A 77 GHz FMCW MIMO Radar System Based On 65nm CMOS Cascadable 2T3R Transceiver

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- Radar Hardware
- Data Processing algorithm
- Measurement
- Conclusion

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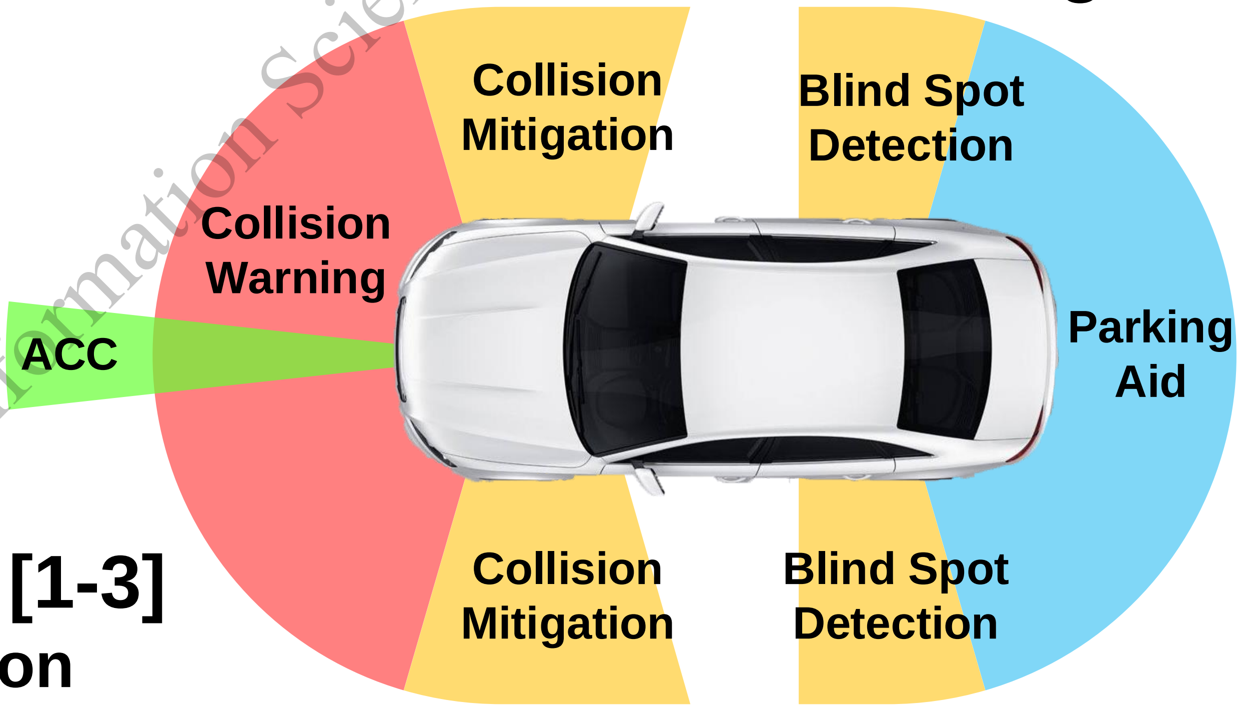
Introduction

- **Requirement of multiple sensors in Advanced Driving Assistant System (ADAS)**
  - ✓ Lidar for ACC
  - ✓ Mm-wave radar for blind spot detection and parking aid
  - ✓ Camera and ultrasound for backup parking aid



- **Advantages of mm-wave radar [1-3]**
  - ✓ Smaller size and higher integration
  - ✓ Higher resolution
  - ✓ Stronger robustness against bad weather
  - ✓ Lower cost

