

Roadside Radar Vehicle Identification

Sean K. Lehman, Dave Chambers, Peter Haugen, Christine Paulson, Kique Romero

Lawrence Livermore National Laboratory

May 20, 2013

LLNL-PRES-637041



Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

Auspices

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.



Problem Definition



A Challenge

Scenario:

The universe consists solely of **one road**, **one fixed wide band pitch/catch radar**, **one computer**, and a **set of vehicles passing on the road**.

Challenge:

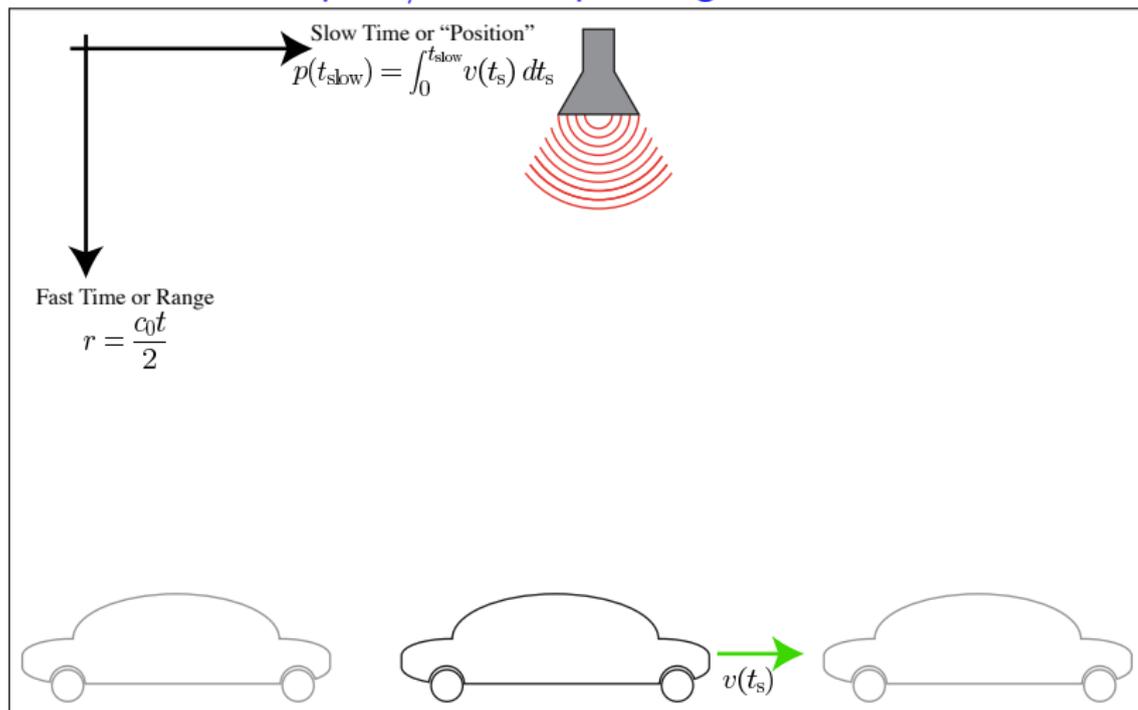
Determine as much information as possible from the single, fixed, wide band radar observing vehicles passing on the road.

- ▶ This is a type of *inverse synthetic aperture radar* (ISAR).
- ▶ Vehicle velocities are **unknown** and must be determined from the data.



