Photogrammetry - Selected Chapters (PSC)

2019 WS

Vehicle detection using SAR

Yin Ying IP

ESPACE - Earth oriented space science and technology

1.1 Motivation (1)

- Large area traffic data(traffic flow rates, vehicular speed, vehicle length and headway, traffic density) is necessary for:
  - Intelligent transportation systems (ITS)
    - Provide real-time information for road users and transportation system operators
    - Decision making aids
  - Urban Planning
    - Assess traffic density → Road network optimization
    - Traffic model simulation → Estimate and forecast traffic density
  - Environmental Study
    - Environmental Model simulation → Estimate and forecast air and noise pollution
  - Emergency response
    - Assess the parking situation → Indicate crowds trying to escape from this zone
  - Military reconnaissance
    - Detect active site by detecting moving vehicles

1.1 Motivation (2)

- Advantages of using SAR:
  - Remote sensing system → Ability to monitor large areas at once
  - Active sensor, do not depend on daylight
  - Almost weather independent
  - Short image acquisition time

1.2 Problems (1)

- Inherent side looking geometry
  - Shadow and layover
  - Strongly affect the radar cross section (a target’s ability to reflect radar signals in the direction of the radar receiver) of an automobile
    → the signal-to-noise ratio (SNR) can vary up to 30 dB
  - Interpretation of urban areas is difficult

- Detect either moving/stationary vehicles
  - E.g. Classic method (e.g. ground moving target indication) detects depending on the motion of the target.
    → Stationary vehicles are neglected

- Ambiguity between vehicles and other moving objects

- Complex space-time variation of doppler shift of signal
  - Doppler-shift = function(Velocity of moving platform, Steering angle)

    ➔leads of the need of joint space and time processing, which is not taken into account in many old papers

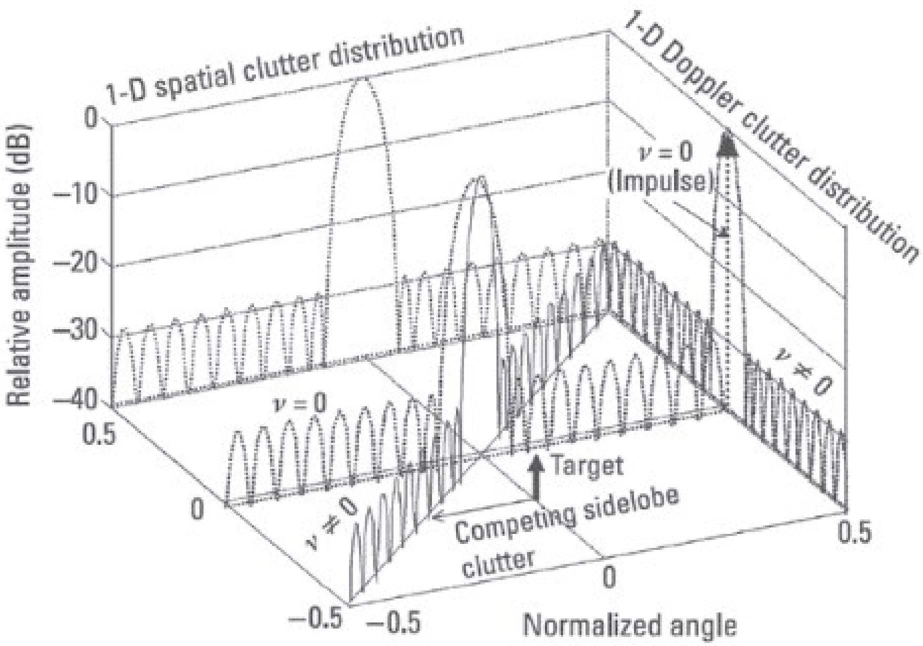
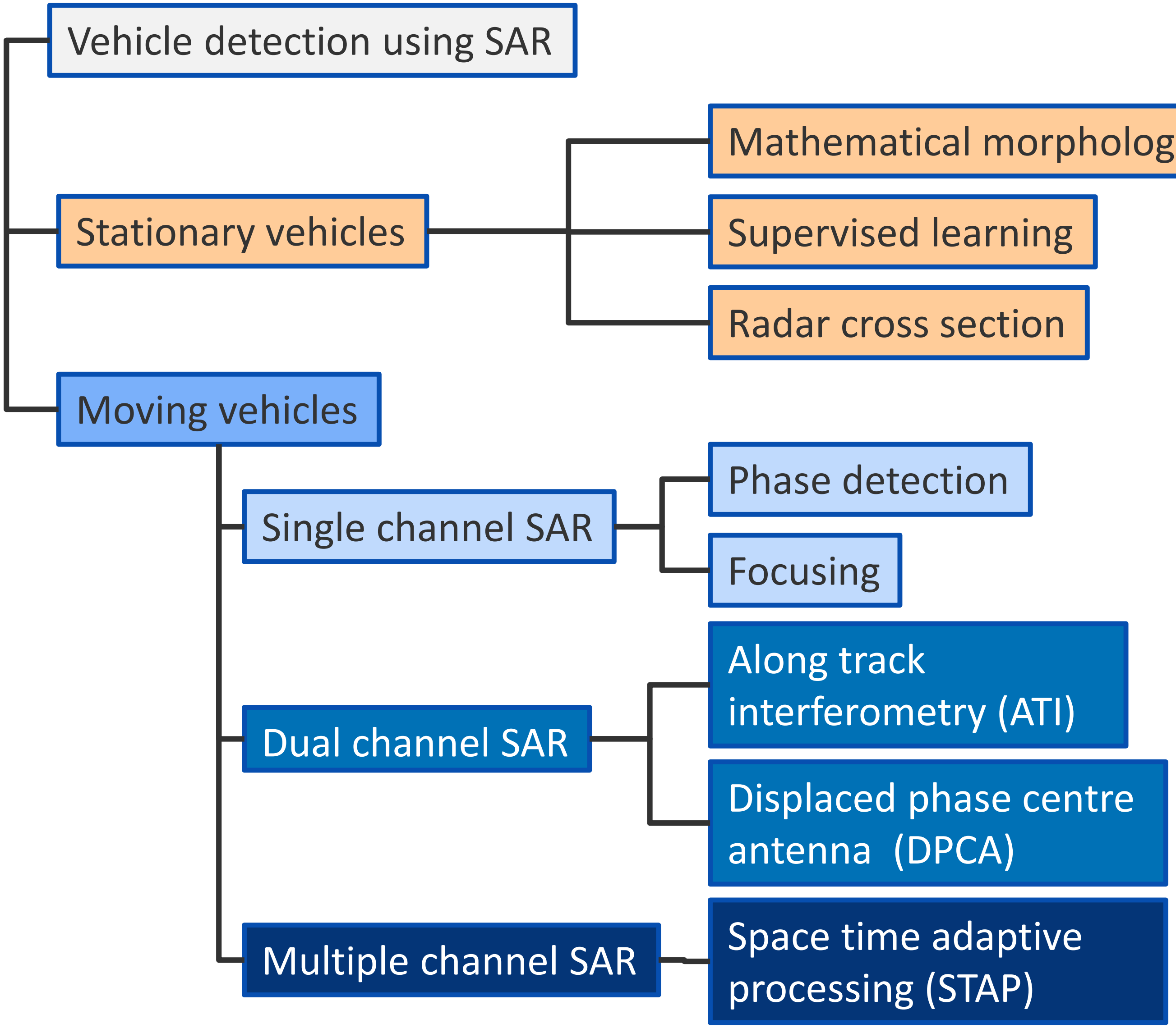


Figure 3.2 Angle-Doppler (space-time) structure of airborne clutter due to ownship platform motion.

