High Resolution mmWave Radar by Radar Fusion and Sparse SAR

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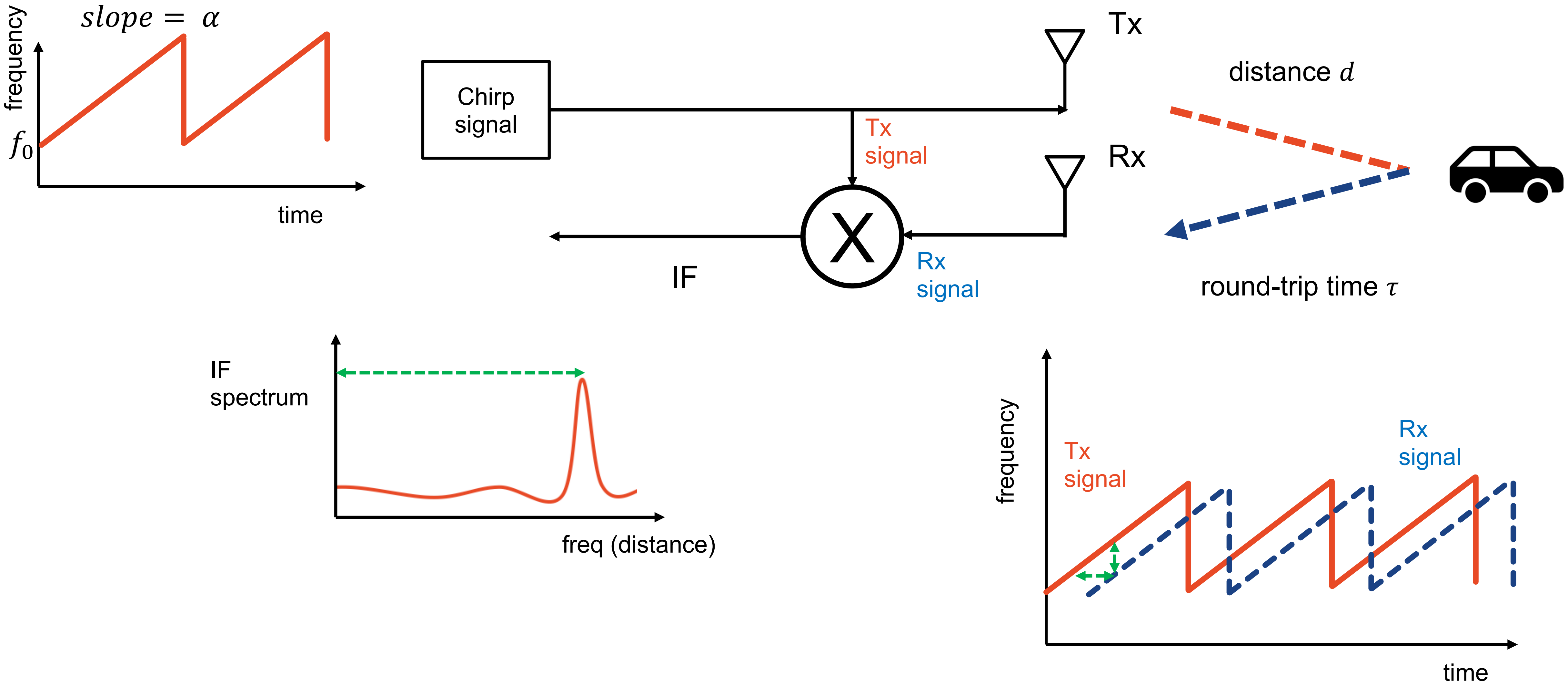
Thomas Moon received the B.S. degree in electrical electronic engineering from Pohang University of Science and Technology (POSTECH), Pohang, Korea, in 2008, and the Ph.D. degree in electrical and computer engineering from Georgia Institute of Technology, Atlanta, GA, USA in 2015. Between 2015 and 2017, he worked at IBM in Burlington, Vermont where he developed mmWave test equipment as a principle development engineer. He joined Coordinated Science Lab, University of Illinois at Urbana-Champaign (UIUC), IL, USA in 2017 as a post-doctoral researcher. He has been a Teaching Assistant Professor at Department of Electrical and Computer Engineering at UIUC. His current research interests include wireless sensing and communication in mmWave.