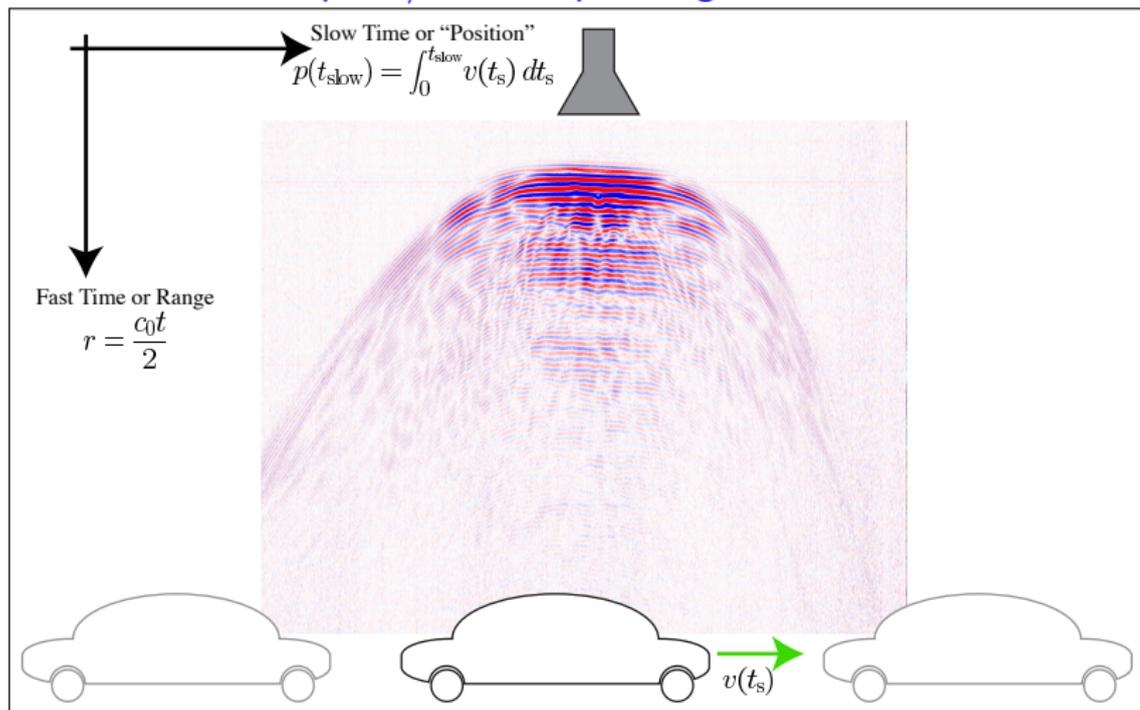
Scenario & Geometry

A single, road side wide band radar collects data in a monostatic “pitch/catch” operating mode.