[Guerci, 2014]

1.3 Assumptions

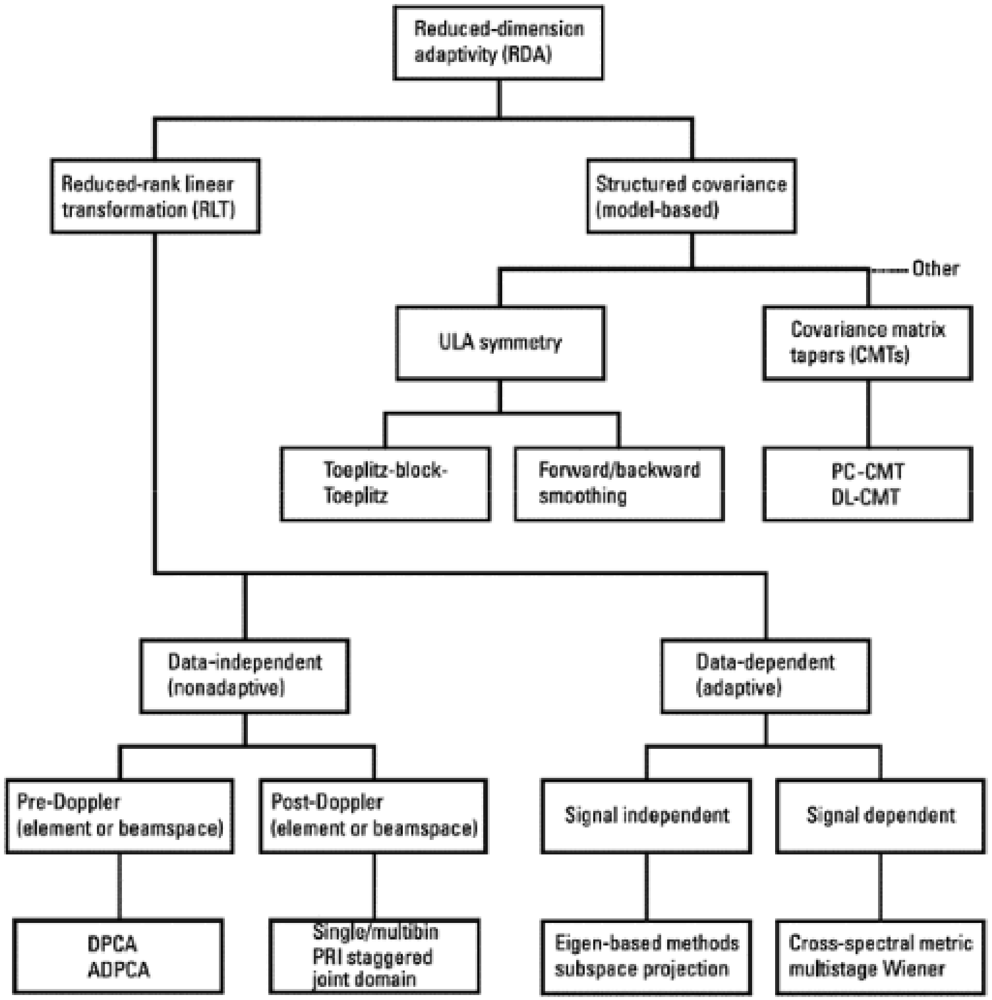
- Stationary vehicle detection
  - Assume pixels which are in a connected component belong to the same object [Maksymiuk et al., 2013]
  - Assume vehicles are often aligned forming group patterns. [Maksymiuk et al., 2012]
  - Assume there are enough samples for supervised learning
- Moving vehicle detection
  - Assume a stationary clutter(background)
  - Assume vehicles are modelled as a point-target
  - Assume a constant velocity [Suchandt et al., 2010]
  - Assume vehicles travel on roads of a known road-network [Hinz et al., 2007]
  - Assume all ground moving object moving on a known road-network could all be regards as vehicles



[Maksymiuk et al., 2013]
[Maksymiuk et al., 2012]
[Palubinskas et al., 2005]
[Raney, 1971]
[Fienup, 2001]
[Breit et al., 2003]
[Hinz et al., 2008]
[Lightstone et al., 1991]
[Baumgartner & Krieger, 2010]
[Cerutti-Maori & Sikaneta, 2013]
[Page et al., 2014]
[Silva & Baumgartner, 2017]
[Baumgartner & Krieger, 2012]

- Characteristics of the vehicle detection using SAR field:
  - Majority of the research is focusing on moving vehicle detection
  - Newer paper tends to use more channels (along track images)
    - Development of more sophisticated and complicated technique
  - Focus of the research is on both **data acquisition technique** and **image processing methodology**
- Note on Space time adaptive processing (STAP):
  - This is a general name of a branch of methods
  - Discussion of various STAP methods is out of scope of this presentation

