Roadside Radar Vehicle Identification

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Disclaimer

Auspices

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Problem Definition

A Challenge

Scenario:

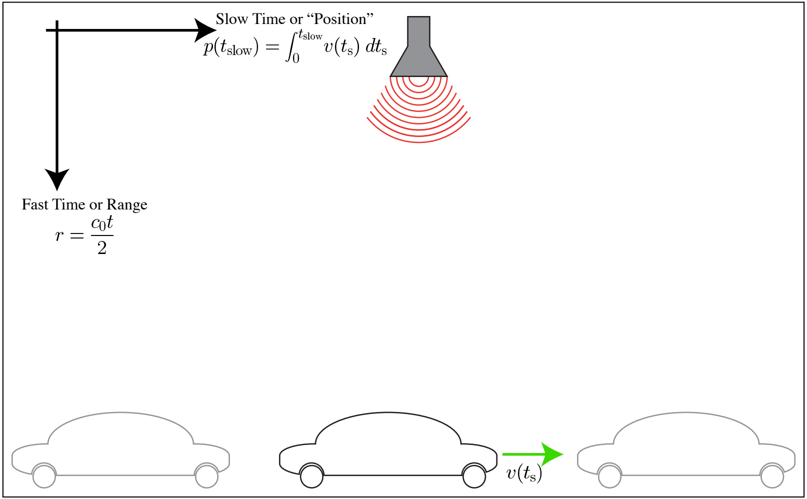
The universe consists solely of one road, one fixed wide band pitch/catch radar, one computer, and a set of vehicles passing on the road.

Challenge:

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

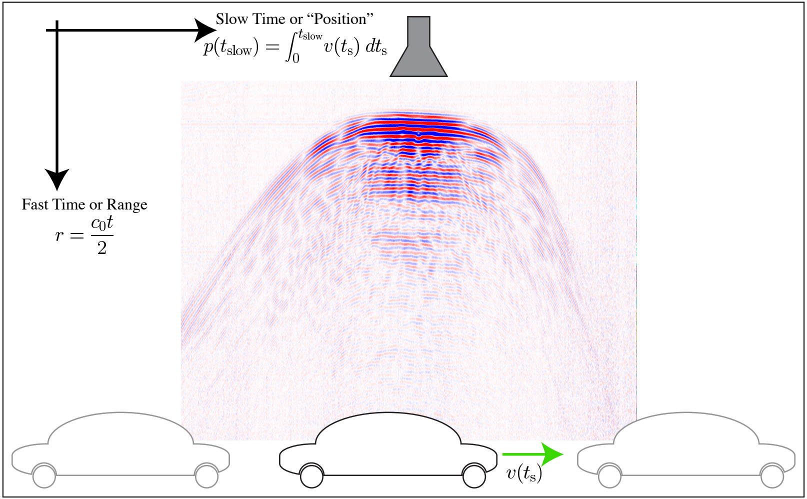
- This is a type of *inverse synthetic aperture radar* (ISAR).
- Vehicle velocities are unknown and must be determined from the data.

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.



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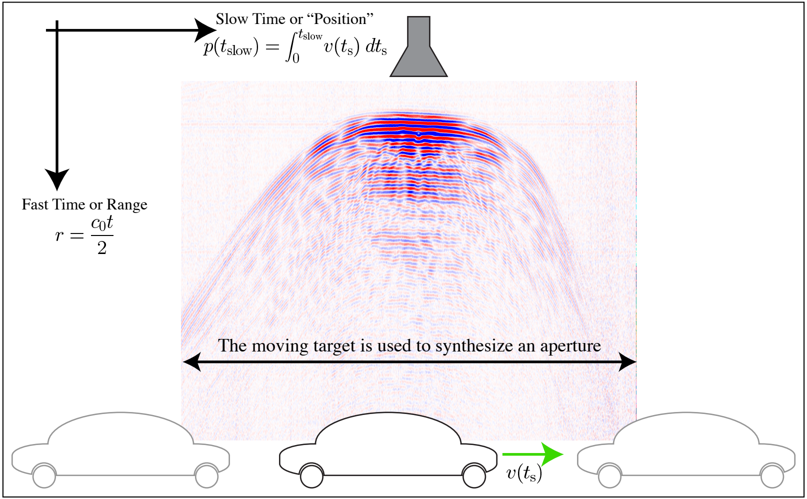

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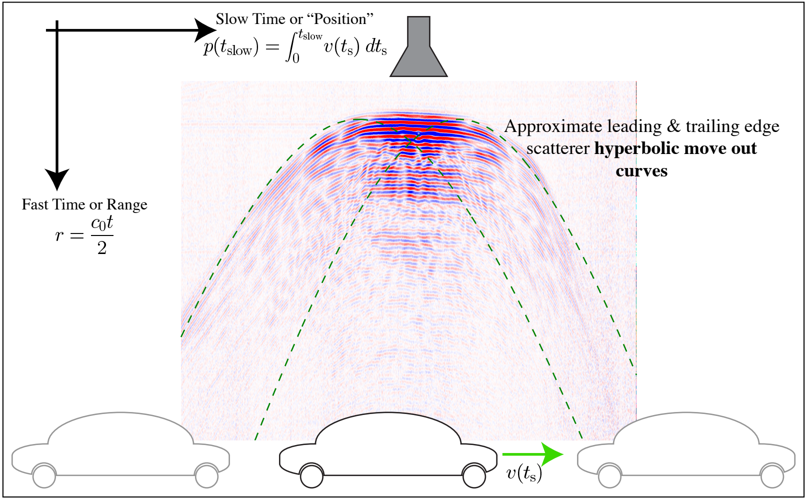

Solution

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**.