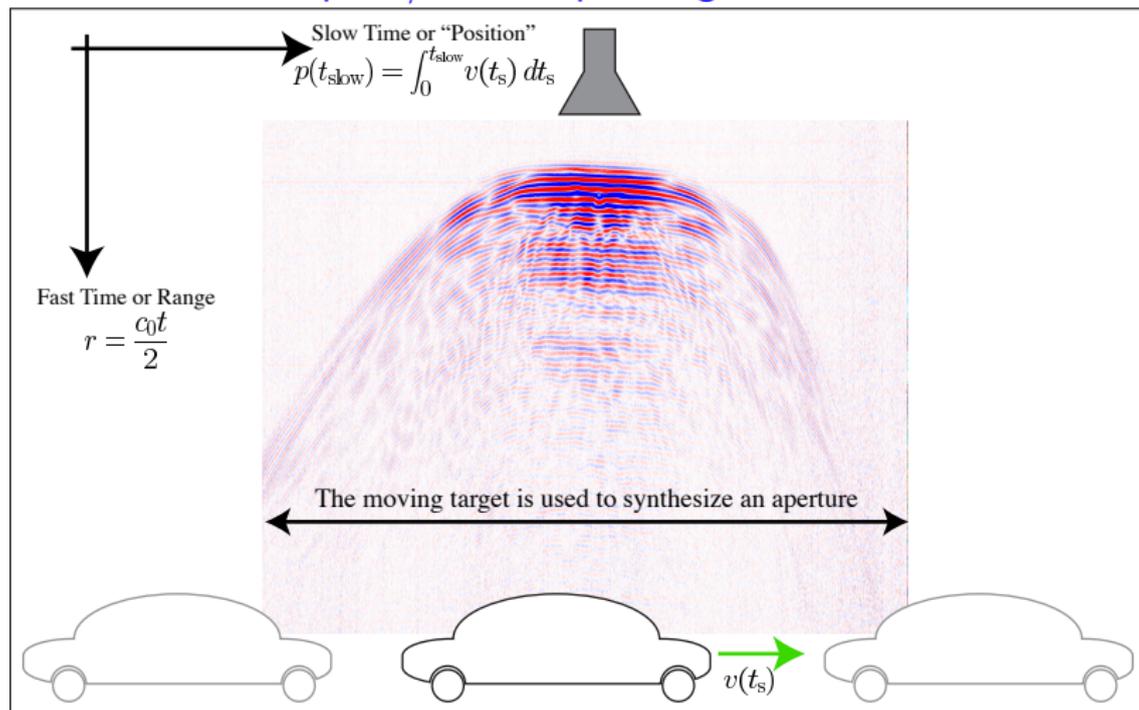
Scenario & Geometry

A single, road side wide band radar collects data in a monostatic “pitch/catch” operating mode.



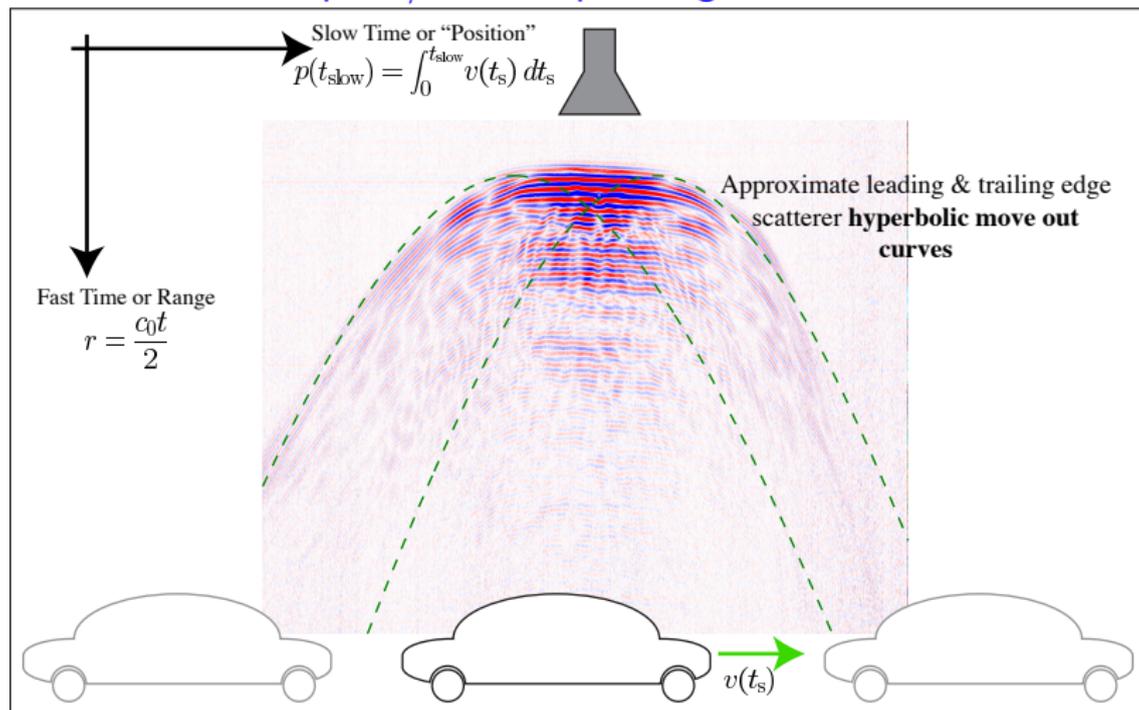
Scenario & Geometry

A single, road side wide band radar collects data in a monostatic “pitch/catch” operating mode.



Scenario & Geometry

A single, road side wide band radar collects data in a monostatic “pitch/catch” operating mode.