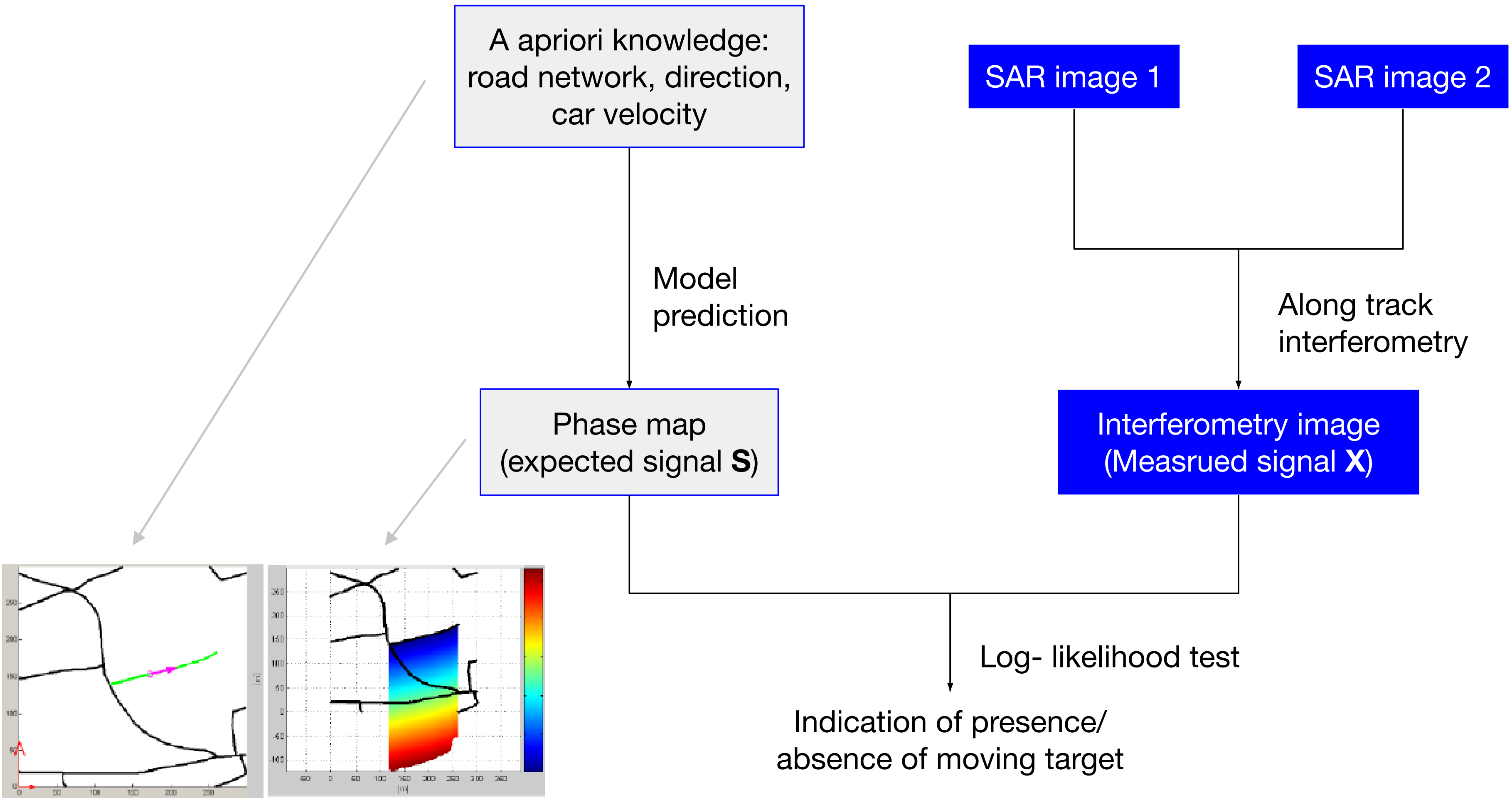
- Taxonomy of reduced-dimension adaptivity STAP algorithms.
- It is important to note that many of the methods can be combined,
- thus greatly increasing the palette of techniques from which to choose



[Guerci, 2014]

3.1 Method1: Along track interferometry (1)

- Main idea of this method is to compare:
  - Interferometry image obtain from **measurement**
  - Interferometry image obtain from **simulation**
- Simulation is possible because:
  - Only deal with vehicles moving on known road network
  - A priori knowledge:
    - Road Network
    - Car velocity
    - Direction
    - Digital Elevation Model



(a) (b)

[Hinz et al., 2008]

3.1 Method1: Along track interferometry (3)

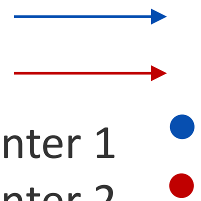
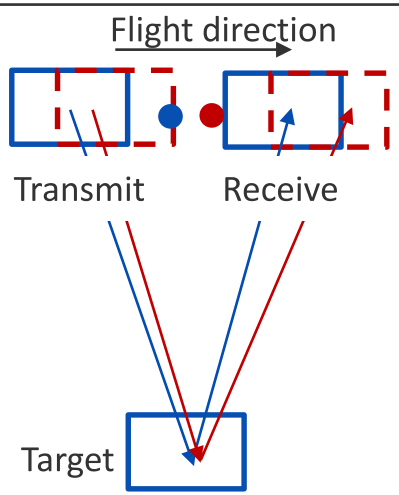
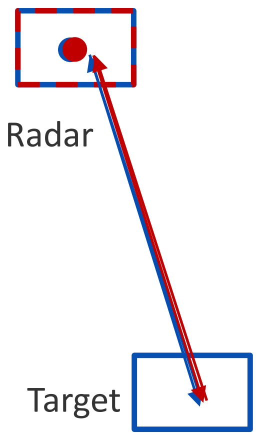
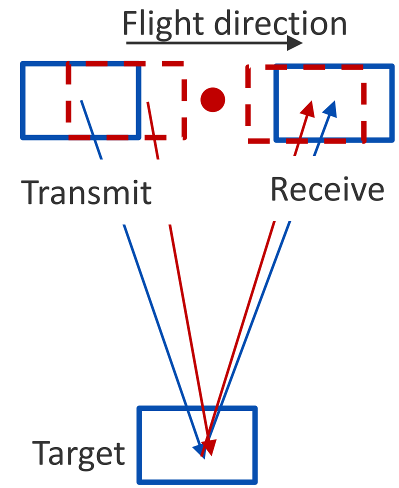
- Assume a piori knowledge of road network and directions are known
- Two hypothesis:
  - H_0: only clutter and noise are existent
  - H_1: signal plus clutter and noise are existent
- Likelihood ratio: $\Lambda = \frac{f(\vec{x}|H_1)}{f(\vec{x}|H_0)}$
- The likelihood PDF is related to the expected signal and measured signal as follow:
  - $f(\vec{x}|H_0) = \frac{1}{\pi^2|C|}\exp\left(-\vec{X}^H C^{-1}\vec{X}\right)$
  - $f(\vec{x}|H_1) = \frac{1}{\pi^2|C|}\exp\left(-(\vec{X}-\vec{S})^{\mathrm{H}} C^{-1}(\vec{X}-\vec{S})\right)$
- Finally, one can derive the Bayesian decision rule of log-likelihood test:
  - $\left|\vec{S}^H C^{-1}\vec{X}\right| > \alpha$

[Hinz et al., 2008]

3.2 Method2: Displaced phase center antenna (1)

[Baumgartner & Krieger, 2010]

- The goal of displaced phase center antenna (DPCA) is **<u>clutter(stationary background)</u>** suppression.
- Clutter could be subtracted from 2 echoes of Monostatic Pulse Radar(transmitter collocated with the receiver), but not from an airborne SAR, as the phase centre is shifting while the platform is moving.