Motivation

	Camera	mmWave Radar	Lidar
Color Vision	Great	Blind	Blind
Distance Resolution	Poor	Fair	Great
Lateral Resolution	Great	Poor	Great
Night Vision	Poor	Great	Great
Rain/Fog/Snow Vision	Poor	Great	Poor
Cost	Medium	Low	High

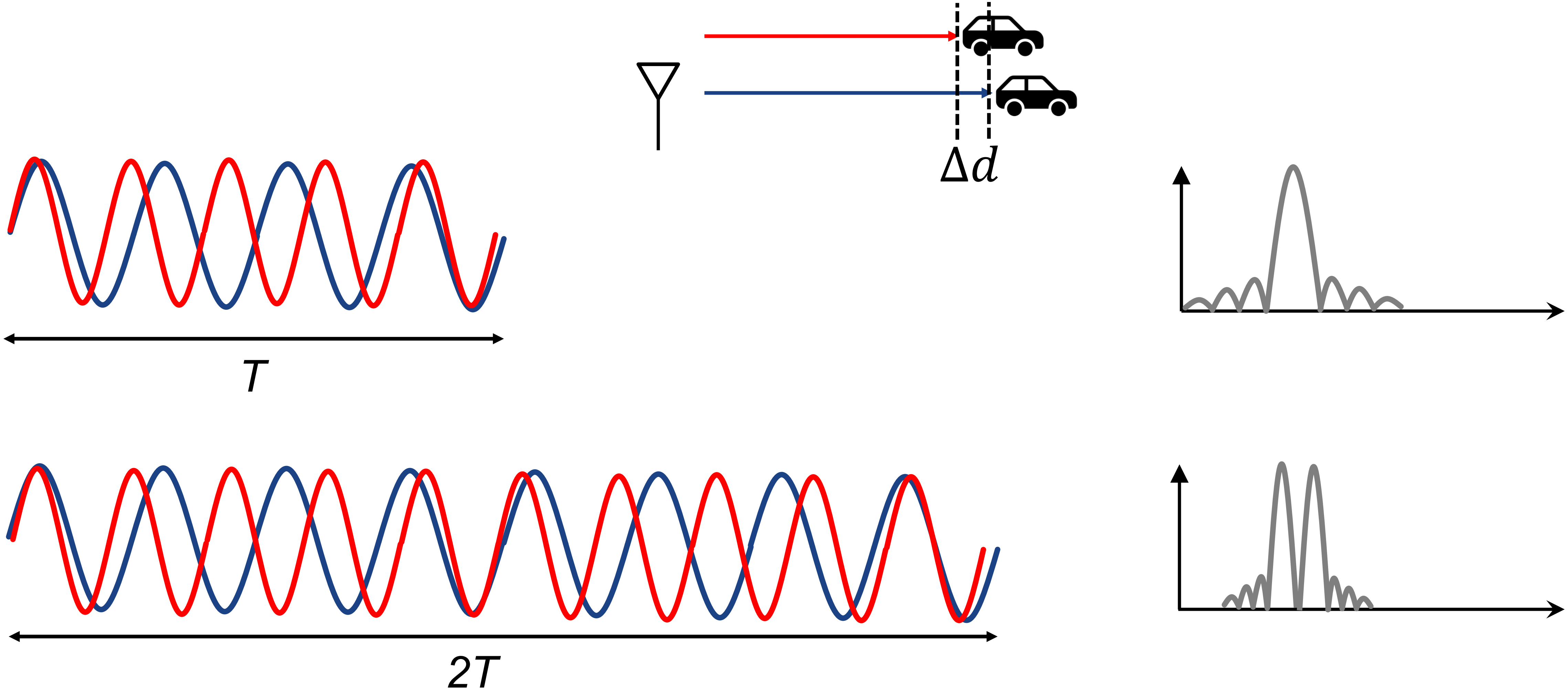
mmWave radar is cheap and robust against harsh weather, but has low distance & lateral resolution

FMCW Radar



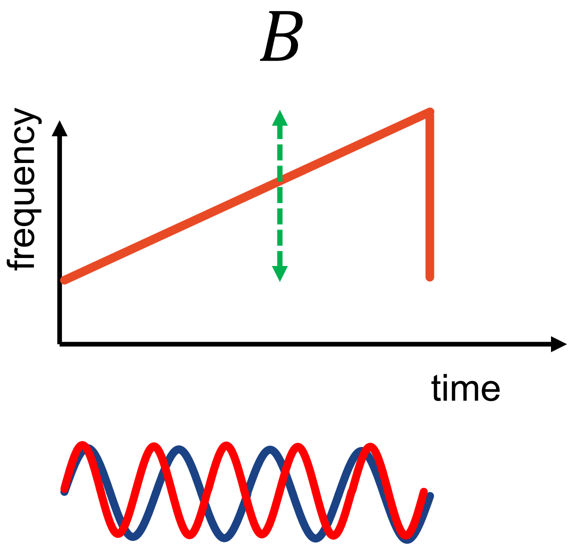
IF frequency ∝ round-trip time τ ∝ distance d