Solution



Inverse Synthetic Aperture Radar

- ▶ Mathematically, Cheney & Borden show in “[Imaging Moving Targets from Scattered Waves](#)”, *Inverse Problems*, **24**, 2008, imaging can be achieved in a [Range/Velocity](#) space.
- ▶ However, an azimuthal velocity estimate can be achieved through geometric analysis of the multimonostatic **hyperbolic move out curves**.

$$\begin{aligned}h_{v,\theta}(t_s) &= |\mathbf{x}_0 + \mathbf{v}t_s - \mathbf{R}^{\text{xvr}}|, \\ &= \sqrt{(x_0 + v_x t_s - x^{\text{xvr}})^2 + (y_0 + v_y t_s - y^{\text{xvr}})^2}\end{aligned}$$

$t_s \equiv n\Delta t_s$ is the slow time,

n is the slow time index,

Δt_s is the slow time sample interval,

\mathbf{v} is the vehicle velocity (the vertical velocity is assumed to be zero), $(v_x, v_y) \equiv v(\cos \theta, \sin \theta)$,

\mathbf{R}^{xvr} is the transceiver location.



Inverse Synthetic Aperture Radar

- ▶ Mathematically, Cheney & Borden show in “[Imaging Moving Targets from Scattered Waves](#)”, *Inverse Problems*, **24**, 2008, imaging can be achieved in a [Range/Velocity](#) space.
- ▶ However, an azimuthal velocity estimate can be achieved through geometric analysis of the multimonostatic **hyperbolic move out curves**.

$$\begin{aligned}h_{v,\theta}(t_s) &= |\mathbf{x}_0 + \mathbf{v}t_s - \mathbf{R}^{\text{xvr}}|, \\ &= \sqrt{(x_0 + v_x t_s - x^{\text{xvr}})^2 + (y_0 + v_y t_s - y^{\text{xvr}})^2}\end{aligned}$$

Two points are selected on the move out curve and $h_{v,\theta}(t_s)$ is solved for the velocity.



Inverse Synthetic Aperture Radar

- ▶ Mathematically, Cheney & Borden show in “[Imaging Moving Targets from Scattered Waves](#)”, *Inverse Problems*, **24**, 2008, imaging can be achieved in a [Range/Velocity](#) space.
- ▶ However, an azimuthal velocity estimate can be achieved through geometric analysis of the multimonostatic **hyperbolic move out curves**.

$$\begin{aligned}h_{v,\theta}(t_s) &= |\mathbf{x}_0 + \mathbf{v}t_s - \mathbf{R}^{\text{xvr}}|, \\ &= \sqrt{(x_0 + v_x t_s - x^{\text{xvr}})^2 + (y_0 + v_y t_s - y^{\text{xvr}})^2}\end{aligned}$$

This is used to distinguish vehicles which have identical lengths in measurement space.



Inverse Synthetic Aperture Radar

- ▶ Mathematically, Cheney & Borden show in “[Imaging Moving Targets from Scattered Waves](#)”, *Inverse Problems*, **24**, 2008, imaging can be achieved in a [Range/Velocity](#) space.
- ▶ However, an azimuthal velocity estimate can be achieved through geometric analysis of the multimonostatic **hyperbolic move out curves**.

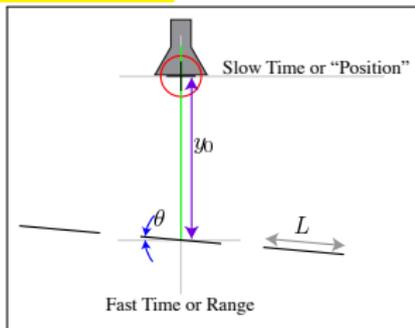
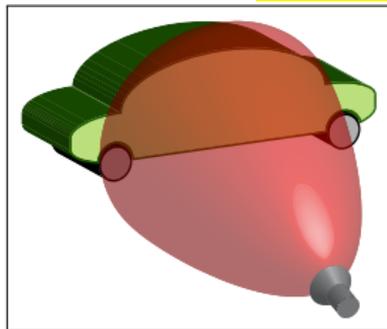
$$\begin{aligned}h_{v,\theta}(t_s) &= |\mathbf{x}_0 + \mathbf{v}t_s - \mathbf{R}^{\text{xvr}}|, \\ &= \sqrt{(x_0 + v_x t_s - x^{\text{xvr}})^2 + (y_0 + v_y t_s - y^{\text{xvr}})^2}\end{aligned}$$

Imaging is achieved in [Range/Azimuth](#) space.