<table>
<tr><td>Case</td><td>Airborne SAR without DPCA</td><td>Monostatic Pulse Radar</td><td>Airborne SAR With DPCA</td></tr>
<tr><td>Geometry
Pulse 1
Pulse 2
Phase Center 1
Phase Center 2
</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Phase Center</td><td>Displaced</td><td>Fixed</td><td>Fixed</td></tr>
<tr><td>clutter suppression</td><td>Not possible</td><td>Possible</td><td>Possible</td></tr>
</table>

3.2 Method2: Displaced phase center antenna (2)

- For DPCA,
  - any two successive pulses
  - received by the two different antenna parts

  ➔ appear to come from one phase centre fixed in space

  ➔ Influence of platform motion is compensated

- Following information is needed for designing DPCA:
  - Pulse repetition interval (PRI)
  - Platform speed

- As moving target
  - Produced **doppler shift** in its signal and
  - Its signal would be **preserved** in the clutter suppression process in DPCA

  ➔ moving target detection is possible

[Baumgartner & Krieger, 2010]

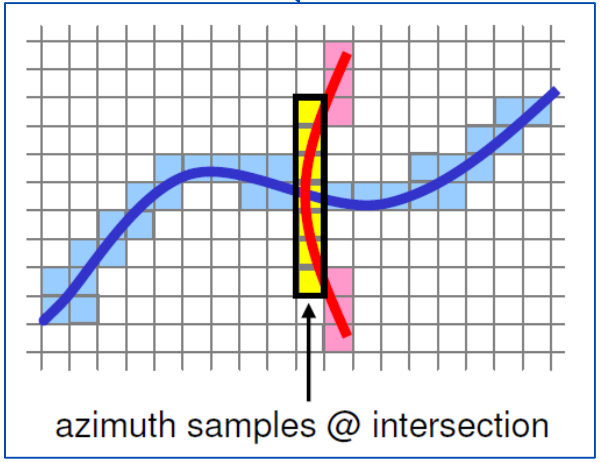
3.2 Method2: Displaced phase center antenna (3)

- Note on the difference between cases:
  - Monostatic Pulse Radar
  - Airborne SAR with DPCA
- Although images of DPCA appear to have one phase centre fixed in space
- The platform motion still leads to a doppler shift in clutter
- Thus, the clutter signal in the 2 cases are not the same

[Baumgartner & Krieger, 2010]

3.2 Method2: Displaced phase center antenna (3)

- Outline of the proposed algorithm
  - A priori: The road axis is known
  - Step 1: Map Road axis from global Cartesian UTM coordinate to SAR range-azimuth coordinate
  - Step 2: clutter suppression by DPCA
  - Step 3: Extract Azimuth Samples Around Road Point
  - Step 4: Detection
    - Convert Signal to Frequency domain
    - moving vehicle signal appears as a sharp peak
  - Step 5: Moving parameter estimation
    - Velocity=function(
      - Doppler-shift,
      - Vehicle position,
      - Road angle with respect to flight direction)
  - Step 6: clustering
    - Group detection signal that likely belongs to the same vehicle

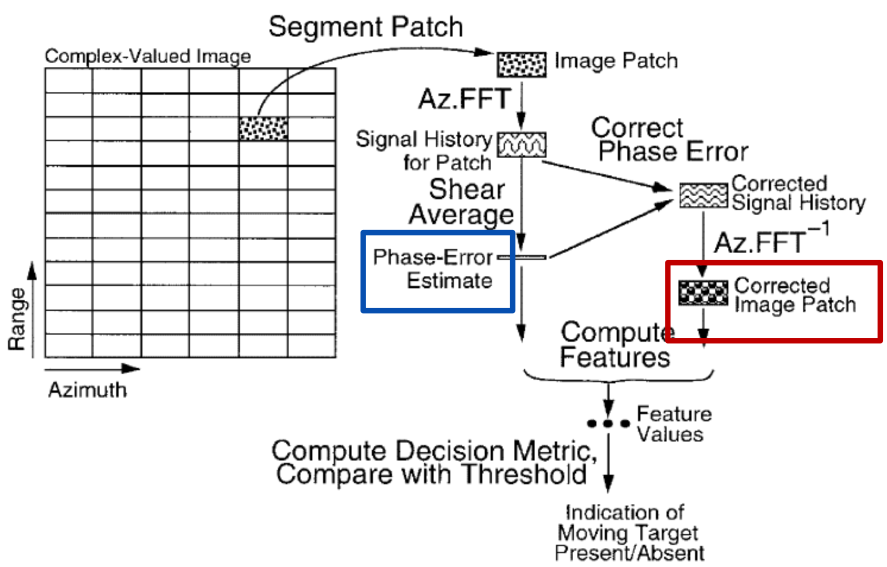


[Baumgartner & Krieger, 2010]

3.3 Method3: Focusing (1)

- Main idea of this method:
- Considering the phase error (smearing) due to the motion of the moving target
- Analogy of phase error in SAR image: Motion blur in optical image
- Try to focus the smearing to one point of signal

- 1. Create image patches
- 2. Estimate Phase Error using shear average algorithm
- 3. Create 'Corrected' Image patches
- 4. Compute Features
  - Standard deviation of phase error
  - Standard deviation of the derivative of the phase-error estimate
  - Quadratic component of the phase error estimate
  - Sharpness ratio
- 5. Indicate presence/ absence of moving target



[Fienup, 2001]

3.3 Method3: Focusing (3)

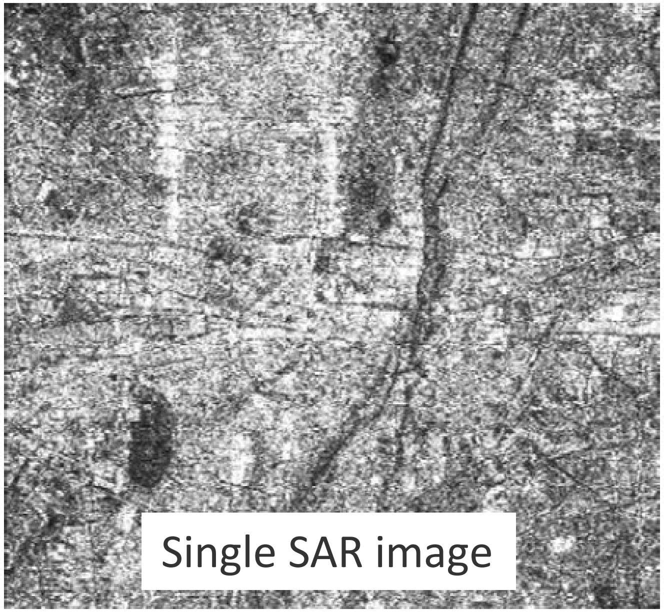
- Size of image patch
  - Should be similar to the size of moving target
  - Patch length in azimuth ~ velocity of the moving target
    - If a wide range of velocities are expected, the algorithm would be run with different patch length

