94 GHz 3D-IMAGING RADAR FOR SENSORBASED LOCOMOTION

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Abstract

For obstacle detection, navigation and route planning acquisition of 3D sensor information in realtime is essential for autonomous vehicles operating in partially predetermined, dense environments like production plants. Featuring direct access to range information and doppler signal processing, this radar sensor, suited for autonomous locomotion is an alternative to video sensors, due to it's realtime capability.

This paper reports on system design and imaging results of an agile 94 GHz pulse doppler radar with 25 cm radial and 1.5° angular resolution. Test environment is a laboratory, representing a structured, stationary indoor scene, which is comparable to those expected in future applications. Results are discussed with respect to the visibility of typical mm-wave scattering phenomena as well as to the potential identification of object contours and zones free of obstacles.

Introduction

Substantially improved flexibility in partially unknown environments is the most promising feature of autonomous vehicles. One major requirement for attaining real autonomy is the capability of acquiring relevant information about the scene the vehicle operates in. Complex operating modes like reconnaissance, navigation, optimum route planning and docking require high level information extracted from sensor data, for example detection of collision situations or measurement of sensor orientation, displacement and velocity relative to fixed objects.

One field of application will be mobile robots in production plants [1], for which the radar system presented is designed. Common approaches for sensors providing suitable information for sensorbased locomotion are standard video or stereo vision systems and infrared or acoustical proximity sensors with their restrictions in maximum range. While video sensors offer excellent resolution and very high data rates, capabilities in object identification under varying illuminations and calculation of radial distance in realtime still seems to be limited. Self illuminating sensors with high angular resolution and the ability of direct range measurement seem to be a promising solution to overcome these limitations and keeping the necessary data processing power at a realistic level. Laser scanners demonstrated good results, but requiring eyesafeness, the range of vision for arbitrary objects is around 10 m. Application of a mm-wave pulse doppler radar allows coherent signal detection, resulting in considerably increased sensitivity and direct access to range and velocity information, an important feature, since the environment the vehicle operates in generally appears moving. To realize a sensor with sufficient angular resolution a high carrier frequency of 94 GHz had to be chosen, causing typical doppler frequencies in the kHz region, convenient for signal processing.

Currently at the Technical University of Munich a demonstrator vehicle equipped with a scanning laser camera for the very close range and a multitask mm-wave radar providing 3D realtime information in the range from 1.4 m to 50 m is set up to perform autonomous sensorbased locomotion in industrial indoor scenes.

System Configuration

A fixed radar head in combination with a scanning flat reflector, as shown in Fig. 1a and 1b, was chosen in order to maintain low inertia and polarization decoupling. The far field beamwidth of 1.5° in azimuth and elevation is generated with a lens of 168 mm diameter, illuminated by a corrugated horn. Due to the high antenna gain scatterers within a range of approximately 18 m are observed under nearfield conditions, virtually decreasing sensitivity and angular resolution, unless the lens system is focussed to a moderate distance. The reflector design was optimized to enable fast scanning operation via servo motors as well as focussed looks to objects of interest where up to 5 arbitrary beam directions per second can be processed. A separate rack containes the necessary interface circuitry, signal processing facilities and power supply.

Multirole features of this sensor require maximum range gate agility, only offered by time domain radar principles. Resulting losses in sensitivity by 10 dB compared to FMCW techniques can be tolerated in this special case because of the near range application. The radar head is characterized by the microwave block diagram in Fig. 3. As demonstrated already in [2, 3], the homodyne principle is effectively used to gain the phase related radar pulse information, without sacrificing performance due to 1/f noise. This is achieved, because of a very high pulse repetition frequency of 1 MHz, which is unambiguous for this near range application.

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Operating Frequency	94 GHz	Integration Time	100 µs (100 Blips)
Pulse Repetition Frequency	1 MHz	Data Rate	10000 Resolution Cells per Second
Pulse Width	1.7 ns		
Range Resolution	25 cm	Operating Modes	- Arbitrary Sectorscan (1D, 2D or 3D)
Accuracy of Rangemeasurement	±1.5 cm		
Doppler Increment	1.6 mm		- Tracking
Maximum Unambiguous Velocity	±10 m/s		- Random Look (5 Arbitrary Directions per Second)
Antenna Beam Width	1.5°		
Azimuth Coverage	360°		
Elevation Coverage	±20°		- Precision Measurement of Displacement (Phasetracking)
Transmitted Peak Power	10 mW		
Operating Range	1.4 m - 50 m		

