

THE RISING WAVE OF MILLIMETER- WAVE SENSING

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Corporate Sector Research and
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Agenda

- Motivation
- Radar for Fully Automated Driving vs. Advanced Driver Assistance
- System on Chip (SoC)
- Digital Accelerators
 - Synthetic Aperture Radar (SAR)
 - Machine Learning
- Adapting to new Markets:
 - Robotics
 - Buildings / Smart Home
- Frequency Regulation
- Conclusion

The Rising Wave of Millimeter-Wave Sensing

Motivation



Millimeter-wave radars provide robust and high-resolution information about remote objects:

Distance, Velocity, Angle and
Small movements (Microdoppler)



Since it's introduction in the automotive area, Radar has become a key sensing modality for driver assistance and automated driving



Semiconductor Technology allows constantly higher integration density



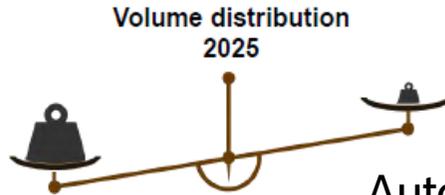
Algorithms move radar sensing from simple detection to classification and mapping



Small size, invisible integration, low cost, and privacy are advantages of Radar that make it attractive for markets beyond Automotive

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Automotive Radar Sensor Market Dynamics



Safety & ADAS



- ▶ ADAS availability trend: luxury → executive → middle class
- ▶ ADAS in emerging markets

High volume market share

Autonomous Driving



- ▶ First in luxury and commercial cars, robotaxis
- ▶ Yet sensors supporting these functions demanded by the OEMs

Must be supported by new sensor generations

Source: <https://markus.gardill.net/talk/dml/>

Radar sensor manufacturers need to address both markets

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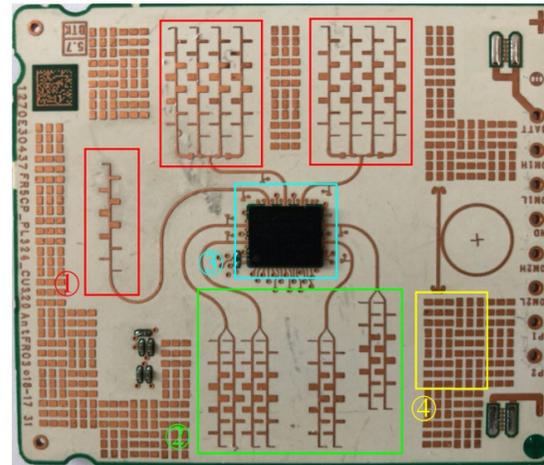
Example: State of the Art Automotive Radar

- ▶ Bosch Gen5 Radar for Advance Driver Assistance
- ▶ Single PCB
- ▶ RF Frontend SiGe BiCMOS



Parameter		Value
Frequency	band	76–77 GHz
Distance	max.	210 m
	accuracy	0.1 m
	resolution	0.2 m
Velocity	accuracy	0.05 m/s
	resolution	0.1 m/s
Hor. angle	accuracy	0.1 deg
	resolution	3.0 deg
Vert. angle	accuracy	0.2 deg
	resolution	6.0 deg