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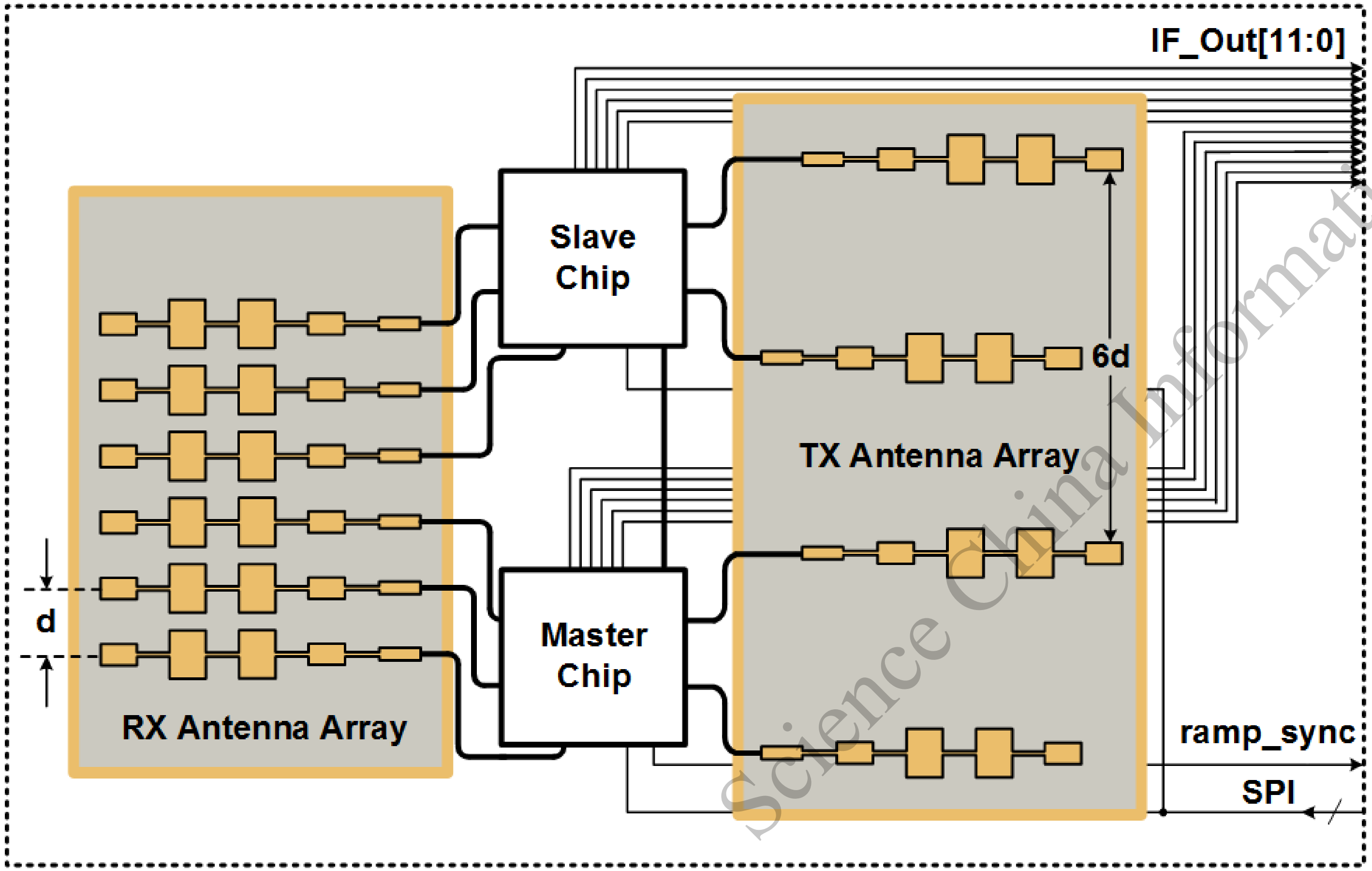
Radar Hardware

- **RF Module**



✓ **Cascaded FMCW transceiver chips [4]**
- **Waveform: Support 4 GHz and 200 us sawtooth chirps**
- **Theoretical range resolution:**