Moving Line Move Out Curve

Vehicle as moving line



$$h_{v,\theta}(t_s) = \begin{cases} \sqrt{(v t_s \cos \theta + L/2)^2 + (v t_s \sin \theta + y_0)^2} & v t_s \cos \theta < -\frac{L}{2} \\ v t_s \sin \theta + y_0 & |v t_s \cos \theta| \leq \frac{L}{2} \\ \sqrt{(v t_s \cos \theta - L/2)^2 + (v t_s \sin \theta + y_0)^2} & v t_s \cos \theta > \frac{L}{2} \end{cases}$$

Do not yet have a solver for this.

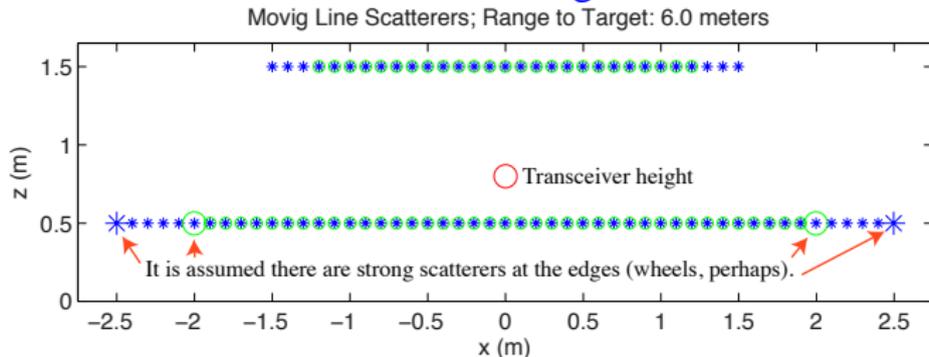


Simulation

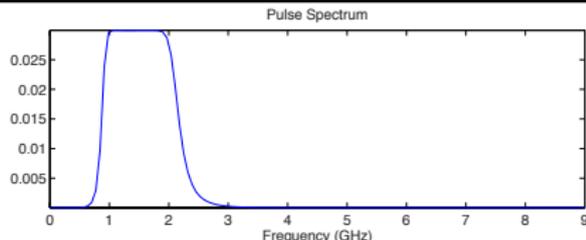
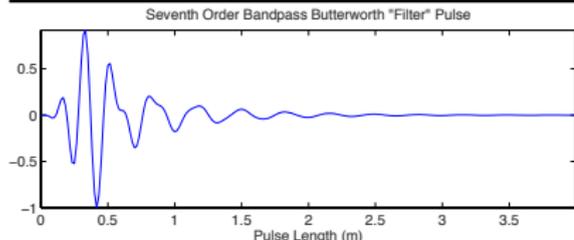


Simulation: Use Line Length to Distinguish "Vehicles"

Proof-of-concept simulations were performed using "vehicles" of two different lengths



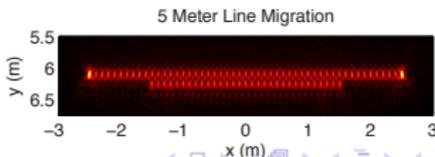
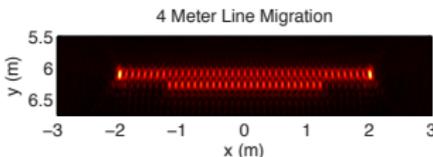
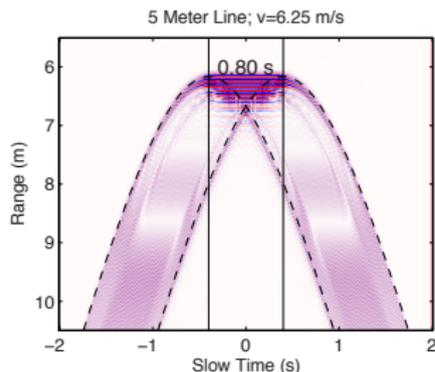
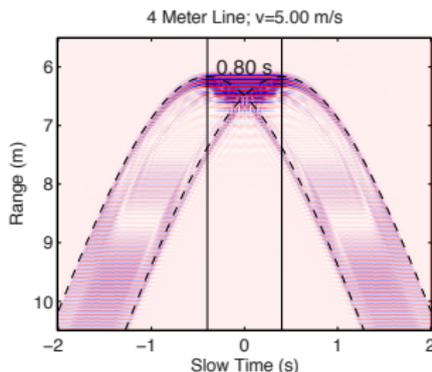
The blue asterisks represent the longer line. The green circles represent the shorter line.
The relative scatterer strength is indicated by the marker size.