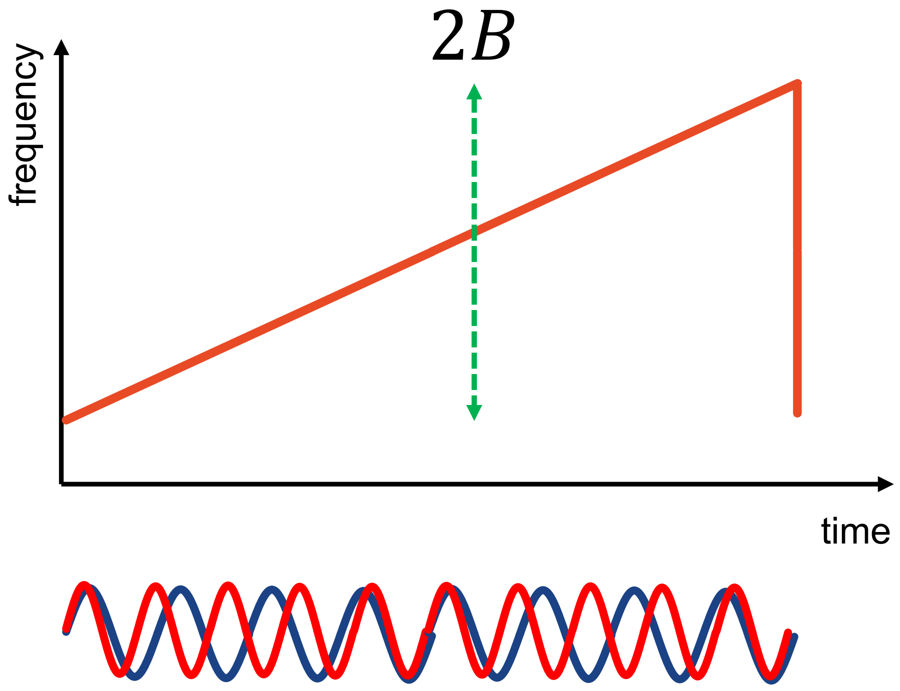
Challenge 1 : Distance Resolution



Spectral Analysis:
Longer Observation → Better Spectral Resolution

Challenge 1 : Distance Resolution





C: the speed of light

B: the bandwidth of FMCW

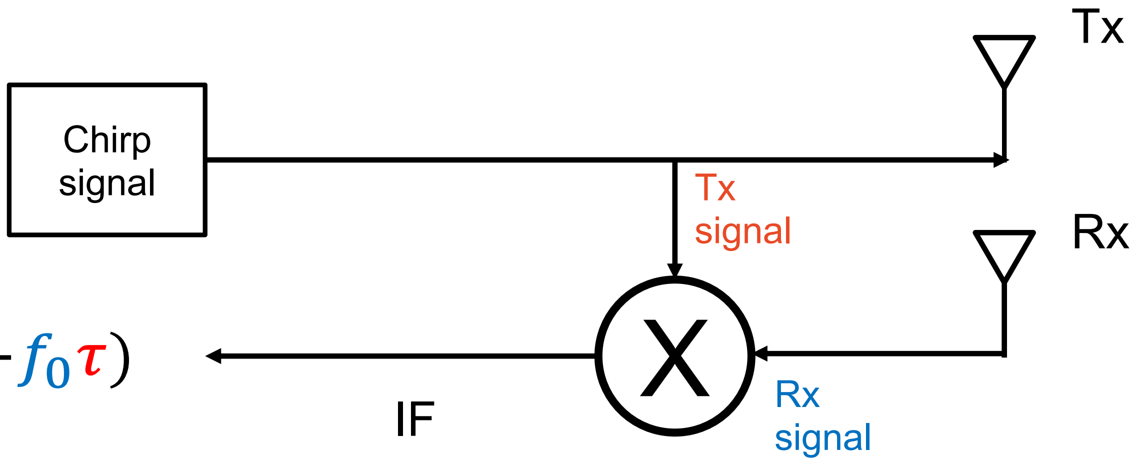
$$\Delta d = \frac{C}{2B}$$

In practice, B is limited (<5GHz) due to hardware constraints (antenna, oscillator, amplifier)