Tab. 1: System Parameters

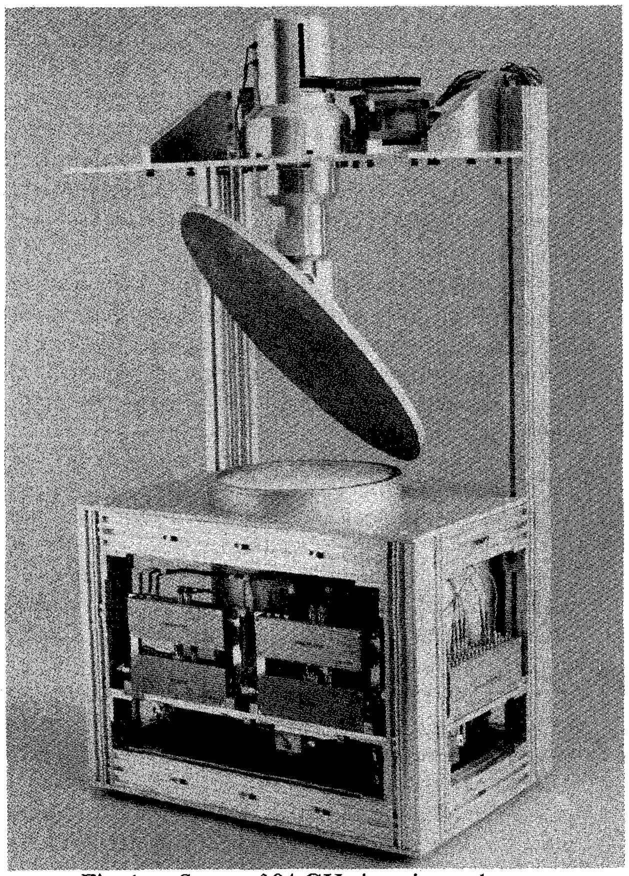

Fig. 1a: Setup of 94 GHz imaging radar

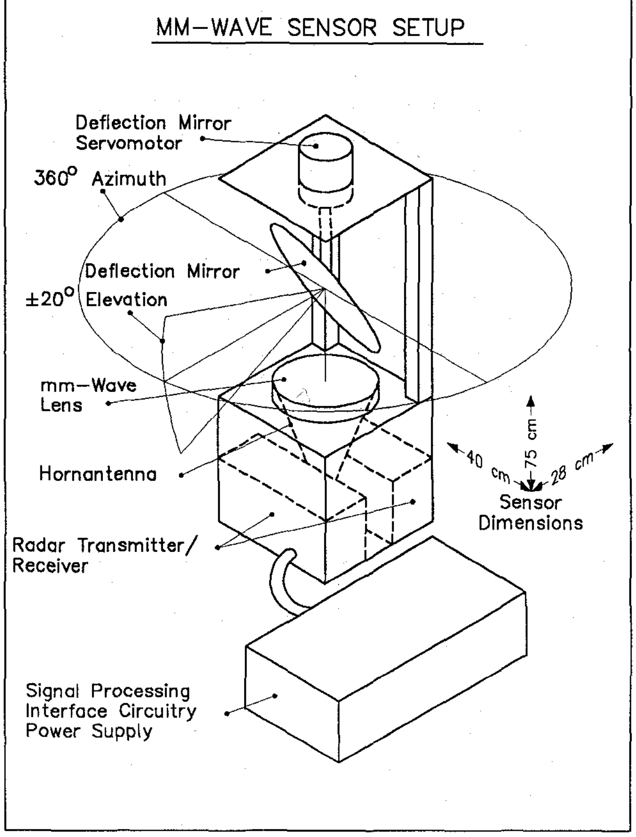

Fig. 1b: Basic components of the mm-wave sensor

To obtain sufficient transmitter power at 94 GHz a gunn oscillator is phaselocked to a 200 mW IMPATT source, feeding an ultrafast PIN-switch which generates coherent pulses of 1.7 ns width, resulting in an effective radial resolution of about 25 cm. Received signals are downconverted with a homodyne quadrature mixer, amplified and converted to digital data by sampling each pulse train at the set range gate position. Range scanning is realized by sequentially shifting the range gate across the region of interest. This limitation could be overcome in advanced designs by using multiple samplers or ultra high speed A/D converters, increasing system speed significantly. Separate processors are in charge of signal processing and the time and data management of the system itself, so that low level functions like doppler analysis, scattering map generation and beam control are performed simultaneously with high level functions like recognition of paths free of obstacles and navigation. Tab. 1 gives a survey of the achieved system parameters.