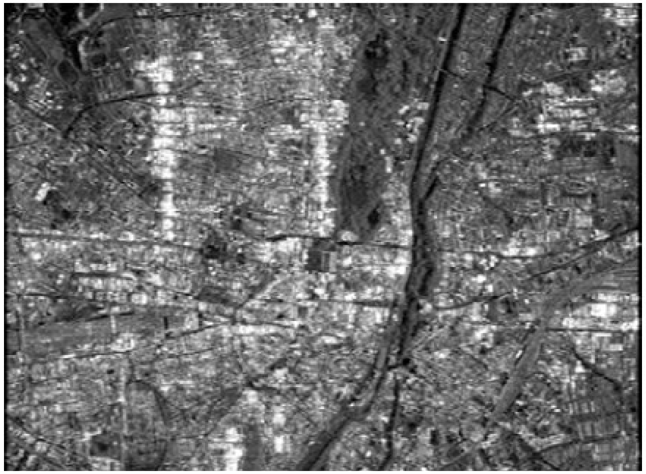
- Shear averaging algorithm
  - Smeared image $g(x, y)$ → Fourier Transsform
  - Shear averaged quantity: Average of the product of nearby smeared image pairs in frequency domain, which could related to the phase error
  - Estimate of the phase error from Shear averaged quantity

- Sharpness Ratio
  - Using Muller—Buffington image-sharpness metrics
    - $\frac{S_1(after\ correction)}{S_1(before\ correction)} = \frac{\Sigma_{x,y}|g_{cor}(x,y)|^4}{\Sigma_{x,y}|g(x,y)|^4}$

[Fienup, 2001]

- Data of the German SAR satellite TerraSAR-X (**spaceborne platform**)
  - acquired with the Aperture Switching mode
- Scene: the Autostrada del Sole, a major motorway in Italy
  A line of dense truck traffic
- Ground Truth: Video observations from motorway bridges
- Velocity of vehicles(estimated by a GPS on a reference car 86 km/h

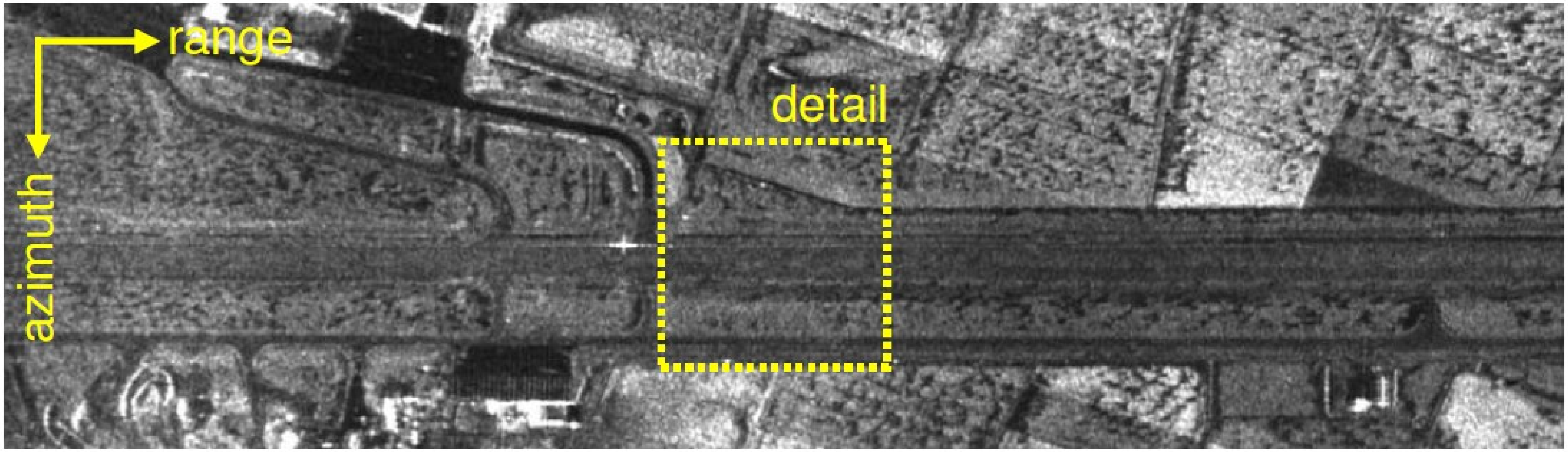




Temporal average of multiple SAR image → Clutter signal

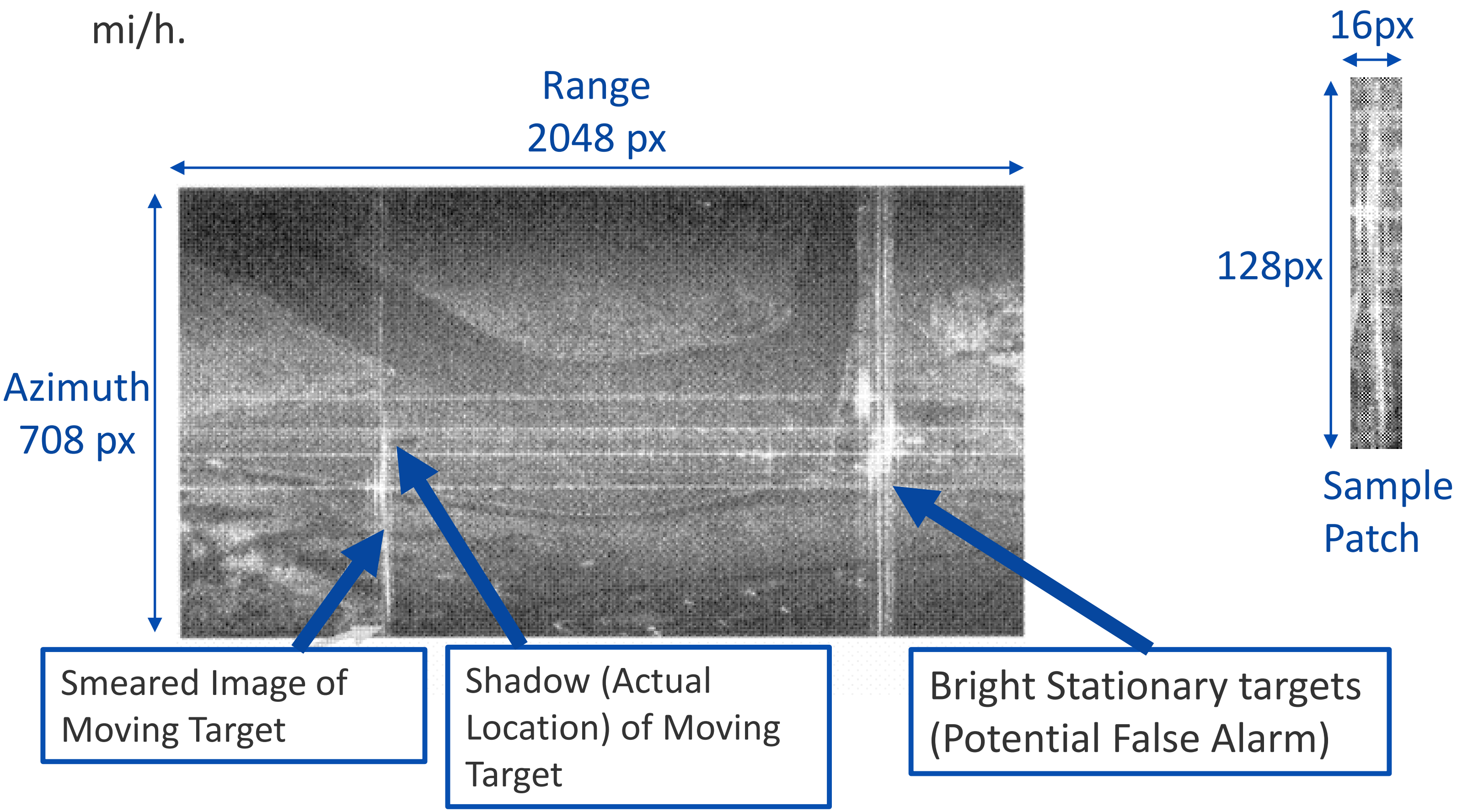
[Hinz et al., 2008]