FMCW:

Larger Bandwidth → Better Distance Resolution

Proposed Method1



$$x(t) = e^{j2\pi(\alpha\tau t + f_0\tau)}$$

Known: α, f_0

Unknown: τ

Error function

$$E(\tilde{\tau}) = \Big\| \underbrace{e^{j2\pi(\alpha\tau t + f_0\tau)}}_{x_{meas}(t)} - \underbrace{e^{j2\pi(\alpha\tilde{\tau} t + f_0\tilde{\tau})}}_{x_{model}(t)} \Big\|^2 \rightarrow \min_{\tilde{\tau}} E(\tilde{\tau})$$

Proposed Method1

$$E(\tilde{\tau}) = \left\| e^{j2\pi(\alpha\tau t + f_0\tau)} - e^{j2\pi(\alpha\tilde{\tau}t + f_0\tilde{\tau})} \right\|^2$$

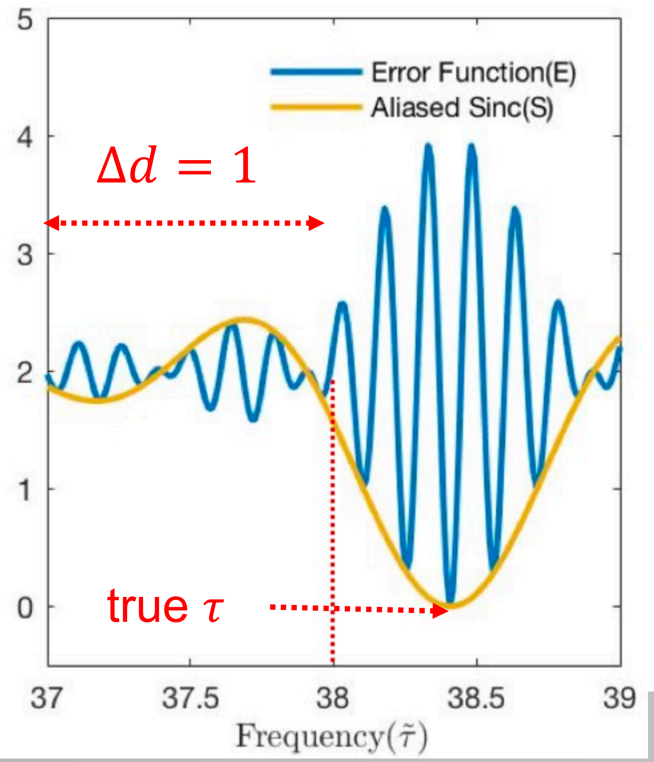
$$\approx 2 - \cos[2\pi f_0(\tau - \tilde{\tau})] \cdot sinc[D \cdot (\tau - \tilde{\tau})]$$

D:constant

Amplitude-modulated signal

- carrier frequency $\approx f_0$
- centered at $\tilde{\tau}$
- enveloped by sinc function

Find $\min_{\tilde{\tau}} E(\tilde{\tau})$ by
exhaustive search (longer computation)
or using sinc envelop