Sensor Performance



Frontside



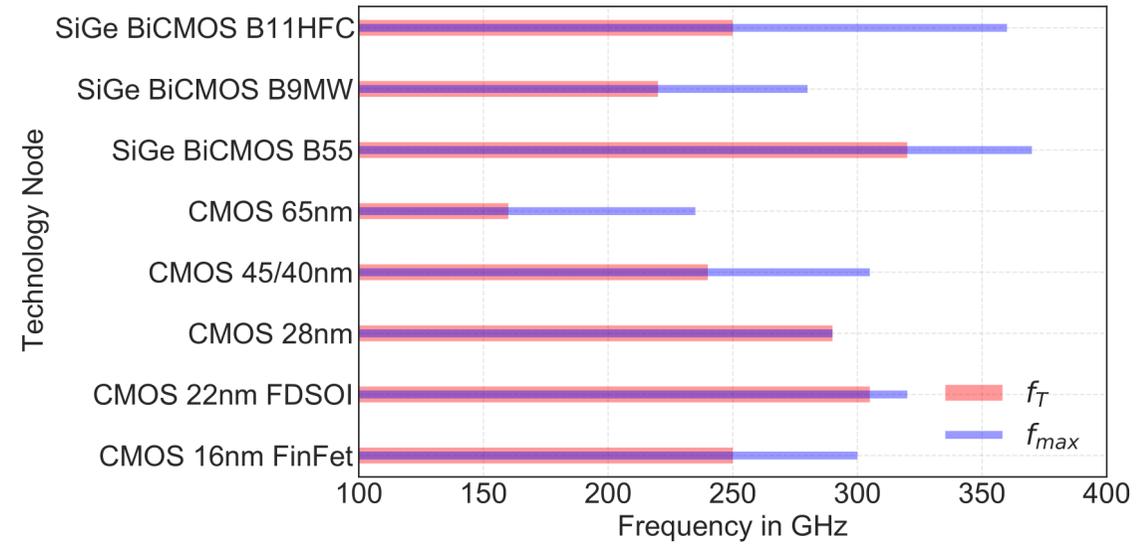
Backside

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What is next in Radar Technology?

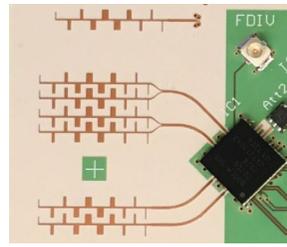
- ▶ Small is beautiful: Reduction of sensor volume
- ▶ Radar as established technology: Lowering costs
- ▶ Exploit technological progress: Higher integration density due to CMOS

- ▶ Modern CMOS technology nodes and higher volumes allow realization as System on Chip (SoC).

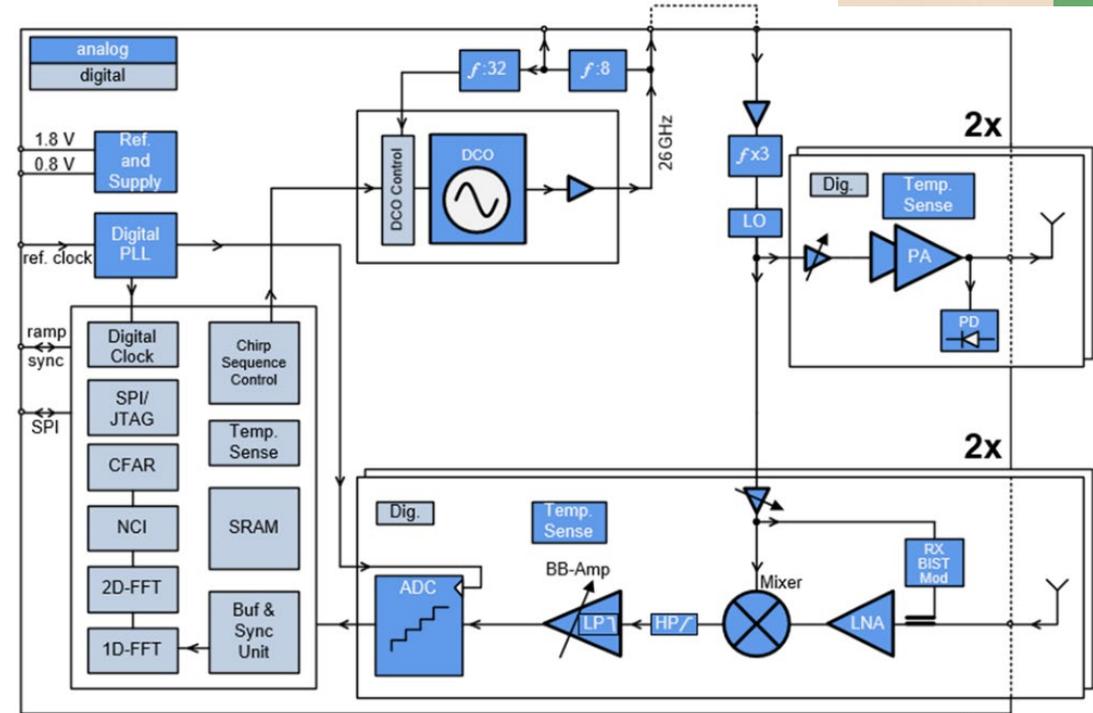


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Example: Test Chip CO705



- ▶ Radar SoC evaluation chip in 22 nm FDX Global Foundries technology
- ▶ Free running digitally controlled oscillator with an internal frequency divider or external LO source
- ▶ Two transmit channels
- ▶ Two receive channels
- ▶ Analog baseband with analog-to-digital conversion(ADC) and on-chip memory for radar data storage
- ▶ Digital backend with Fast Fourier Transform (FFT) and Constant-False-Alarm-Rate (CFAR) engines
- ▶ Wafer level ball-grid-array package



