3D-Scan Millimeter-Wave Radar for Automotive Application

Kazuo SHIRAKAWA Shuhei KOBASHI Yasuhiro KURONO Masayoshi SHONO Osamu ISAJI



Abstract

We have developed an innovative automotive millimeter-wave radar with a simple architecture that provides 3D-Scan which is capable of covering and detecting range direction, azimuth direction and elevation direction. This leading-edge radar has been realized by SiGe Multi Channel Transceiver, uniquely-arranged Sector Antenna and sophisticated and advanced signal process technology (technology co-developed with FUJITSU LABORATORIES LTD.). This paper will highlight consideration of detection area which must be covered, and principle and architecture of the 3D-Scan. It will also explain the principle of direction of arrival operation in which the direction of the detected target is calculated by use of phase difference between a transmitted signal and a received signal at the radar. Moreover, it will show that our proposed method achieves 3D-Scan, based on our simulated results and the results of the mounted sensor performance in the real world test. Introduced 3D-Scan Radar will provide solutions for its simpler installation to a vehicle, and for more promised detection of the objects existing in elevation region both down below and up above and fallen objects.

Introduction

It has been known that the automotive millimeterwave radar has been spread on various vehicles from high-end to ordinary vehicles recently. More growth of millimeter-wave radar market is estimated and expected with taking the opportunity that the new regulations requires AEBS (Autonomous Emergency Braking System) for every single heavy vehicle (e.g. truck) in Europe in 2013 at the earliest. With this market growth, not only the conventional requirements such as lower cost, broader Field-of-View (FoV) and higher resolution, but also additional requirements for new functions for millimeter-wave radar have emerged. The additional requirements are, for example, more simple radar beam alignment for mounting and attaching, realization of detecting up-above objects and fallen objects, and compensation for beam axis declination occurred on loading trucks. In order to accomplish these requirements, it is necessary to develop 3D-scan radar that detects targets in elevation region in addition to the conventional two dimension (range direction and azimuth region) scanning. The detection mechanism of the elevation region has to provide high-speed scanning and calculation because it is used for detecting up-above objects and fallen objects. In terms of cost, the 3D-scan radar has to be developed without large complex change based on the conventional 2D-Scan radar¹⁾⁻³⁾.

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Consideration of Detection Area

The illustration in Fig. 1 represents the considered 3D-scan radar detection area. In azimuth region, by a socalled MMR (Multi-Mode Radar) which executes azimuth region Direction-of-Arrival (DoA) operation within entire middle/long range, narrowed down beam covers a maximum range up to 250m for long range detection, and broad beam covers assumed range of radial 50m in an FOV angle of \pm /- 45 degrees for middle range detection. In elevation region, in order to recognize the up-above objects and the fallen objects on the road which move into Pre-Crash Safety (PCS) decision area, the radar executes DoA operation within the azimuth direction \pm /- 9 degrees region which is the overlapped area detected by



Fig.1 Considered Detection Area for 3D-Scan Radar

middle range beam and long range beam (see hatched area in **Fig. 1**). If the radar is capable of the DoA operation of the elevation direction in this area, the radar will provide more simple radar beam alignment and compensation for beam axis declination.

Concept of 3D-Scan Radar

In order to accomplish 3D-scanning, M antennas each of which possesses a discrete receiver are located toward azimuth direction, and N antennas each of which possesses a discrete transmitter are locataed toward elevation direction. The radar transmits beams from single arbitrary transmitting antenna (Tx), receives the reflected beams by M receiving antennas (Rx), and then executes the azimuth DoA operation by ESPRIT (Estimation Signal Parameter via a Rotational Invariant Technique). On the other hand, the radar transmits time-divided beams from N Tx antennas sequentially, receives the reflected beams at the arbitrary antenna chosen among M Rx antennas, and then executes the elevation DoA operation by ESPRIT. The reason why the radar transmits time divided beams is to identify the transmitting antenna. In practical situation, the radar that receives the beams by M Rx antennas during transmitting the time divided beams sequentially from N Tx antennas accomplishes simultaneous azimuth and elevation scanning. Images of azimuth and elevation DoA operation are shown in Fig. 2. Modulation scheme is FMCW. Switching detection area between middle range and long range for MMR could be accomplished by applying L Tx antennas for narrow beams and N-L Tx antennas for broad beams. We have applied M=N=4, L=2 for a prototype.