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

$t_{\mathrm{s}} \equiv n\Delta t_{\mathrm{s}}$ 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), $(v_x, v_y) \equiv v(\cos\theta, \sin\theta)$,
$\mathbf{R}^{\mathrm{xvr}}$ is the transceiver location.

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

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

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

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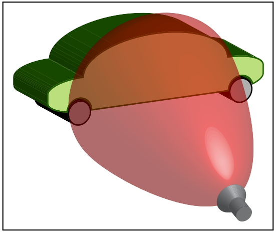
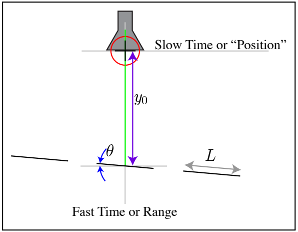
Imaging is achieved in Range/Azimuth space.

Moving Line Move Out Curve

Vehicle as moving line





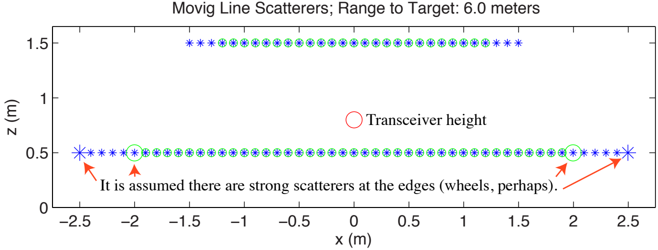
$$h_{v,\theta}(t_s) = \begin{cases} \sqrt{(vt_s\cos\theta + L/2)^2 + (vt_s\sin\theta + y_0)^2} & vt_s\cos\theta < -\frac{L}{2} \\ vt_s\sin\theta + y_0 & |vt_s\cos\theta| \leq \frac{L}{2} \\ \sqrt{(vt_s\cos\theta - L/2)^2 + (vt_s\sin\theta + y_0)^2} & vt_s\cos\theta > \frac{L}{2} \end{cases}$$

Do not yet have a solver for this.

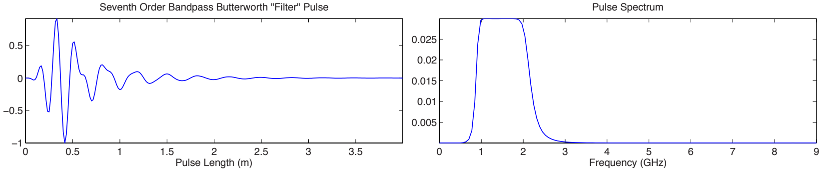
Simulation

Simulation: Use Line Length to Distinguish “Vehicles”

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



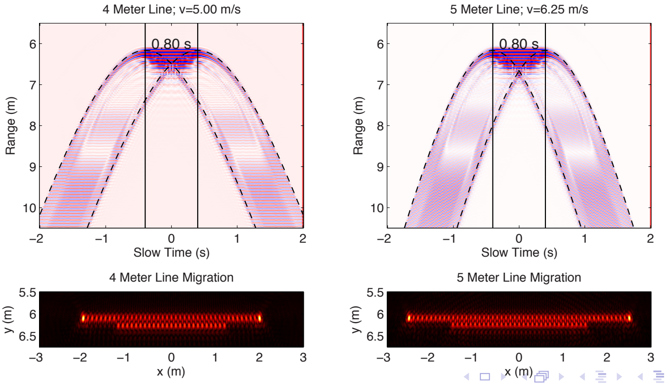
The blue asterisks represent the longer line. The green circles represent the shorter line.
The relative scatterer strength is indicated by the marker size.



