IMAGING ALGORITHM AND EXPERIMENTAL DEMONSTRATION OF ROTATING SCANNING INTERFEROMETRIC RADIOMETER

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ABSTRACT

Synthetic aperture interferometric radiometer (SAIR) was introduced from radio astronomy into passive microwave remote sensing in the late 1980s as an alternative to real aperture radiometry for earth observation [1]. Several airborne SAIR systems have been successfully developed, such as ESTAR [2], 2D-STAR [3] and HUT-2D [4]. The first space borne SMOS (Soil Moisture and Ocean Salinity) system has also been successfully launched and completed its first phase of life in orbit. Furthermore, NASA has proposed the GeoSTAR project that applying SAIR to atmospheric sounding and weather forecasting in geostationary orbit [5]. All these instruments are worked in snapshot mode that simultaneously collecting all the needed visibilities for image reconstruction. Snapshot operation inevitably requires complex hard wares with a large number of antennas, especially for space borne systems with high spatial resolution. This is the most challenging work for space application.

Rotating scanning SAIR (RS-SAIR) provided an effective way to overcome the complexity problem, which employs a simple non-redundant array to collect all the required spatial frequency points during the rotating scan. It takes advantage of relative motion between the array and the viewing source, conceptually in the same way as the earth rotation synthesis radio astronomy, and only need to simultaneously sample the visibility points in the radical direction, then by means of rotating the array to fulfill the complete sampling coverage. Therefore the array complexity is highly reduced by $N^{1/2}$ times comparing to the snapshot systems. In essence, the reduction in antenna count is achieved at the cost of a reduction imaging frame rate, thus it particularly fit for the no time emergent but high resolution required applications, for example, the GEO earth observation witch may relax the imaging time to 5-10 minutes per frame.

Image reconstruction is an important problem need to be solved for RS-SAIR. Because the spatial frequency samples of RS-SAIR are laid on polar grid of concentric circles, the conventional Cartesian FFT based method can not be used directly. The prevailing belief seems to be that there is no such Fourier transform algorithm for polar discrete data that would be invertible and rapidly computed like FFT in equi-spaced Cartesian grid data. The other methods such as Clean method broadly used in radio astronomy [6] and the Moore-Penrose pseudo inverse based G-matrix method used for ESTAR system [2] are

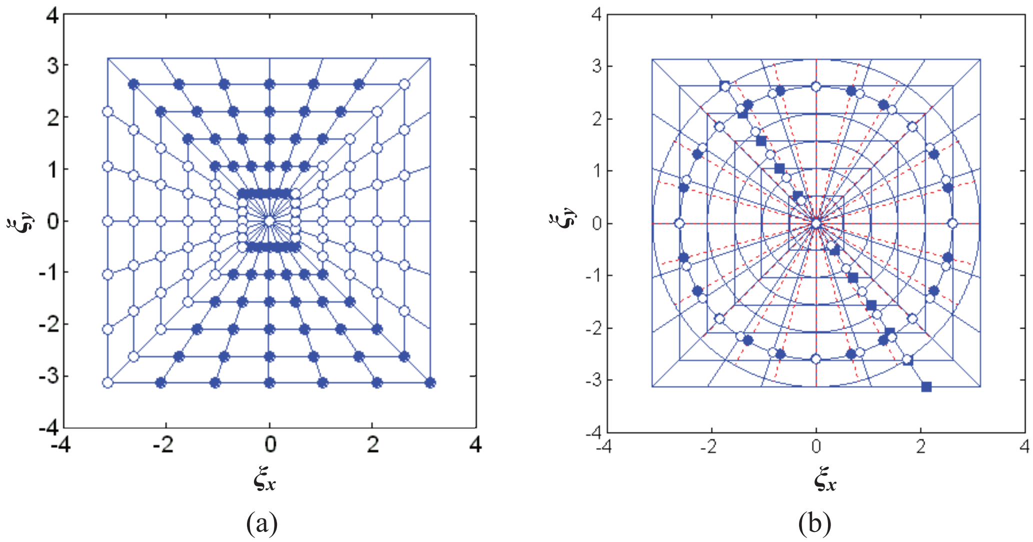

Fig.1. Schematic diagram of pseudo-polar grid (N=6) (a), which is composed of concentric equi-spaced rectangles and equi-sloped rays; and the 1-D interpolations applied to transform the polar grid to pseudo-polar grid (b), witch include two interpolation steps - the angular interpolation and radical interpolation.

both inapplicable for this case. In this paper a fast and accurate imaging algorithm is given to inverse the polar sampling grid data. It takes pseudo-polar grid as the intermediate interpolation destination and then implement Fourier transform to get the final image. The pseudo polar grid, which is composed of concentric squares shown as Fig. 1(a), is more close to concentric circles polar grid. The advantages of this algorithm are threefold. Firstly, the more similarity between the polar grid and pseudo-polar grid gives the shorter interpolation distances. Secondly, only 1-D interpolations are needed to do the grid conversion which ensures a higher accuracy than traditional 2D interpolations, the interpolation process is shown in Fig. 1(b). Finally, there exists a fast Fourier transform between Cartesian grid and pseudo-polar grid that the total computation complexity is still on level of $O\{N^2 \log N\}$[7,8].

An experimental RS-SAIR system in X band (λ=3.2 cm) is set up to validate the rotating scanning time-shared imaging concepts. The system is made up in a modular concept with eight receiver channels in all. The power supply, receiver and correlator modules are all integrated into one building block, which is mounted on a turning platform. The antenna elements, circular polarization horn antennas, are mounted on the system main body and could form an arbitrary array distribution. The system array can be rotated by 360º with at least 1º step around the turn platform central axis that controlled by computer, the tilt angel of viewing direction can be manually adjusted from -90º to 90º. Fig. 2(a) illustrates the system structure.