Ambiguity Resolution & Geometric Velocity Determination

Lines may have identical lengths in measurement space but differing hyperbolae.

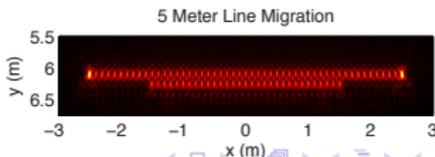
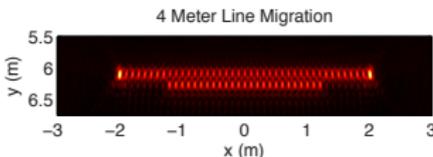
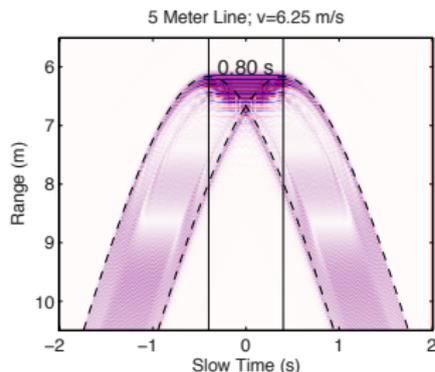
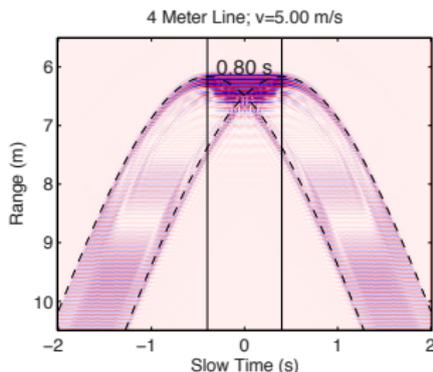
$$\begin{aligned} h_{v,\theta}(n) &= |\mathbf{x}_0 + n\mathbf{v}\Delta t_s - \mathbf{R}^{xvr}|, \\ &= \sqrt{(x_0 + nv \cos(\theta)\Delta t_s - x^{xvr})^2 + (y_0 + nv \sin(\theta)\Delta t_s - y^{xvr})^2} \end{aligned}$$



Ambiguity Resolution & Geometric Velocity Determination

Lines may have identical lengths in measurement space but differing hyperbolae. *An incorrect geometric measurement may result in errors.*

$$\begin{aligned}h_{v,\theta}(n) &= |\mathbf{x}_0 + n\mathbf{v}\Delta t_s - \mathbf{R}^{xvtr}|, \\ &= \sqrt{(x_0 + nv \cos(\theta)\Delta t_s - x^{xvtr})^2 + (y_0 + nv \sin(\theta)\Delta t_s - y^{xvtr})^2}\end{aligned}$$



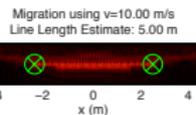
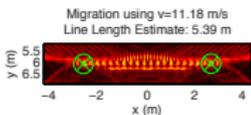
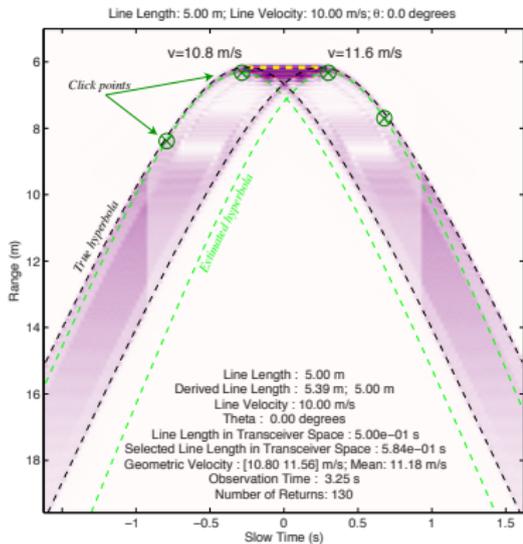
10 m/s; 0 & 5 degrees