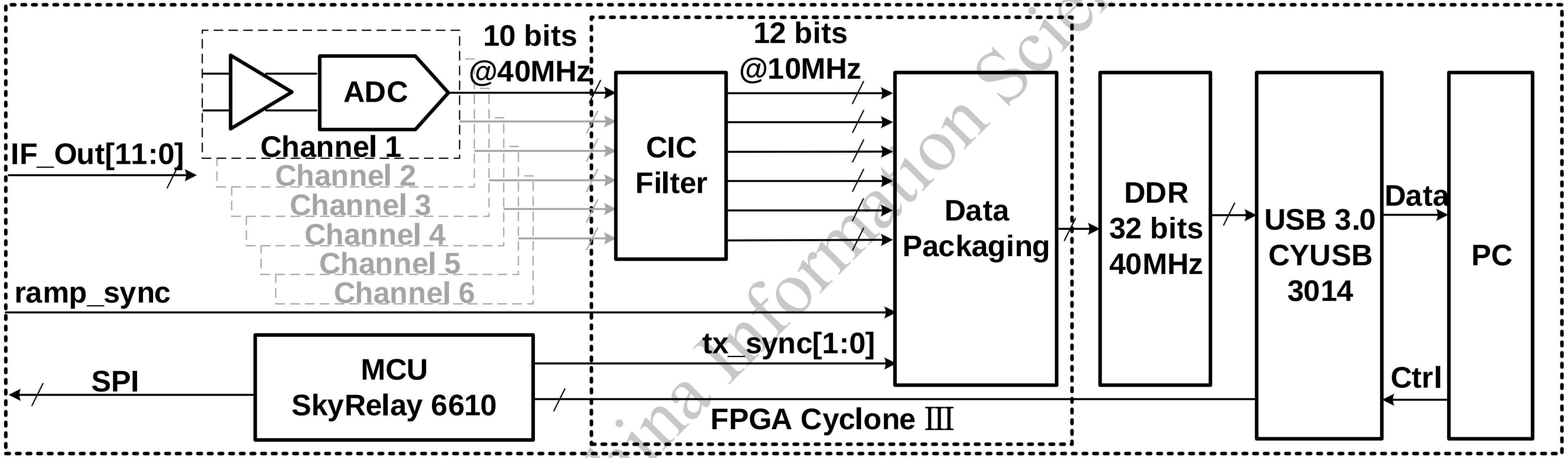
$$\Delta R = \frac{c}{2B} = 3.75cm$$

✓ **TX & RX MIMO antenna arrays**
- **Non-uniform series-fed patch antenna [5]： 11.2 dB gain， 2 GHz bandwidth, -20 dB SLL.**
- **Antenna spacing: d = 2.2mm**
- **FOV:** $\theta = arcsin(\pm\frac{\lambda}{2d}) = \pm 55°$
- **Angular resolution (2T6R):**

$$\Delta\theta = 0.88\frac{\lambda}{Nd} = 7.2°$$

Radar Hardware

- **Data Collection Module**



✓ **ADC**
- **Six 10 bits ADC with 40 MHz synchronized clock**

✓ **Cyclone Ⅲ FPGA**
- **CIC filter**
- **Package data from 6 channels and tx and ramp synchronization signals**

✓ **USB 3.0**
- **CYUSB 3014 for communication between PC and radar hardware**

✓ **MCU**
- **SkyRelay 6610 for transceiver controlling**

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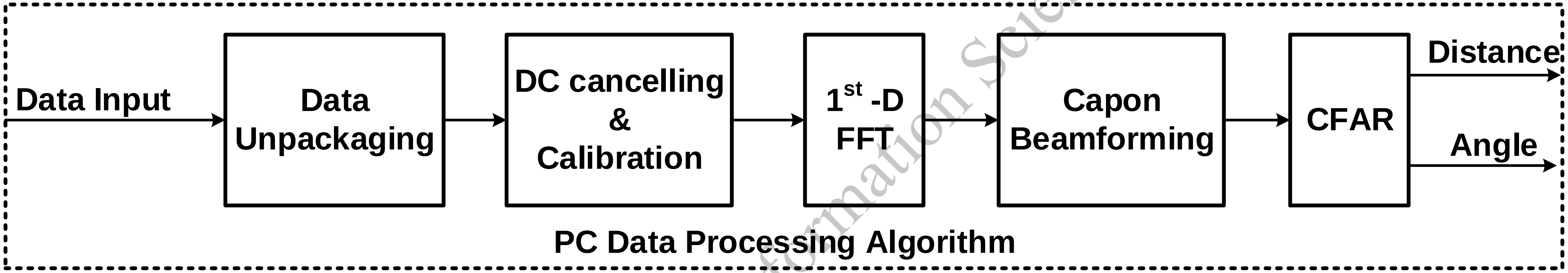
Data Progressing Algorithm