Imaging Results

For sensor evaluation the radar was placed in the middle of a laboratory, 1.3 m above the floor. From this location several 360° azimuth scans with different elevations were measured to get familiar with mm-wave scattering in typical indoor scenes. While in radar images measured with 35 GHz carrier frequency only few specular reflections dominate, at 94 GHz diffuse scattering already contributes substantially to the return signal, generating realistic contours of objects. Still mm-wave specific artefacts can be observed, as described in Fig. 2, where scattering intensity underlaid with the actual geometry is displayed, representing a 2D horizontal cut through the laboratory scene.

Transformation of polar sensor data to a rectangular coordinate system, aligned parallel to dominant directions of reflections, followed by a CFAR scheme applied to volume resolution cells lead to 3D radar images, that can be interpreted for obstacle detection and navigation. The processed 3D image of a structured scene composed of walls, furniture and a door spacing, measured in 1° x 1° increments from a single sensor location, is displayed in Fig. 4 together with a simplified CAD model for verification. Grey scales are assigned to different layers in y direction for better visualisation. Essential geometrical properties like the door spacing, distance to the rear wall or object outlines are reconstructed satisfactorily for sensorbased locomotion, since individual missing volume cells of solid objects will not affect route planning or collision avoidance.

Conclusion

A mm-wave radar sensor at 94 GHz with full 360° x 40° field of vision and high resolution of 25 cm in each dimension suitable for sensorbased locomotion of autonomous vehicles has been developed. Several nearfield 3D images of realistic indoor environments demonstrate the feasibility of realtime collision avoidance and navigation by high resolution 3D radar images. Currently the system is adapted to a transportation platform to carry out performance tests under locomotion conditions.

References

[1] Proc. of the Symp. "Informationsverarbeitung in autonomen, mobilen Handhabungssystemen" des SFB 331, Okt. 87, Technische Universität München, in German.

[2] M. Lange, J. Detlefsen: A 35 GHz Homodyne Pulse Doppler Radar with very High Resolution for Short Range Applications, Int. Conf. on Radar, Paris May 1984, p. 210 - 214.

[3] M. Lange, J. Detlefsen, M. Bockmair: Resonant Pulse Amplification for Radar Imaging Applications, Proc. 15th Europ. Microwave Conf., Paris 1985, p. 1005 - 1010.