5 meter line length;

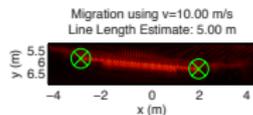
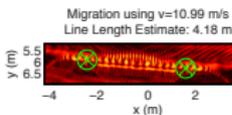
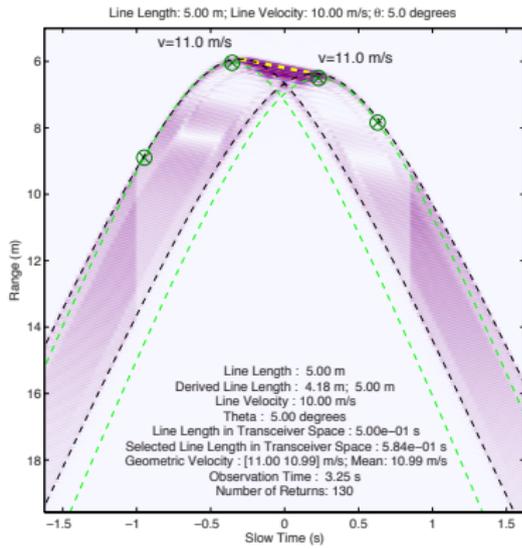
10 m/s;

3.25 s observation time

0 degrees



5 degrees

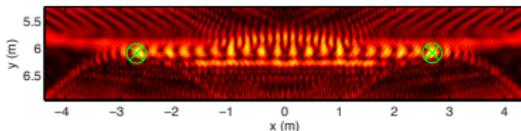


10 m/s; 0 & 5 degrees; Migrations

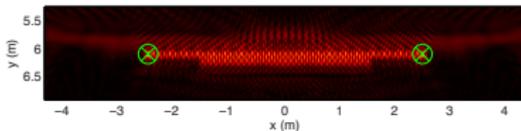
0 degrees

Velocity estimate: 11.18 m/s
5.39 m derived length

Migration using $v=11.18$ m/s
Line Length Estimate: 5.39 m



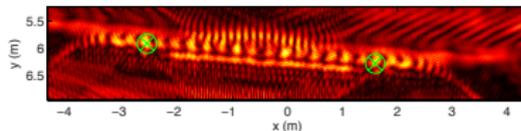
Migration using **correct velocity**, $v=10.00$ m/s
Line Length Estimate: 5.00 m



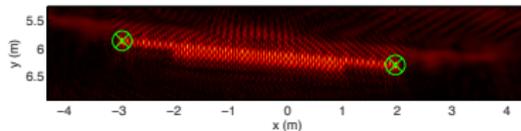
5 degrees

Velocity estimate: 10.99 m/s
4.18 m derived length

Migration using $v=10.99$ m/s
Line Length Estimate: 4.18 m



Migration using **correct velocity**, $v=10.00$ m/s
Line Length Estimate: 5.00 m



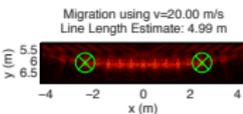
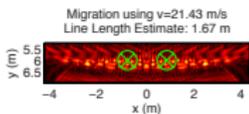
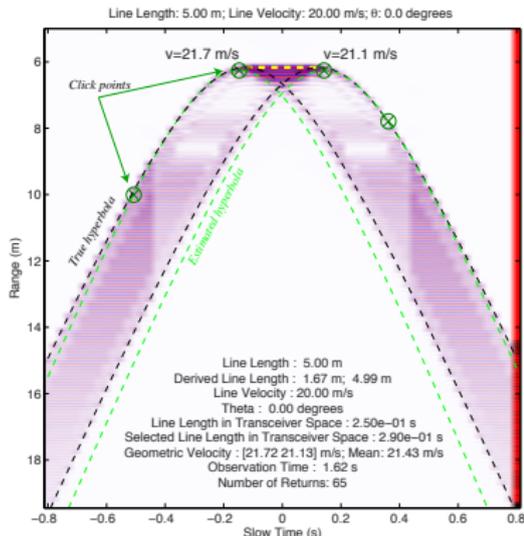
20 m/s; 0 & 5 degrees