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Digital Accelerators: Synthetic Aperture Radar

Principle

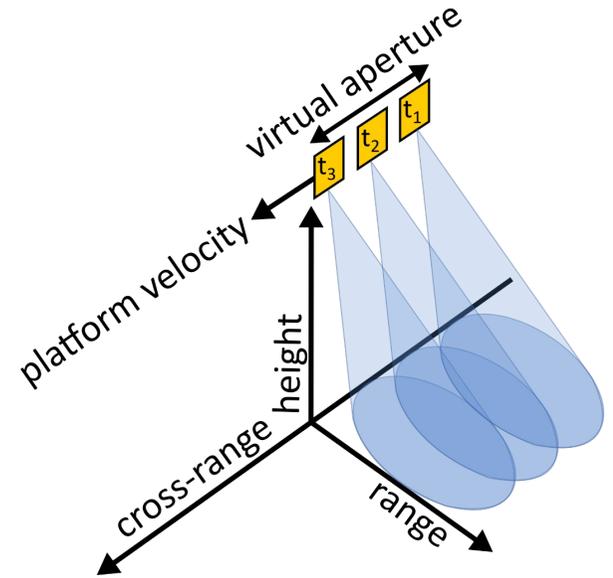
- ▶ SAR is a microwave imaging technique that uses radar's own motion to synthesize a large aperture
- ▶ Obtains high angular resolution based on known vehicle movement

Potential benefits for automotive radar:

- ▶ Solution to the dilemma of high angular resolution vs. restricted installation space in side-looking applications
- ▶ Reduction of costs of HF front-end

Constraints:

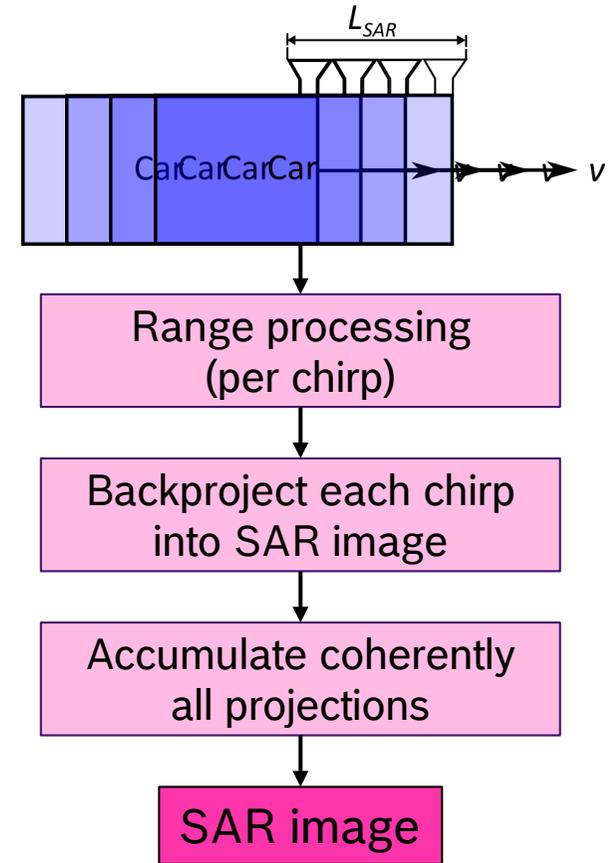
- ▶ Stationary target assumption
- ▶ Very precise ego motion information