- Radar: DLR's F-SAR system (**Airborne platform**)
  - X- band, Dual-channel mode
  - GSD: 0.2m (Azimuth), 0.3m (Range)
- Test site: an airfield in Memmingen, vehicle are moving in across-track direction
- Ground Truth: GPS equipped on controlled vehicles
  - Reference positions and velocities
  - Taken simultaneously with SAR image
- Numerical result of the 'Detail' region is presented in the article.



[Baumgartner & Krieger, 2010]

- Demonstration of detection technique
- Scene: A smeared image of **a schoolbus** moving in a circle at a speed of about 20 mi/h.



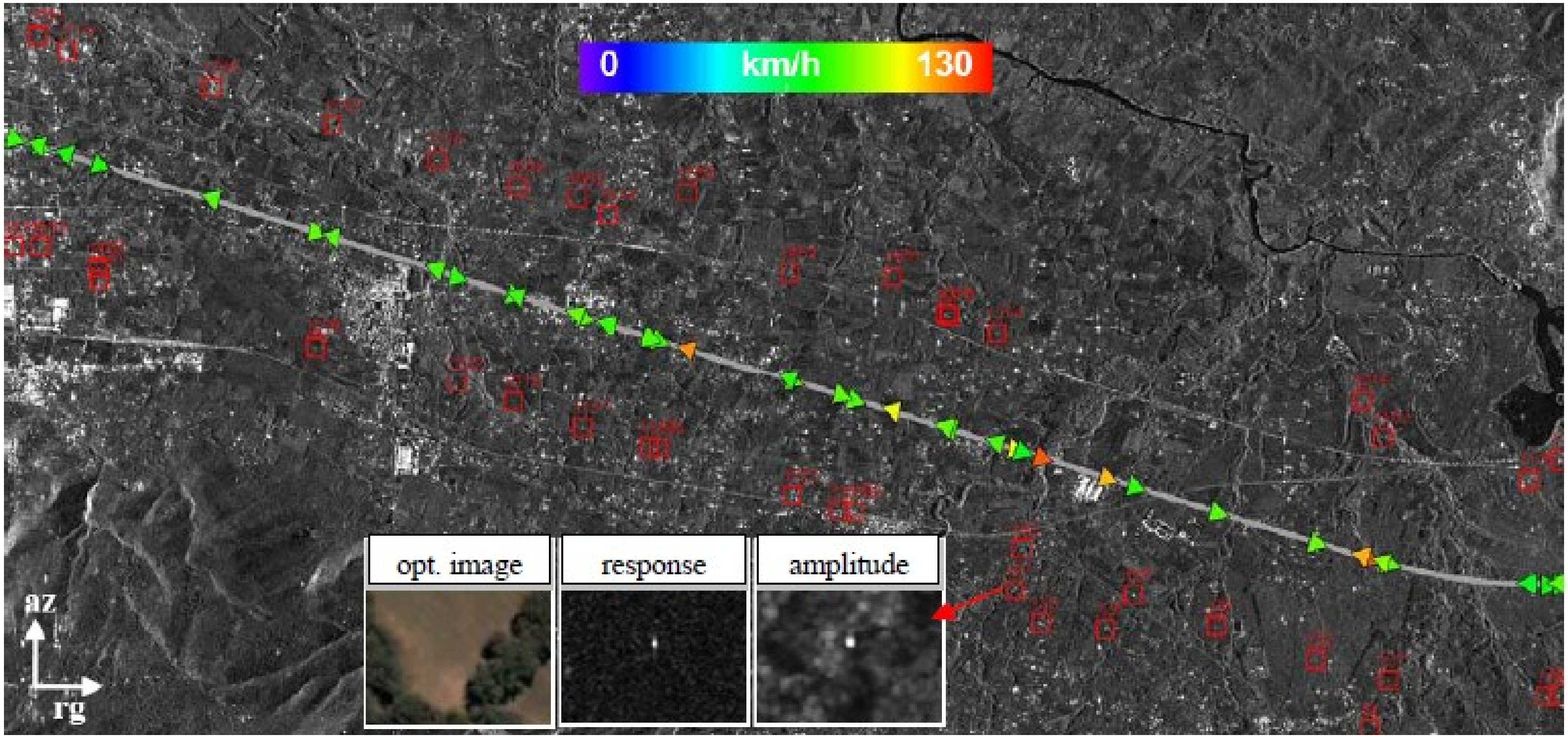
[Fienup, 2001]

4.3 Method3: Focusing Data (2)

- The performance of the detection algorithm is done in the following 2 ways:
  - by computer simulations
    - simulated the smearing effects typical of target motion
    - embedded the smeared images into real SAR images with various backgrounds:
      - Trees, grass, desert, a subdivision, a highway area, and a motor pool.
    - Simulated target/background ratios:
      - 0.5, 2.0, and 10
  - by testing on real data
    - due to lack of data, the result is not statistically meaningful