Ambiguity Resolution & Geometric Velocity Determination

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

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



Ambiguity Resolution & Geometric Velocity Determination

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

$$
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h_{v,\theta}(n) &= \left|\mathbf{x}_0 + n\mathbf{v}\Delta t_{\mathrm{s}} - \mathbf{R}^{\mathrm{xvr}}\right|, \\
&= \sqrt{(x_0 + nv\cos(\theta)\Delta t_{\mathrm{s}} - x^{\mathrm{xvr}})^2 + (y_0 + nv\sin(\theta)\Delta t_{\mathrm{s}} - y^{\mathrm{xvr}})^2}
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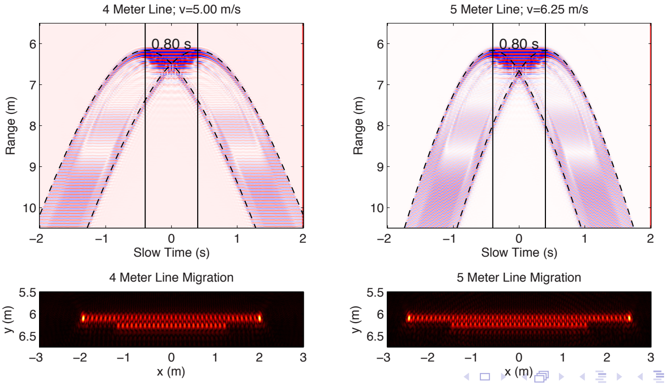
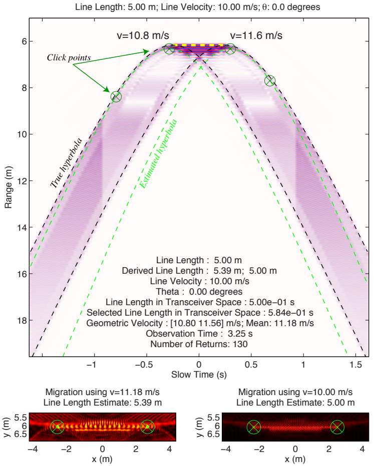


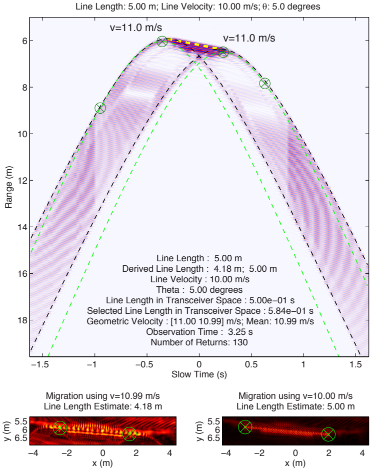
10 m/s; 0 & 5 degrees

5 meter line length; 10 m/s; 3.25 s observation time

0 degrees



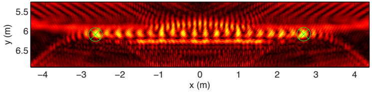
5 degrees



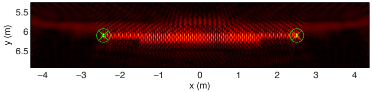
10 m/s; 0 & 5 degrees; Migrations

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

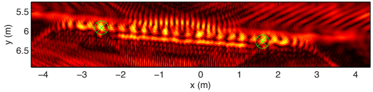


Migration using correct velocity, v=10.00 m/s
Line Length Estimate: 5.00 m

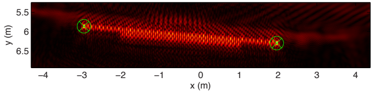


5 degrees
Velocity estimate: 10.99 m/s
4.18 m derived length

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



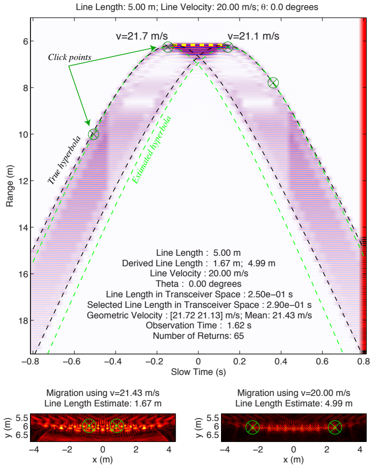
Migration using correct velocity, v=10.00 m/s
Line Length Estimate: 5.00 m



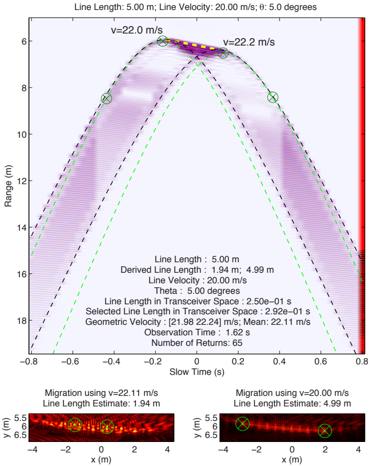
20 m/s; 0 & 5 degrees

5 meter line length; 20 m/s; 1.62 s observation time

0 degrees

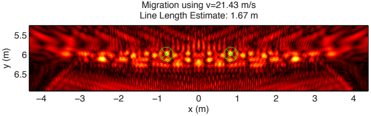


5 degrees

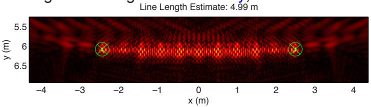


20 m/s; 0 & 5 degrees; Migrations

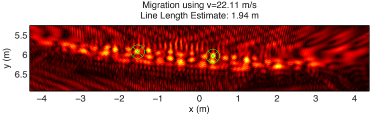
0 degrees
Velocity estimate: 21.43 m/s
1.67 m derived length



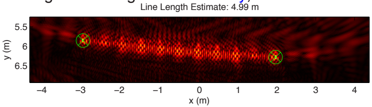
Migration using correct velocity, v=20.00 m/s



5 degrees
Velocity estimate: 22.11 m/s
1.94 m derived length



Migration using correct velocity, v=20.00 m/s



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?