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Digital Accelerators: SAR

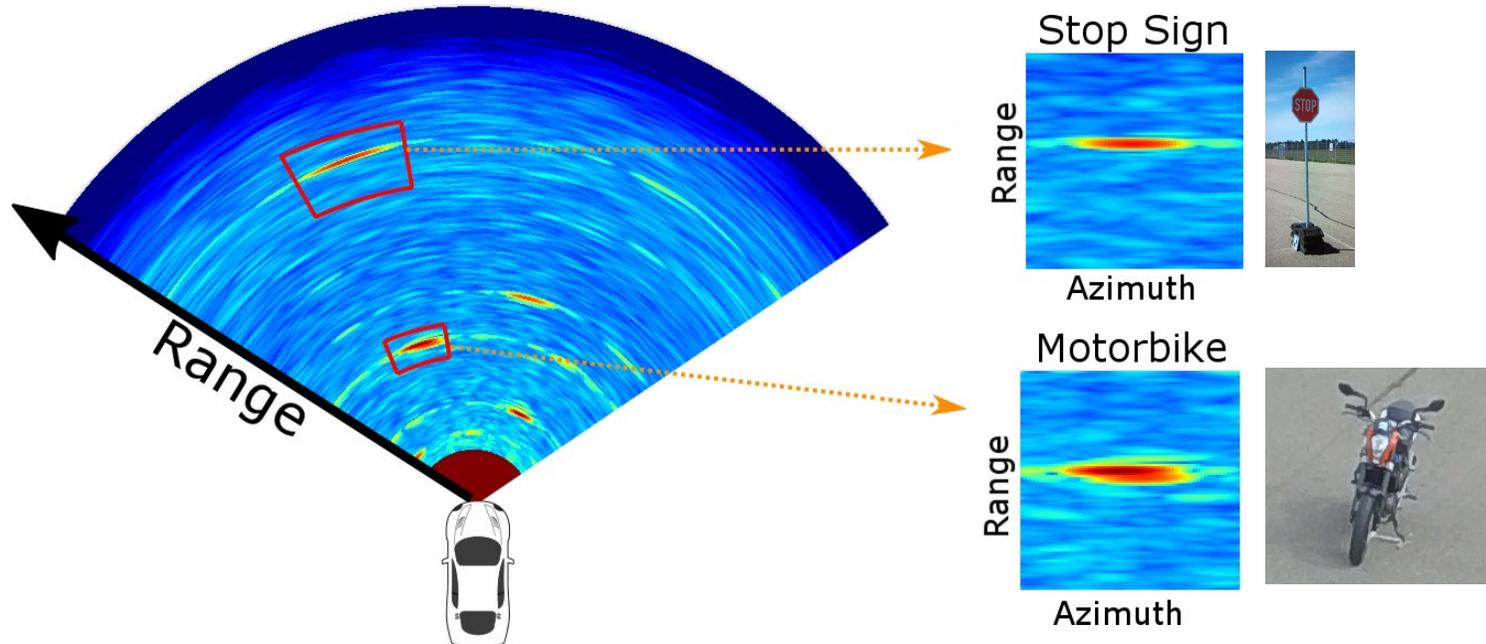
- ▶ Single-channel Radar provides angle high-resolution in azimuth
- ▶ Unprocessed raw sensor data required for signal processing
- ▶ Hardware-realization of SAR signal processing algorithms provide a significant advantage



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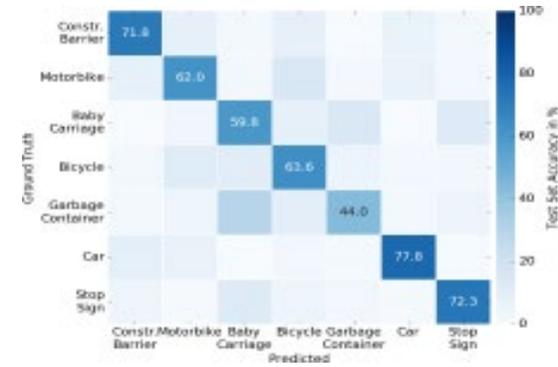
Object Classification using Machine Learning

- ▶ Radar spectrum (range-angle) contains more information than just presence of a remote object
- ▶ No analytic model to connect backscattered signal from a remote object to its type