5 meter line length;

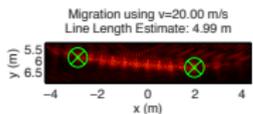
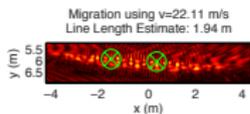
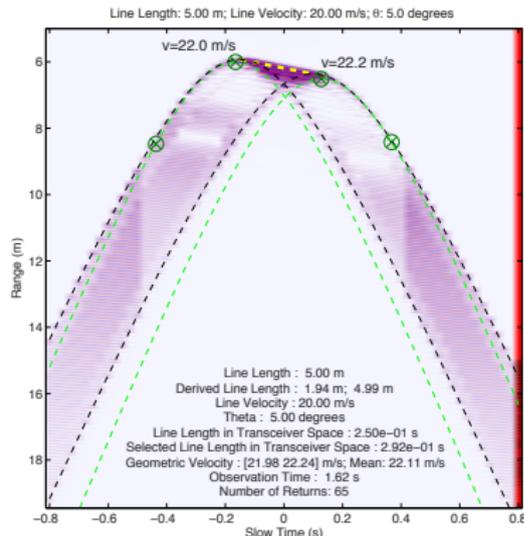
20 m/s;

1.62 s observation time

0 degrees



5 degrees

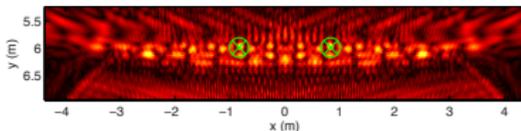


20 m/s; 0 & 5 degrees; Migrations

0 degrees

Velocity estimate: 21.43 m/s
1.67 m derived length

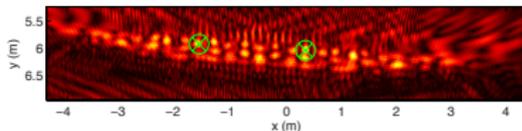
Migration using $v=21.43$ m/s
Line Length Estimate: 1.67 m



5 degrees

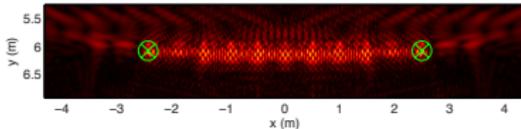
Velocity estimate: 22.11 m/s
1.94 m derived length

Migration using $v=22.11$ m/s
Line Length Estimate: 1.94 m



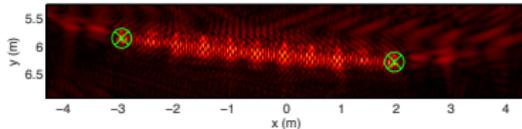
Migration using **correct velocity**, $v=20.00$ m/s

Line Length Estimate: 4.99 m



Migration using **correct velocity**, $v=20.00$ m/s

Line Length Estimate: 4.99 m



Summary & Conclusions

- ▶ **Challenge problem:** Determine as much information as possible from a single, fixed, wide band radar observing vehicle passing on a road.
- ▶ A simulated proof-of-concept used line length to distinguish “vehicles” successfully.
- ▶ But an accurate velocity estimation is required.
- ▶ Open questions:
 - ▶ What is sufficient information for uniquely distinguishing vehicles?
 - ▶ What is the minimum significant feature size?
 - ▶ What are the optimal radar & pulse for maximizing derived vehicle information?
 - ▶ What is the optimal method for *automatically* deriving vehicle velocity from the data?