- **Capon based algorithm**



✓ **Data unpackaging**

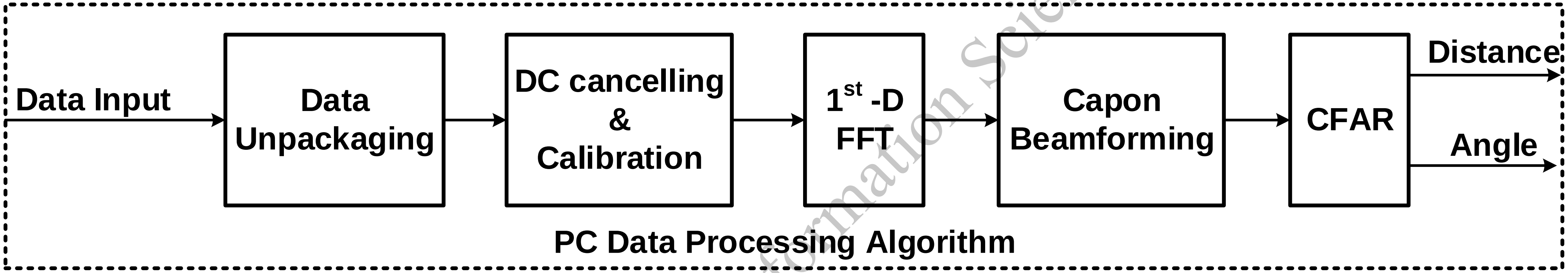
- **Divided packaged data into chirps according and tx and ramp synchronization signals**

$$A_i = \begin{bmatrix} a_{i11} & \cdots & a_{i1n} \\ \vdots & \ddots & \vdots \\ a_{im1} & \cdots & a_{imn} \end{bmatrix}_{m\times n} \quad ,i = 1,2\cdots p$$

- **p is the number of MIMO channels (12 in this work), m is the number of chirps, and n is the number of sample points in each chirps.**

Data Progressing Algorithm

- **Capon based algorithm**



✓ **Calibration**

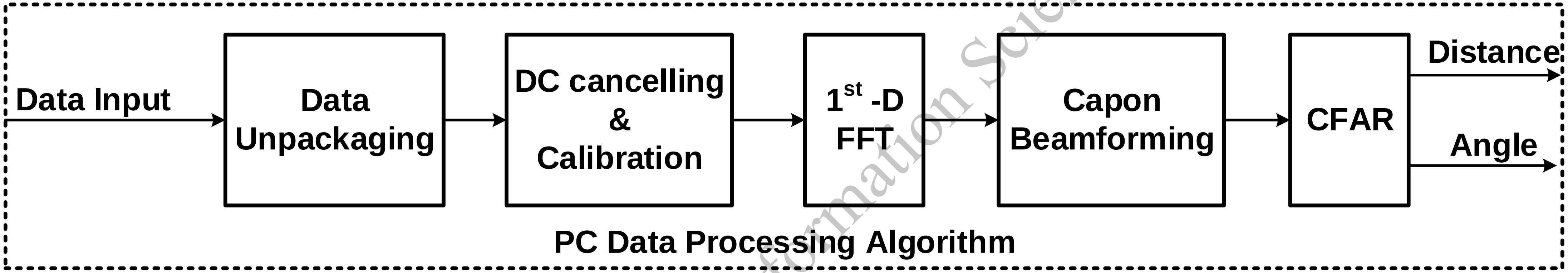
- **a calibration is required to eliminate the offsets due to the asymmetry among different channels and the delay of LO signal between master and slave chips.**

$$S_{jc} = Amp_{jc} \cdot S_{jo} \cdot e^{-i \cdot 2\pi \cdot f_{jc}} \cdot e^{-i \cdot p_{jc}}, j = 2, 3 \cdots 12$$

- **S_{jc} and S_{jo} are calibrated signal and original data of the j^{th} channel. Amp_{jc}, f_{jc}, and p_{jc} are amplitude, frequency, and phase offsets between the j^{th} and the 1^{st} channel.**

Data Progressing Algorithm

- **Capon based algorithm**



✓ **1st –D FFT**

- **FFTs are accomplished for each channel on distance dimension. The spectrums are stored in matrixes $F_{i,m \times n}$, i = 1,2…p, where p is the number of MIMO channels.**

$$F_i = \begin{bmatrix} f_{i11} & \cdots & f_{i1n} \\ \vdots & \ddots & \vdots \\ f_{im1} & \cdots & f_{imn} \end{bmatrix}_{m \times n}, i = 1, 2 \cdots p$$

Data Progressing Algorithm

- ✓ **Capon beamforming [6]:**
  - **The 1-D spectrum of every channels on distance point q is:**

$$X_q = \begin{bmatrix} f_{1q1} & \cdots & f_{1qn} \\ \vdots & \ddots & \vdots \\ f_{pq1} & \cdots & a_{pqn} \end{bmatrix}_{p\times n}$$