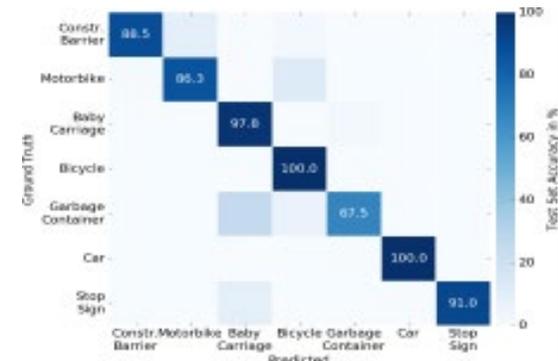


The Rising Wave of Millimeter-Wave Sensing Object Classification using Machine Learning

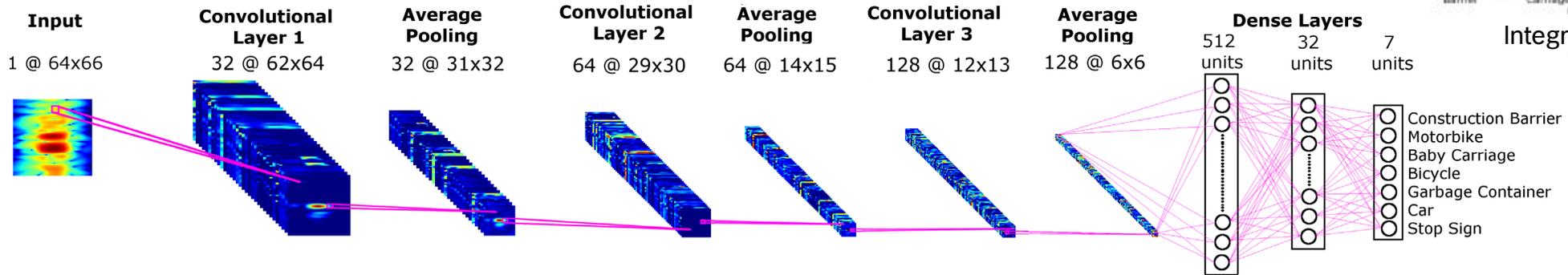
- ▶ Machine Learning using deep neural networks enable object classification directly from backscattered signals
- ▶ Integration of CNN accelerator into SoC enables real-time object classification