First measurements were operated using a linear distribution array with 5 selected receiver channels. In order to achieve a higher spatial resolution, we measured the same object scene several times; each time the array was manually adjusted to form more observing baselines. The baseline spacing is set as Δu = 2cm = 0.626 λ, and the largest baseline is $u_{\max} = 62\text{cm} = 19.375\ \lambda$, so the spatial resolution is $\Delta\theta \approx 1.5^{\circ}$ and the aliasing free FOV is $\theta_{\text{free}} \approx 73.7^{\circ}$ in theory. Using the newly developed imaging algorithm, the initial imaging result is shown in Fig.2(c,d). The gravity tower and around buildings are clearly reconstructed, even the little windows and the tower lightning rod can be recognized from the reconstructed image. Some antenna reflectors and window glass within the FOV present low brightness temperature because of reflecting the cold sky. It should be pointed out that, there are some errors still exist in the visibilities that caused some blurred effects in the image, further calibration works for this RS-SAIR system need to be carried out in the Future work.

Anyway, the experimental result is rather good as our expectation to validate the feasibility of RS-SAIR system combined with this new imaging algorithm.

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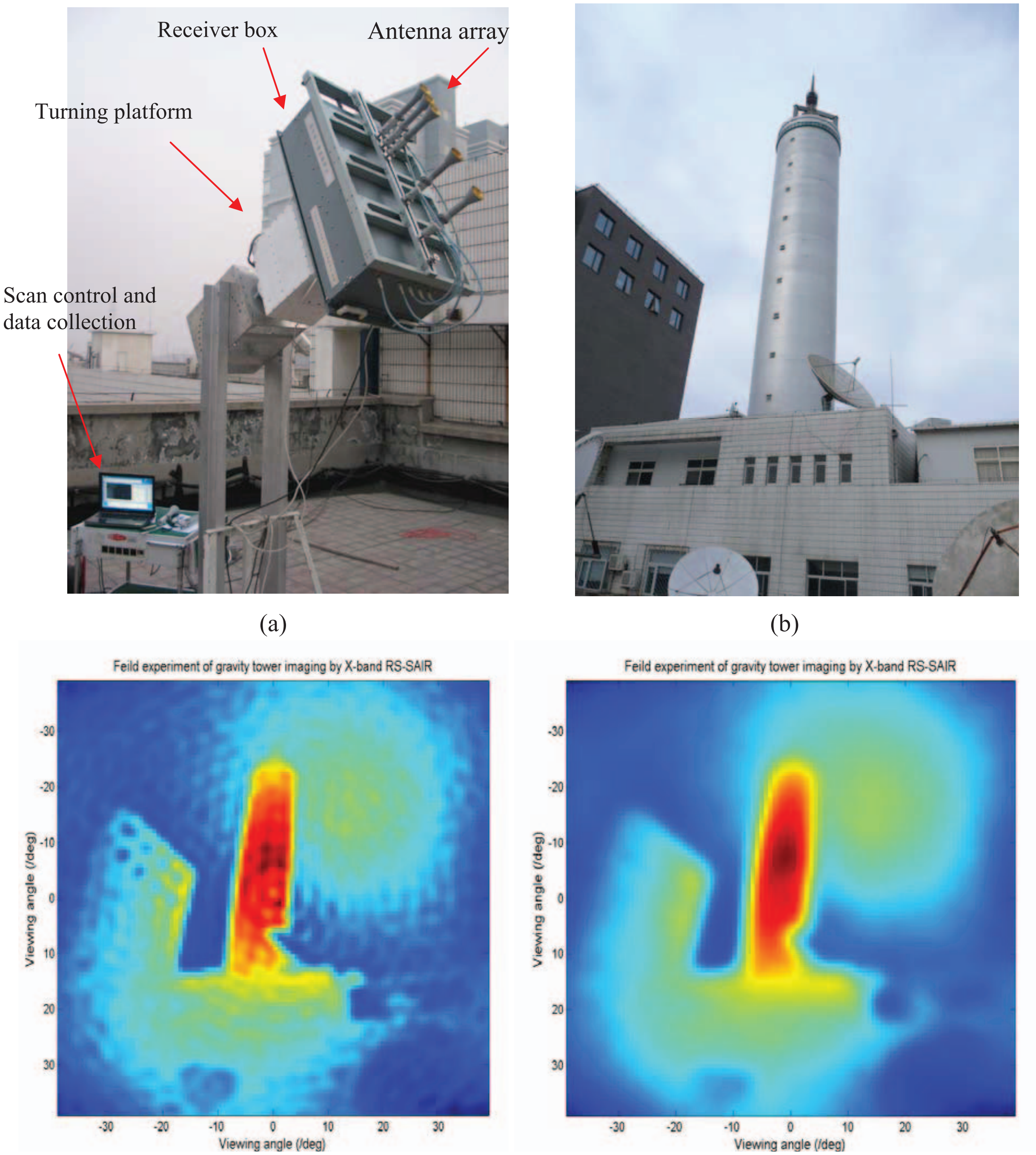

Fig.2. Field measurements of X-band RS-SAIR. The structure configuration of the experimental RS-SAIR system (a); the viewing scene of the gravity tower buildings (b); the reconstruction result without tapering (c), which has a higher spatial resolution but keeps circular Gibb's oscillation caused by rotation scan; and the smoothened image tapered by Blackman window (d), which has a lower spatial resolution but higher temperature sensitivity.