[Fienup, 2001]

Category	Detection rate
Large vehicles (e.g. trucks and Busses)	60-80%
Smaller cars	30-50%

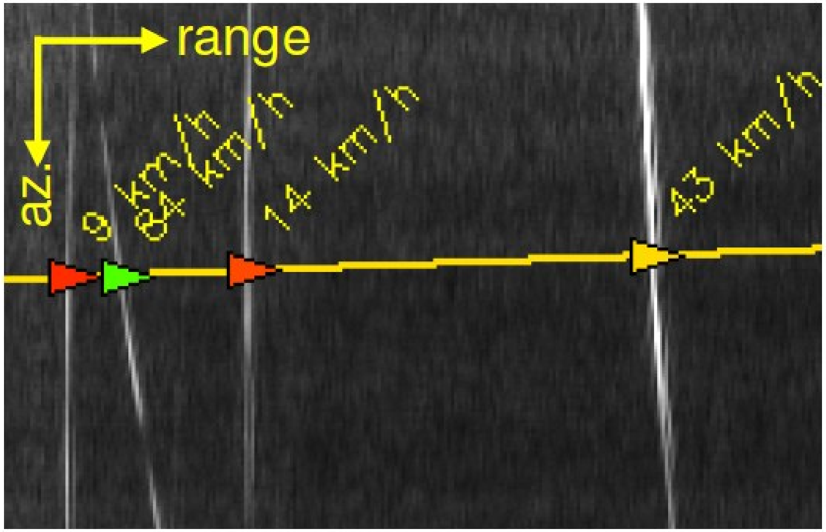


[Hinz et al., 2008]

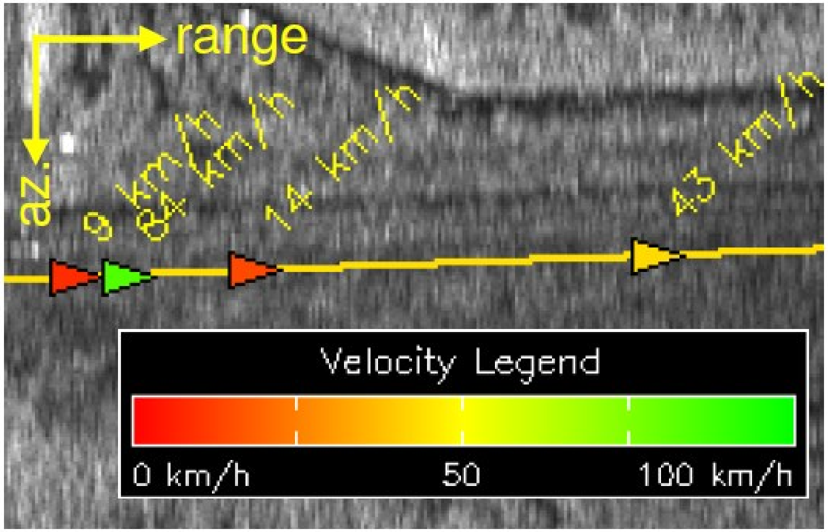
5.1 Method1: Along track interferometry Result (2)

- In the result image, the positions of vehicles are overlay on the SAR scene in range-azimuth projection.
- The velocity and moving direction of the vehicle estimated by the algorithm is indicated by arrows with different color.
- It is important to note that in this paper, validation is done on:
  - ✓ the detection the presence of the vehicles
  - ✗ Position accuracy
  - ✗ Velocity accuracy
- However, as the scene is a line of dense truck traffic, the velocity of vehicles could be assumed to be similar

[Hinz et al., 2008]



Result overlaid on range compressed DPCA image



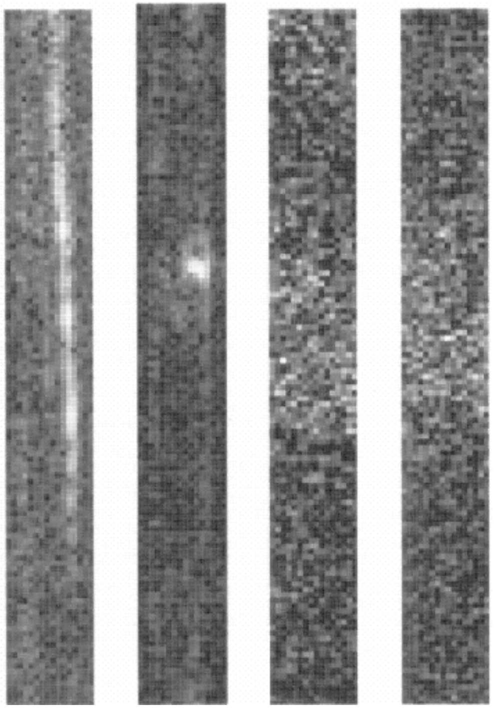
Result overlaid on SAR image

Target #	Position Error [m]	Estimated Velocity [km/h]	Estimated Velocity Error [km/h]
1	17.9	8.6	-1.5
2	9.9	84.2	3.5
3	17.3	14.2	-1.8
4	16.5	42.7	-1.3

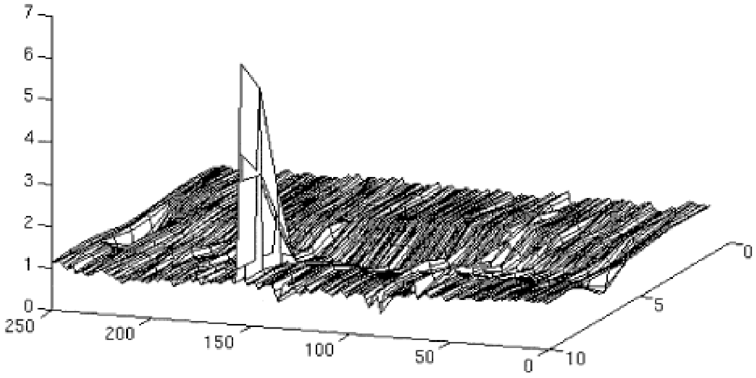
[Baumgartner & Krieger, 2010]

5.2 Method2: Displaced phase center antenna Result (2)

- In the result image, the positions of vehicles are overlay on the compressed DPCA scene& SAR scene in range-azimuth projection.
- The velocity and moving direction of the vehicle estimated by the algorithm is indicated by arrows with different color.
- The authors did not account for the huge velocity difference between vehicles on the same highway.



(a) (b) (c) (d)



Detection result

Numerical detection performance is not mentioned in this paper

Focusing Image

(a) Image patch including smeared image of moving target.

(b) Focused image of chip (a).

(c) Image patch of clutter background only.