Single Snapshot



Integration over 4s

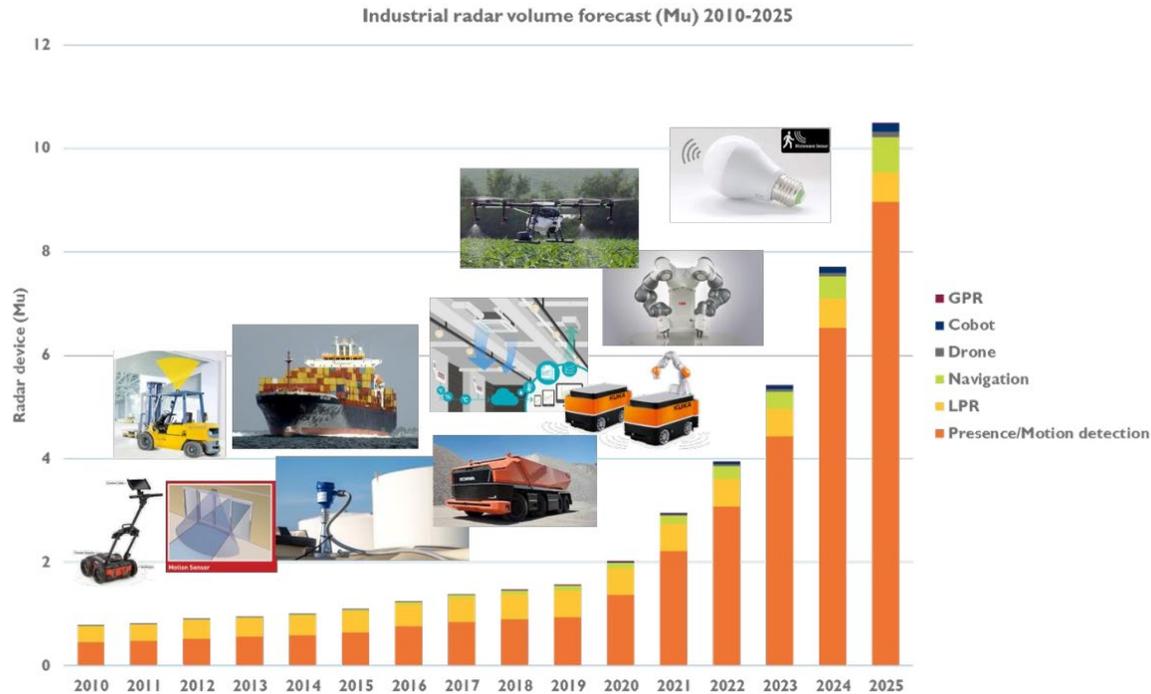


Network Topology*

* Patel: Deep learning-based object classification

The Rising Wave of Millimeter-Wave Sensing Non-Automotive Applications

- ▶ 20 Years of development for Automotive Radar has enabled low-cost sensors with high performance
- ▶ Large opportunities in industrial and consumer applications

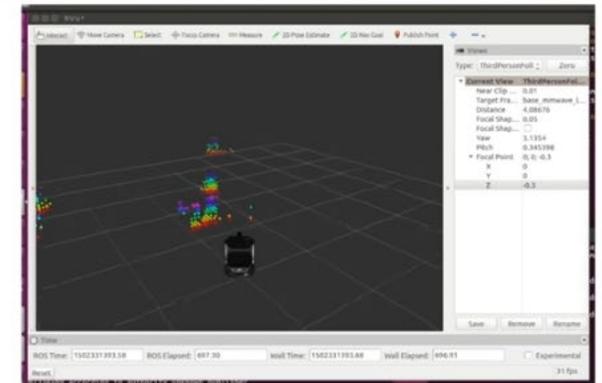
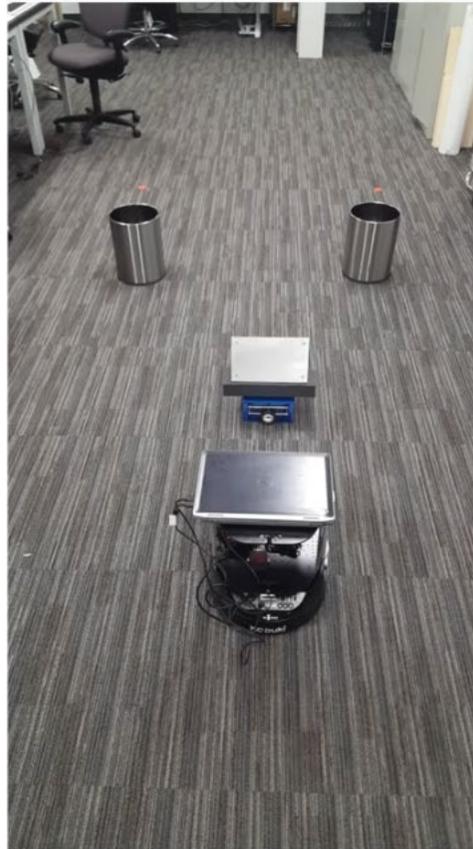


Source: Yole Developement

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Example: Robotics

- ▶ Object detection and avoidance of autonomous platforms
- ▶ Replaces expensive Lidar sensors
- ▶ Works in dusty or outdoor scenarios



Texas Instruments: Robotic Sense and Avoid

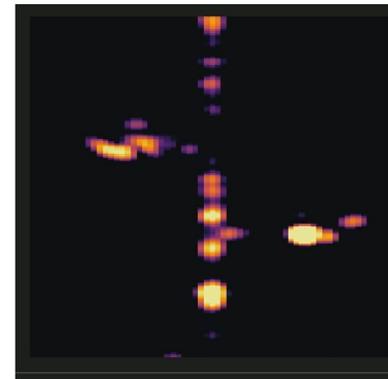
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Example: Presence Detection and Tracking

- ▶ Detect persons inside a specified area
- ▶ Identify number, speed and movement patterns of persons
- ▶ Sustain privacy of persons