  - **The covariance matrix:** $R_x = XX^H / n$
  - **The steering vector for θ is:** $a(\theta) = [1, e^{-i\pi \sin(\theta)}, \cdots e^{-i\pi(p-1)\sin(\theta)}]^T$
  - **The Capon spatial spectrum on the distance q:**

$$w_{Capon}(\theta) = \frac{1}{a(\theta)^H R^{-1} a(\theta)}$$

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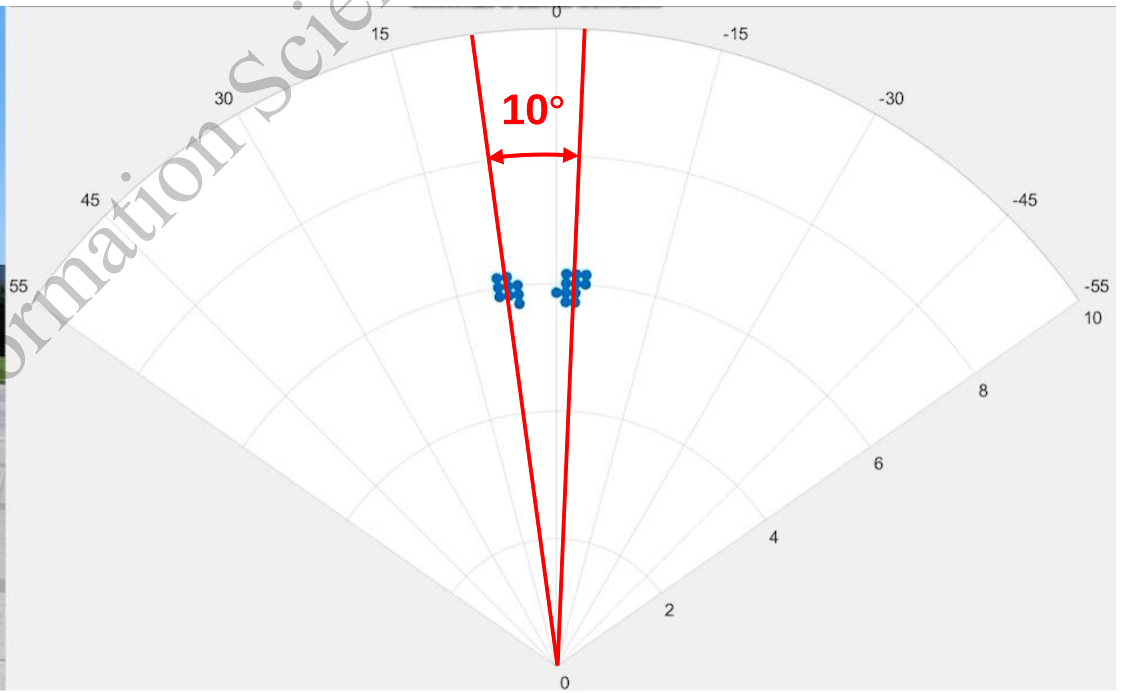
Measurement

- **Pedestrians detection**



- ✓ **Pedestrians are successfully detected**
- ✓ **Achieve a FOV of ±55°**
- ✓ **Achieve a angular resolution of 10°**

