All Directions Through the Wall Imaging Using Omnidirectional Bi-static FMCW Transceivers

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Abstract—This paper introduces a new technique for through the wall imaging capable of providing 360° image of building interiors and hidden objects behind the walls in a short time. To achieve high cross range resolution, a large and dense 2D synthetic aperture is formed by sampling the reflected signals at different locations in the imaging area using a moving receiver with omnidirectional antenna and then applying a beam forming technique. Using a synthetic aperture instead of a real aperture enables high mobility for the imaging system. An imaging system realizing the proposed method is introduced and a sample of imaging using the fabricated system is presented. The system is a wideband bi-static FMCW radar utilizing wideband circularly polarized omnidirectional antennas for both transmitter and receiver. It is shown that using antennas with orthogonal circular polarizations reduces the spurious images due to multiple reflections of the transmitted signal.

Keywords—Circular polarization; FMCW; synthetic aperture; through the wall imaging

I. INTRODUCTION

Through-the-wall imaging systems are capable of imaging of the buildings’ interiors, hidden rooms and pathways, and static or moving objects behind the walls independent of the ambient condition such as external light source [1]–[2]. This information enables better threat assessment in rescue and law enforcement operations.

Conventional methods for through the wall imaging rely on large antenna arrays (real apertures) to provide high cross range resolution. However, the size of the antenna arrays limits the mobility of the system and thus in many cases, the imaging is performed from outside of the buildings. In addition, the directive antennas utilized in conventional systems only provide the image of the area in front of the array. With directive antennas, multiple scans from different directions (if possible) are required to provide a 360° image of the imaging area. In this paper, a new method for through the wall imaging is proposed capable of providing 360° image in a short time while maintaining a high mobility for the imaging system. In the method, instead of using a real aperture, a 2D large and dense synthetic array is utilized to obtain high cross range resolution images. The method uses omnidirectional antennas for both transmitter (Tx) and receiver (Rx) to directly form 360° images eliminating the need for multiple scans from different directions. As shown in Fig. 1, a Tx transmits signals in all directions and a moving Rx samples the reflected signals at different points in the imaging area. By applying a beam forming technique to the samples a large 2D synthetic array is formed. Although omnidirectional antennas enable all-directions imaging, they receive multiple interactions of the transmitted signals with the building’s interiors which results appearance of spurious images in the final image. This issue is addressed in the method by utilizing orthogonal circular polarizations for Tx and Rx antennas.

A wideband bi-static FMCW radar system with wideband circularly polarized omnidirectional antennas realizing the proposed imaging method is designed and fabricated. Different parts of the system are introduced and a preliminary imaging result obtained by the fabricated system is presented in this paper. The result shows that the system can provide 360° image while the effect of multiple reflections is significantly reduced in the image.

II. IMAGE FORMATION TECHNIQUE

Fig. 1 shows a sample of Tx and Rx configuration in the proposed imaging method. A Tx with a fixed position transmits signals in all directions and a moving Rx (mounted on a small robot) moves in the imaging area and samples the reflected signals at different locations (sampling points). It is assumed that the Tx and Rx form a bi-static FMCW transceiver. Using the modified back-projection technique described in [3] (adapted for FMCW imaging radars), the image is formed using the obtained samples. In the proposed method, a flying robot repeatedly takes the photo of the robots

Fig. 1. Tx and Rx configuration in the proposed method. Also shown the significant higher order interactions of the transmitted signal with walls.
to determine the position of the Tx and sampling points. The arrangement of sampling points is important and may result in appearance of spurious images and variation of cross range resolution in different directions. Simulations show that placing the sampling points on concentric circles with centers located at Tx, provides a uniform cross range resolution in all directions and reduces the unwanted spurious images.

III. OMNIDIRECTIONAL CIRCULARLY POLARIZED ANTENNAS TO REDUCE EFFECT OF MULTIPLE REFLECTIONS

The image of walls and objects are formed by the first reflections of the transmitted signal. Including the signals experienced higher order reflections in the image formation results appearance of spurious images. The significant higher order reflections are double reflections from corners and parallel walls as shows in Fig. 1. To reduce the effect of these signals, orthogonal circular polarizations are used for Tx and Rx. In this case, the signals experienced even number of reflections have the same polarization as the transmitted signal and are attenuated by polarization isolation of the Rx antenna. This also attenuates the unwanted direct signal from Tx to Rx.

IV. BI-STATIC FMCW TRANSCEIVER WITH CIRCULARLY POLARIZED OMNIDIRECTIONAL ANTENNAS

To realize the proposed imaging method, an imaging system operating in the range 1.2–2 GHz was designed and fabricated. The signals within the selected frequency range can penetrate in the typical walls and provide theoretical range resolution of 18.75 cm which is enough for typical through-the-wall imaging applications. As required by the proposed method, the imaging system is bi-static (Tx and Rx are at different locations). To simplify the synchronization process, the radar architectures is FMCW which requires only the synchronization of the start of the chirp signals at both Tx and Rx. The synchronization is performed by transmitting a CW signal at 915 MHz. The signal is received at both Tx and Rx and then its frequency is reduced by frequency dividers and counters at both Tx and Rx. The resulting low frequency signal is used to start the chirp signal. With this configuration, any instability in frequency of the transmitted signal has the same effect on Tx and Rx. Fig. 2(a) shows the FMCW transmitter. The measured phase noise is better than -100 dBc at 18.75 kHz offset over the band 1.2–2 GHz. The sweep time for the chirp signal is 47 µs. Fig. 2(b) shows the synchronization circuit and FMCW receiver in Rx. A high speed A/D module (100 MSamples.s) is also designed to sample the IF signal at Rx and send the collected data via an ad hoc Wi-Fi network. Fig. 2(c) shows the A/D module. Fig. 2(d) shows the fabricated low profile (height 47 mm) wideband circularly polarized (CP) omnidirectional antenna. This is a novel antenna which operates based on excitation of orthogonal circular waveguide TE_{11} modes in free space. In the fabricated system, left-handed CP is used for Tx and right-handed CP is used for Rx.

Fig. 3 shows a preliminary imaging result using the fabricated system. Fig. 3(a) shows the geometry of the imaging area. The imaging area includes three metallic walls and one metallic sphere. Tx is located at the center. Reflected signal is sampled at 143 points on two circles with radii of 0.7 and 1 m. Fig. 3(b) shows the resulting image. It can observed that the three metallic walls and the sphere are imaged. In this image, the location of the double reflection from the parallel walls on the bottom and top is indicated by dashed line. It can be observed that by using orthogonal circular polarizations, the effect of double reflections from the parallel walls are eliminated in the image (no spurious image of wall appeared around the dashed line).

REFERENCES