Tracking



Range-Doppler

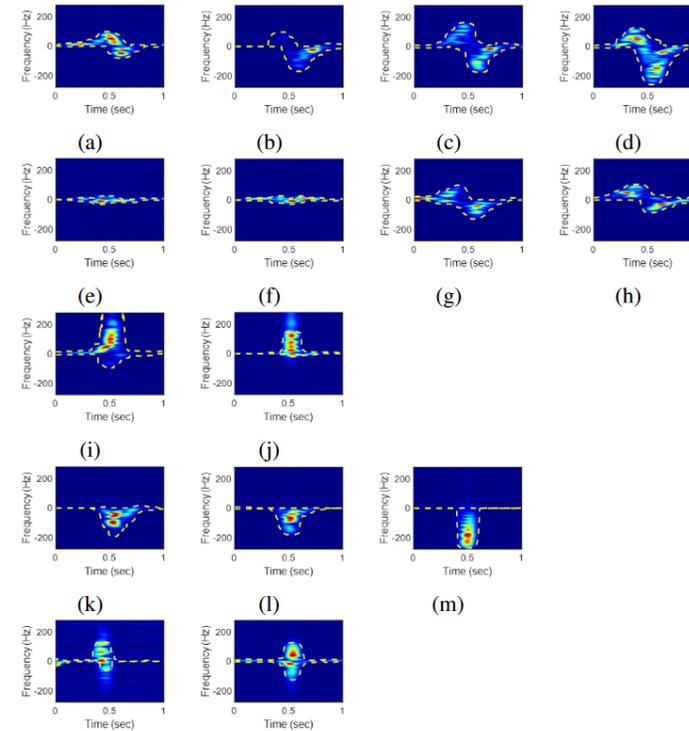
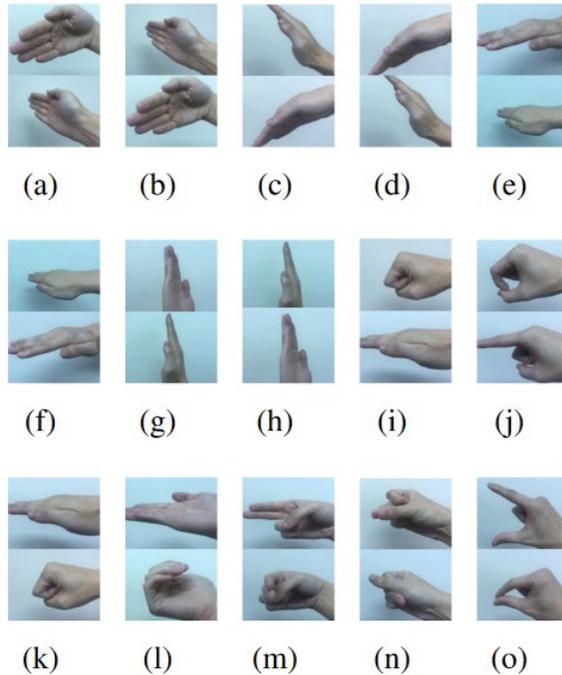


Scene

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Example: Gesture Recognition

- ▶ Contactless / remote sensing of gestures
- ▶ Invisible integration into devices



Amin: Hand Gesture Recognition based on RadarMicro-Doppler Signature Envelopes

Cai: Efficient Convolutional Neural Network for FMCW Radar Based Hand Gesture Recognition

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Frequency Regulation

- ▶ Only a few selected frequency ranges are available for radar applications > 10 GHz
- ▶ New frequency bands will only become available long-term
- ▶ International status is often not harmonized (e.g. EU vs. US vs. other countries)

Frequency Band	Bandwidth	Comment
24 GHz	125 MHz	
60 GHz	250 MHz	
57-64 GHz	7 GHz	
76-77 GHz	1 GHz	Automotive applications only
77-81 GHz	4 GHz	Automotive applications only
122 GHz	1 GHz	
> 122 GHz	> 10 GHz	Envisioned in Future

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Conclusion

- ▶ Current generation of Automotive Radars
 - ▶ Low cost
 - ▶ High volume
 - ▶ Enable object classification
- ▶ Strong trend to SoC in CMOS for Advance Driver Assistance
- ▶ Next generation SoC-based Radars will have an increasing number of algorithm accelerators
Examples:
 - ▶ Synthetic Aperture Radar (SAR)
 - ▶ Machine Learning (ML)
- ▶ Large opportunities in robotics and consumer applications

Acknowledgement

This work is funded by the German BMWi
(Bundesministerium für Wirtschaft und Energie)
in the frame of the
Important Project of Common European Interest (IPCEI).

The IPCEI is also funded in Germany by the State of Saxony and
the Public Authorities from France, Italy and U.K.