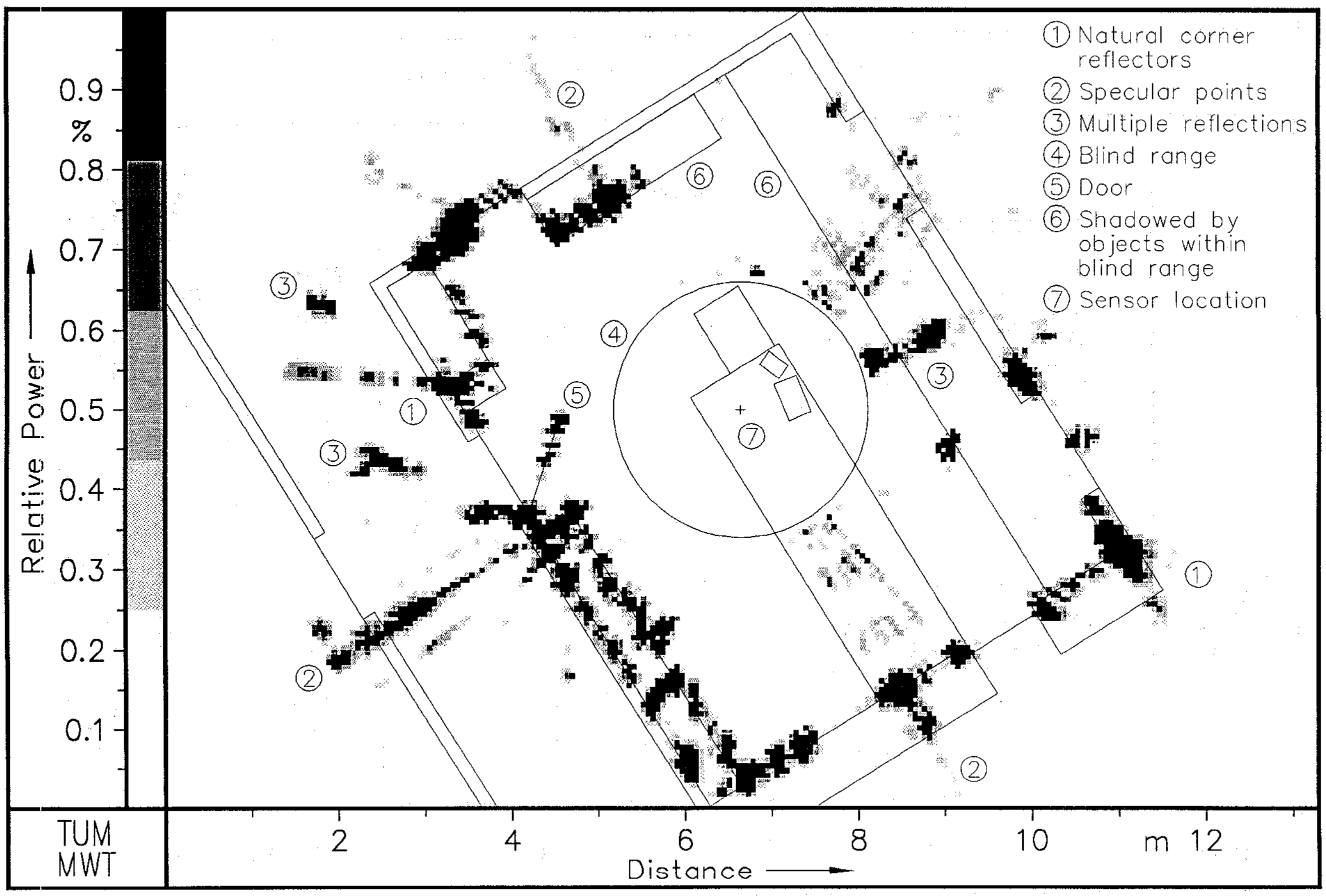

Fig. 2: Scattering of mm-wave in a horizontal 2D image of a laboratory scene

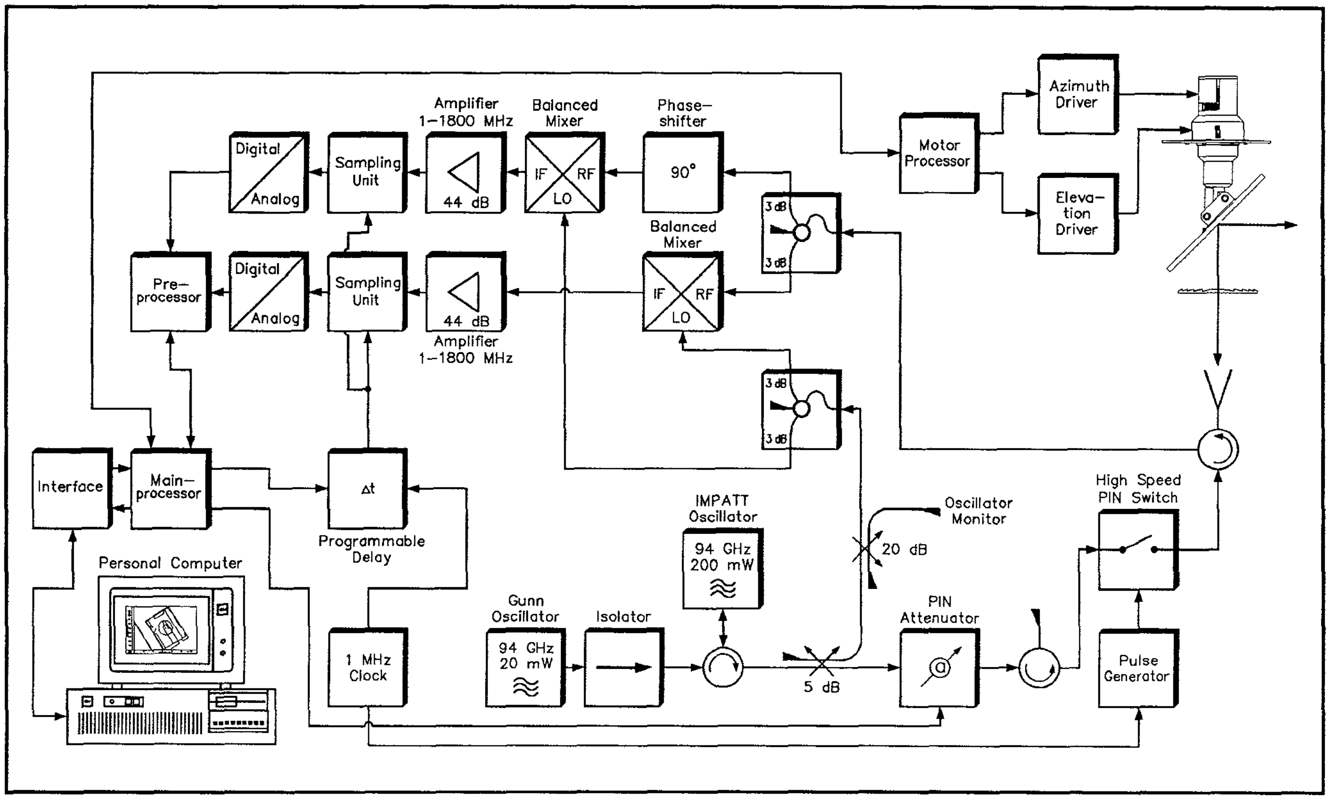