Measurement

- **Flag-poles and bicycles detection**

- ✓ Multiple flag-poles
- ✓ Traffic lights and warning signs
- ✓ Bicycles

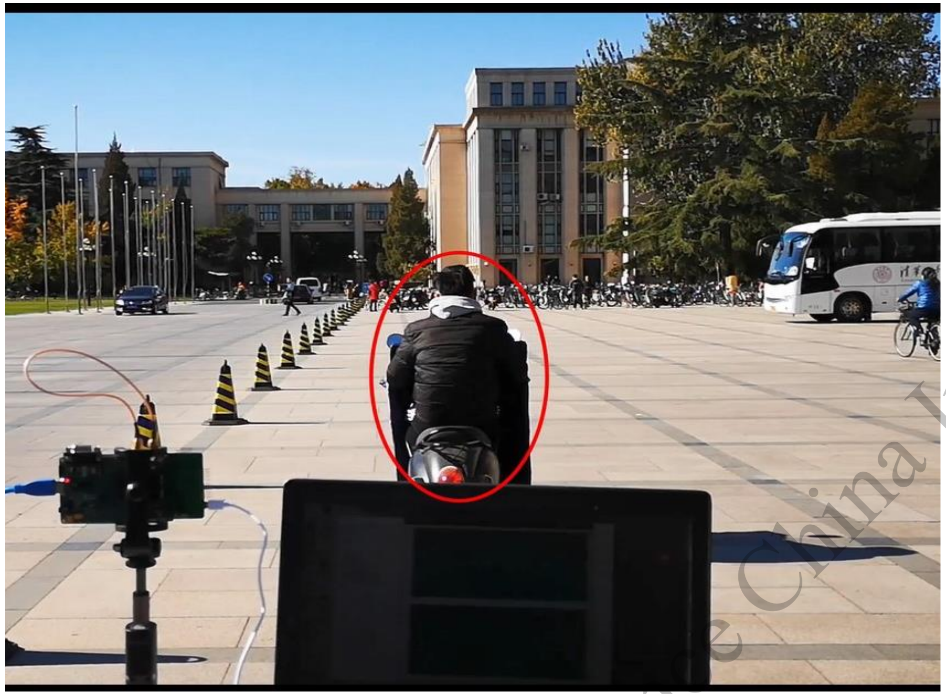
Measurement

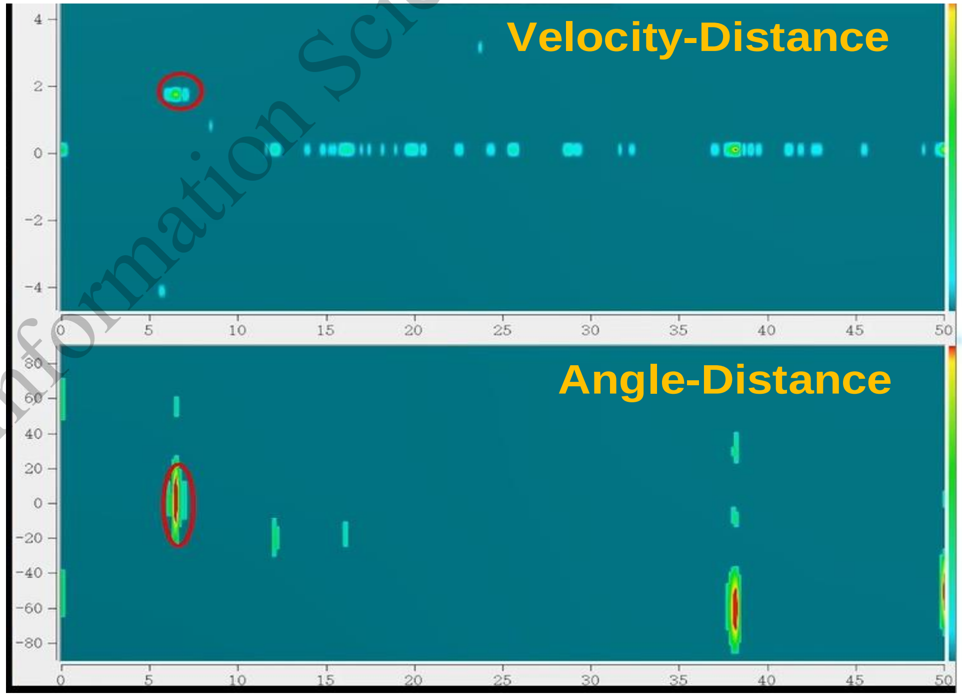
- **Cars detection**

✓ Edge of the road
✓ Cars

Measurement

- **Velocity measurement**





- ✓ **Chirps with 200 us chirp-up time and 4 GHz bandwidth are used.**
- ✓ **Achieve a ±4.7 m/s maximum detectable velocity**
- ✓ **Electric bicycle with a velocity of 1.8 m/s is detected.**

Content

Conclusion

- **Present a radar hardware including a RF module based on 65nm CMOS FMCW MIMO radar transceiver and a data collection module that consists of 6 ADCs, a MCU, a FPGA, a DDR, and a USB 3.0 chip.**

- **Develop a Capon based data processing algorithm which involves a data unpackage module to recover the chirps from different channels, a calibration module to eliminate offsets among channels, a 1-D FFT module to get spectrum on distance dimension, a Capon beamformer to find the DOA of targets, and a CFAR to filter clutters.**

- **Accomplish a series of measurement to evaluate the performance of the radar system. 55° FOV, 10° angular resolution, and 4.7 m/s maximum detectable velocity are achieved. Pedestrians, flag-poles, bicycles, and cars are successfully detected.**

Reference

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Thank You !