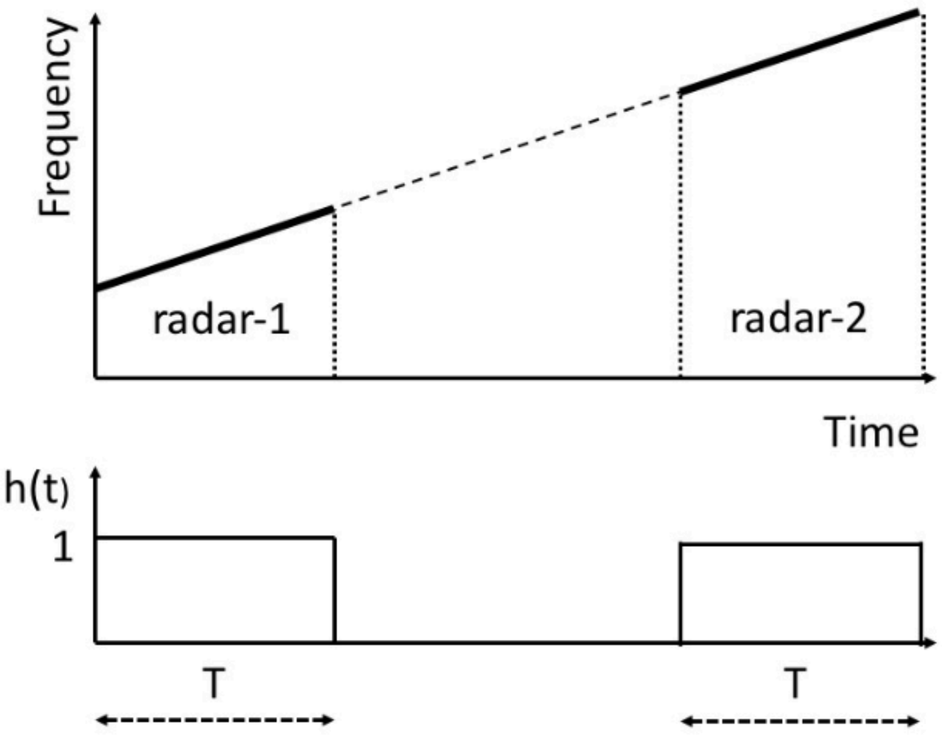
Proposed Method1

$$E(\tilde{\tau}) = \left\| h(t)\left(e^{j2\pi(\alpha\tau t + f_0\tau)} - e^{j2\pi(\alpha\tilde{\tau}t + f_0\tilde{\tau})}\right)\right\|^2$$

truncation window

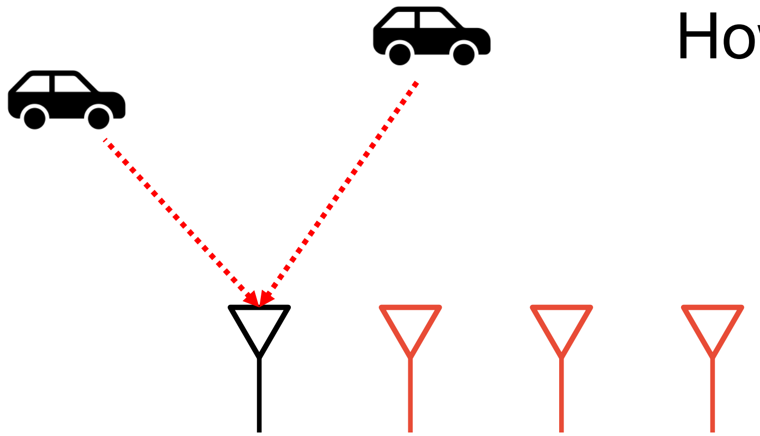
The model based approach can adapt multiple radar platforms operating at different frequencies.

For example,
24GHz radar + 60GHz radar + 77GHz radar



(a) Truncated FMCW

Challenge 2 : Lateral Resolution



How to estimate Ange of Arrival?

By spatial diversity

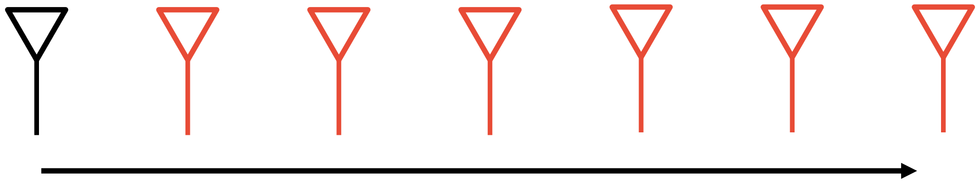
Angle resolution

$$\theta_{res} \propto \frac{1}{N}$$

FMCW:

More Antennas→ Better Lateral Resolution

Challenge 2 : Lateral Resolution

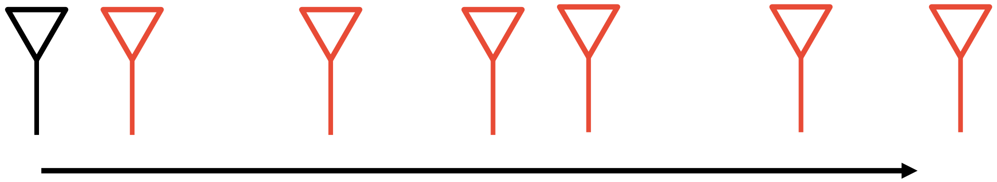


(constantly) move over the time

Synthetic Aperture Array (SAR)