Fig. 3: Blockdiagram of pulse doppler imaging radar

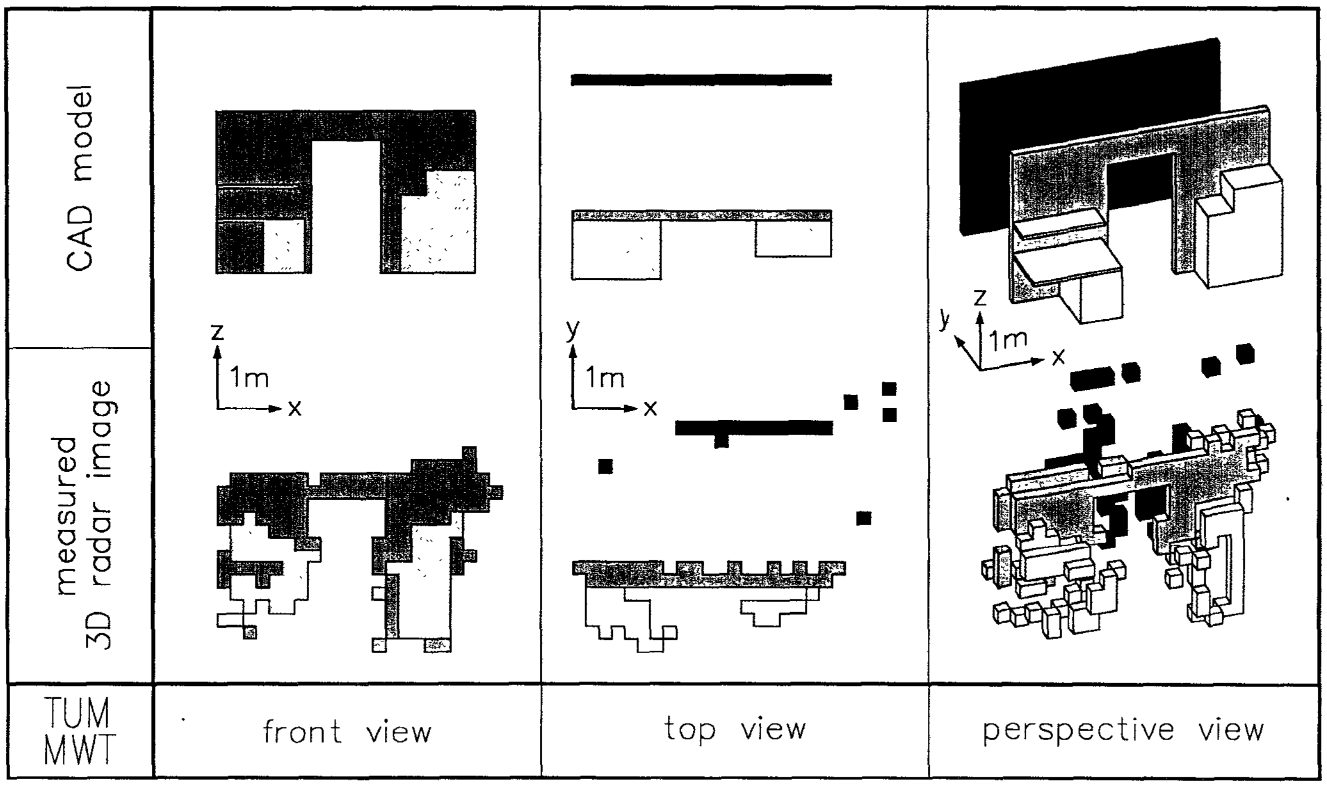

Fig. 4: Measured 3D image of scene (walls, door, table, locker), based on 20 x 20 x 20 cm³ resolution cells