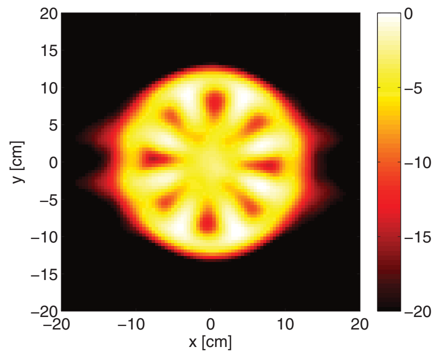


Fig. 3. As for Fig. 2 but for a 25 × 75 dense array (horizontal and vertical antenna spacings: 1.0 cm and 1.0 cm, respectively).

The F-K Kirchhoff migration is applied to the datasets assuming a dense array (1.0 cm horizontal intervals) and two different sparse arrays (2.0 and 3.0 cm horizontal intervals). Fig. 2 shows the image generated using the F-K Kirchhoff migration for the 38 × 75 sparse array with antenna spacing of 2.0 cm. The image is well focused and almost identical to the image shown in Fig. 18 of [8]. Figs. 3 and 4 show the images for a 25 × 75 dense array with an antenna spacing of 1.0 cm, and a 25 × 75 sparse array with an antenna spacing of 3.0 cm. The image for the small dense array shows distortion of some of the spokes of the star and around the rim of the wheel, whereas the image for the sparse array appears better focused. We also see horizontal artifacts in Fig. 4 caused by grating lobes of higher frequencies.

## IV. Conclusion

We have applied the F-K Kirchhoff migration to dense and sparse arrays for evaluating the imaging quality. Compared with the image for the small dense array with the same number of elements, the image for the sparse array shows a higher resolution but a lower dynamic range with the occurrence of grating lobes. In a future study, it will be important to optimize the array topology to enhance image quality. Comparisons with other imaging algorithms will be an important study in the future.

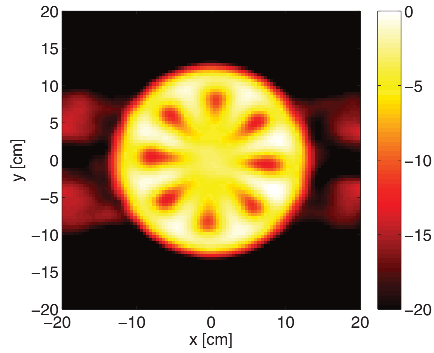


Fig. 4. As for Fig. 2 but for a 25 × 75 sparse array (horizontal and vertical antenna spacing: 3.0 cm and 1.0 cm, respectively).

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