→ Require uniform sampling

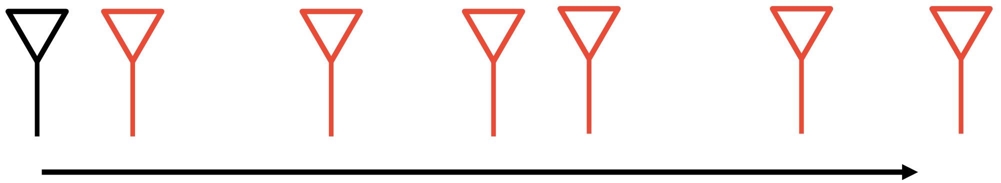
**In automobile application,
radar platform does not move contantly**



sampling locations are non-uniform

Non-uniform
Synthetic Aperture Array (SAR)

Proposed Method2



sampling locations are non-uniform

Non-uniform
Synthetic Aperture Array (SAR)

Goal: Recover a signal from a few (random) measurements

→ Compressive sensing

$$r = As + w$$

r: measurements

A: sampling matrix

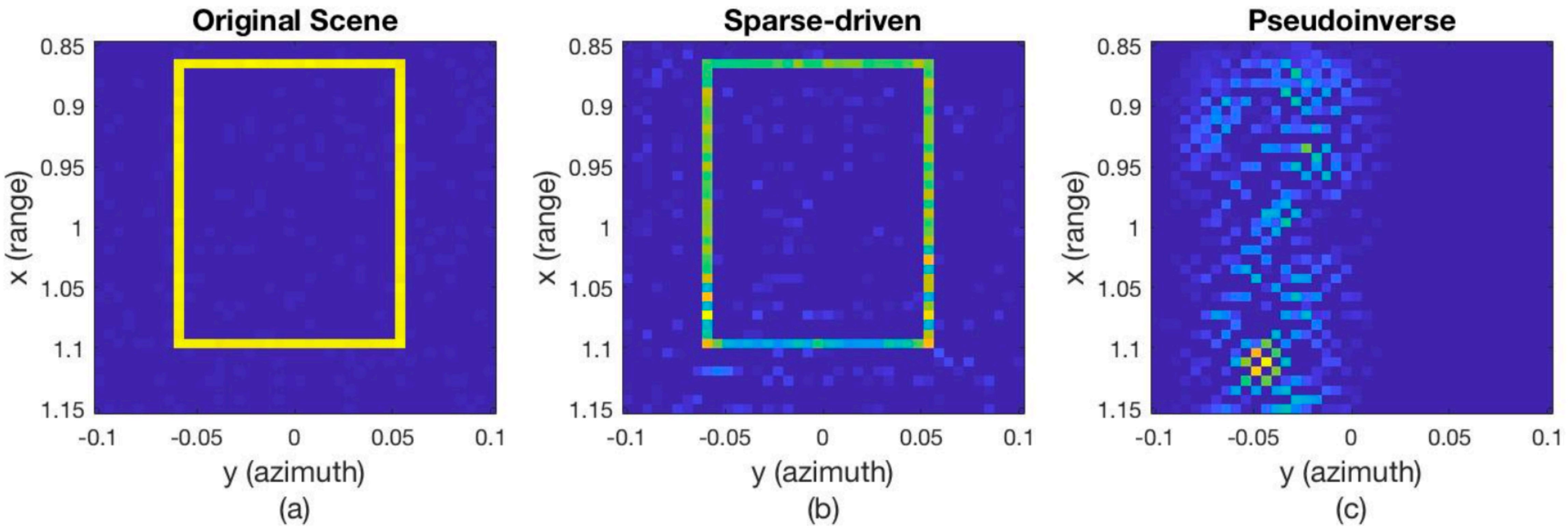
s: original signal

w: Gaussian noise

$$\min_{s} \frac{1}{2} ||r - As||^2 + \lambda ||s||_1$$

Finds the smallest L1 solution from the ill-posed linear system

Proposed Method2



uniformly sampled from the full locations

randomly sampled from 30% of the full locations

Conclusion

- This work demonstrates how the performance of mmWave radar can be extended.
- The mathematical model can fuse the multiple radar platforms to improve the distance resolution.
- Non-uniforam random SAR will improve the spatial resolution in the practical automobile scenario.

Future Work

- Develop the mathematical model to incorporate more scenarios, e.g. interference from the multiple objects, noise, reflections

- Study in depth the practical situations of the non-uniform random SAR, e.g. how to adapt the location errors, computation time

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Thank You
Questions?

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