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

slope = \alpha

IF frequency \propto \text{round-trip time } \tau \propto \text{distance } d
Challenge 1: Distance Resolution

Spectral Analysis:
Longer Observation $\rightarrow$ Better Spectral Resolution
Challenge 1: Distance Resolution

\[ \Delta d = \frac{C}{2B} \]

- \( C \): the speed of light
- \( B \): the bandwidth of FMCW

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

**FMCW:**
Larger Bandwidth → Better Distance Resolution
Proposed Method

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

**Known:** \( \alpha, f_0 \)

**Unknown:** \( \tau \)

**Error function**

\[ E(\tilde{\tau}) = \left\| \frac{e^{j2\pi(\alpha t + f_0 \tau)}}{x_{meas}(t)} - \frac{e^{j2\pi(\alpha \tilde{\tau} + f_0 \tilde{\tau})}}{x_{model}(t)} \right\|^2 \rightarrow \min_{\tilde{\tau}} E(\tilde{\tau}) \]
Proposed Method

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

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

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

\[ \Delta d = 1 \]

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

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

For example, 24GHz radar + 60GHz radar + 77GHz radar.
Challenge 2: Lateral Resolution

How to estimate Angle of Arrival?

By spatial diversity

Angle resolution

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

FMCW:
More Antennas → Better Lateral Resolution
Challenge 2: Lateral Resolution

Synthetic Aperture Array (SAR) (constantly) move over the time → Require uniform sampling

In automobile application, radar platform does not move constantly

sampling locations are non-uniform

Non-uniform Synthetic Aperture Array (SAR)
Proposed Method 2

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

→ Compressive sensing

\[ r = As + w \]

\[ \min_s \frac{1}{2} \| r - As \|^2 + \lambda \| s \|_1 \]

\( r \): measurements  \hspace{1cm} \( s \): original signal
\( A \): sampling matrix  \hspace{1cm} \( w \): Gaussian noise

Finds the smallest L1 solution from the ill-posed linear system
Proposed Method 2

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-uniform random SAR will improve the spatial resolution in the practical automobile scenario.
• 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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