Fig.2 Calculation Image for Each Element by 3D-Scan Radar

Fig. 3 represents the detection image of the conventional 2D-Scan radar that detects the range direction and the azimuth region.



 θ : Target azimuth angle

Fig.3 Image of 2D-Scan Radar Detection

The azimuth angle detection is implemented by azimuth DoA operation with phase difference of the received signals due to the different locations of the M Rx antennas. **Fig. 4** represents the image of azimuth DoA operation.



Fig.4 Image of 2D-Scan Radar Azimuth DoA Operation Using Phase Difference

Fig. 5. illustrates the detection image of the 3D-scan radar that detects the range direction, the azimuth region and the elevation region.

Elevation region detection is provided by elevation DoA operation with phase difference of the transmitted signals due to the different transmission locations of the N Tx antennas in height. The target elevation region detec-



Fig.5 Image of 3D-Scan Radar Detection

tion offers the detection of the up-above objects at the scene as shown in Fig. 6, such as traffic signs and signboards, which were not detected by the conventional 2D-Scan radar.



Fig.6 Image of 3D-Scan Radar Elevation DoA Operation Using Phase Difference

4 Simulation Results

Here is the simulation results based on the assumption of actual road situations. Signal models are prepared based on the assumption of a forward vehicle and upabove objects such as a traffic sign and a destination sign (Fig. 7). Fig. 8 shows the considered antenna elevation beam pattern. The simulated results of detection analysis by the proposed 3D-scan method are illustrated in Fig. 9.



Fig.7 Simulation Model



Fig.8 Elevation Beam Pattern



The simulated results with three different targets that were located in different height, range and lateral distance indicate the adequacy of proposed detection method performance.



Here is the mounted sensor performance result in a real world test. In the test, some targets were detected by the 3D-scan radar installed at the front position (at the back of an emblem) of a vehicle during driving on a freeway. Fig. 10 shows the detected scene where a target (a truck) is driving in front of the vehicle equipped with the 3D-scan radar (ahead of the radar). Fig. 11 shows another detected scene where a new vehicle is passing in an adjacent lane. Fig. 12 shows another scene where objects (traffic signs) are detected.



Fig.10 Mounted Sensor Performance Result in real world test (Detection of Forward Vehicle)



Fig.11 Mounted Sensor Performance Result in real world test (Detection of Passing Vehicle in adjacent lane)



Fig.12 Mounted Sensor Performance Result in real world test [Detection of Up-above Object (Traffic Sign)]

The mounted sensor performance result in real world test with different targets that were located in different height, range and lateral distance also indicate the desired detection performance. Therefore, we confirmed that the detection method works efficiently even in the real world.

Radar External Size

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Fig. 13 shows the external picture of the prototyped 3D-scan radar. The 3D-scan radar can be formed without the complex architecture caused by large change in aperture area compared to the conventional 2D-scan radar, and can be compact and light enough to fit on a palm.



Fig.13 3D-Scan Radar

Conclusion

In this paper, we have presented that 3D-scanning is possible in required area even with a simple architecture based on our proposed method. The 3D-scan radar provides promised detection of up-above and down-below obstacles, and fallen objects. According to this promised detection, the radar is capable of determining targets which PCS do not need to consider for system activation. Therefore, PCS could be achieved not only in high speed region but also in low speed region. Reference

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Profiles of Writers



Kazuo SHIRAKAWA (Doctor of engineering) Advanced Wireless Technologies Laboratory, Network Systems Laboratories, FUJITSU LABORATORIES LTD.



.aboratory, Vetwork Systems Laboratories, EUJITSU LABORATORIES LTD.

Masayoshi SHONO

Research & Development Planning Department.





Shuhei KOBASHI

Sensor Development Dept, AS Engineering Group.

Department General Manager of Sensor Development Dept, AS Engineering Group.

Osamu ISAJI



Yasuhiro KURONO

System Development Dept, AS Engineering Group.