(d) Focused image of chip (c)

[Fienup, 2001]

5.3 Method3: Focusing Result (2)

- The detection result shows only one detection result (the schoolbus)
- Other false alarms are removed

- Performance of detecting vehicle position
  - Not satisfactory for small vehicles
  - Major reason:
    - limited spatial range resolution of civilian **spaceborne** SAR data (1m-3m)

Advantages	Drawbacks
• Low computational load • Fast • Suitable for real-time traffic monitoring applications	• Performance of detecting small cars are bad • Possibility of mixture with background phase • Only sensitive to motion in range direction

[Hinz et al., 2008]

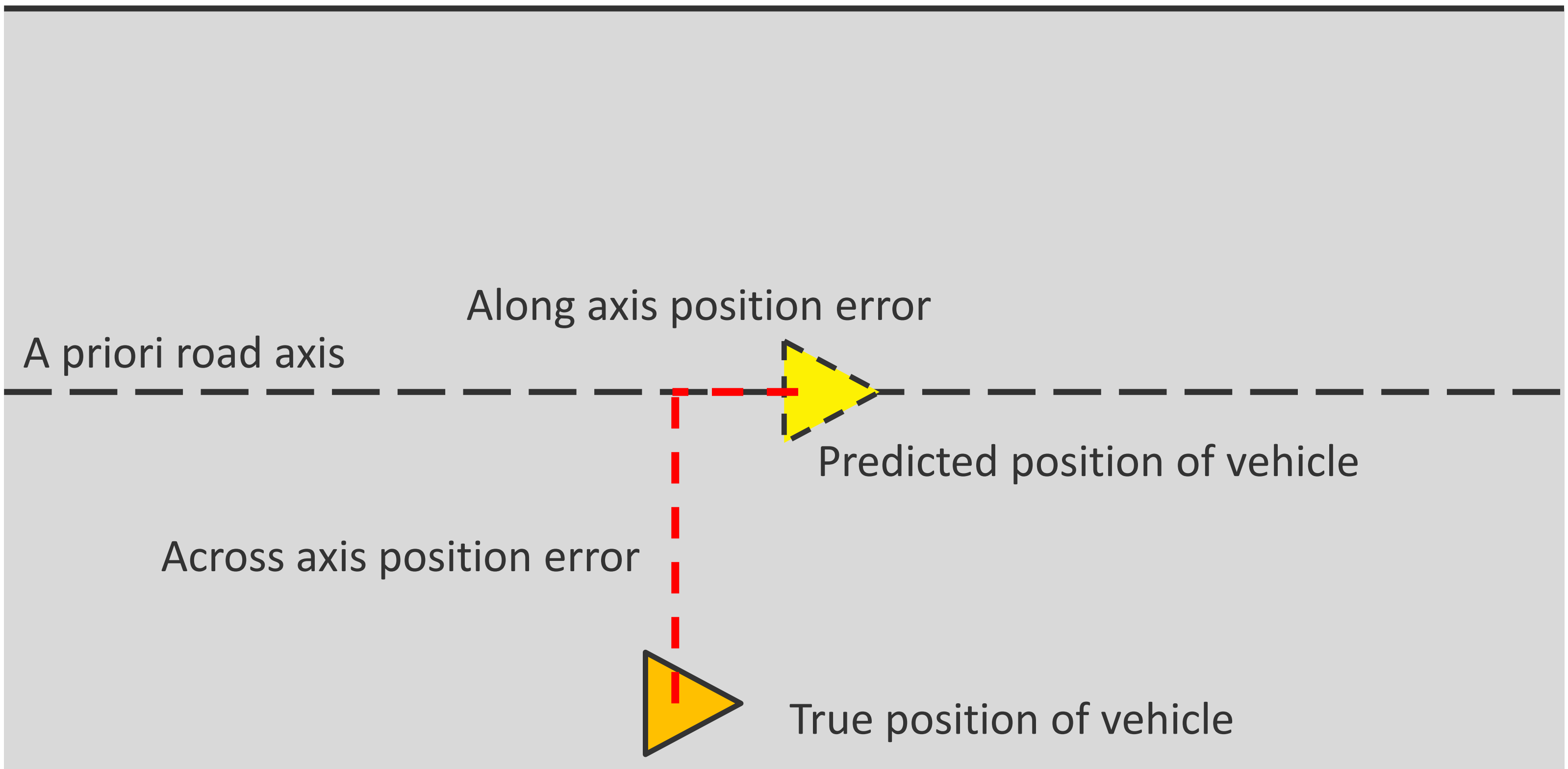
6.2 Method2: Displaced phase center antenna Discussion (1)

- Performance of detecting vehicle position
  - Not satisfactory
  - The position error is significant larger than vehicle length
  - Major reason:
    - Wide runway (30m)
    - The middle of the runway was chosen as road axis for the coordinate transformation
    - In reality, some vehicles move at the edge of the road
- Performance of detecting velocity
  - Satisfactory

Advantages	Drawbacks
• Low computational load • Fast • Suitable for real-time traffic monitoring applications	• Road Width is not taken into account • Not suitable for wide road • Only sensitive to motion in range direction

[Baumgartner & Krieger, 2010]

- Illustration of effect of road width to position accuracy
- The road width leads to an extra across axis position error that could not account by the algorithm



6.3 Method3: Focusing Discussion (1)

- Among 4 features:
  - Sharpness ratio allowed us to distinguish all the cases
  - Sharpness ratio is several times faster to compute than the degree of image correlation
- Investigation of the combination of more than one feature using a likelihood ratio test
  - Did improve detection performance
  - Expensive in terms of computations
  - Required having a good estimate of the statistics of the joint probability functions
- Ability to eliminate some of the false alarm
  - Vibrating Target
  - Wind-blown trees
    - likely to sense **the motion of a single rigid body** within an image patch
    - but **not multiple bodies with different motions** within the same patch.

[Fienup, 2001]

[Fienup, 2001]

- Potential sources of false alarms
  - Moving glints
    - Reflected from curb on a road or a guard-rail interacting with the ground
    - The gentle **convex /concave** curvature makes the point of reflection move **forward/backward**
    - Act very much like moving targets

Curb [Arseneault, 2008]

Guardrail [DeLorenzo, 2011]

Advantages	Drawbacks
• Low computational load • Fast • Sensitive to azimuth velocities • Use only one SAR image	• (Near) real-time application is doubtful • Performance depends on patch size

7 Own opinion (1)

- General opinion to the Vehicle detection using SAR field
  - Stationary Vehicle Detection
    - Papers proved that this is possible
    - Difficult to analysis in compare with sensor with nadir view
  - Moving Vehicle Detection
    - Active and Popular field
    - Ongoing development of more sophisticated and complicated technique, e.g. STAP
    - Unique advantages: **Phase information**, which is helpful to detect moving **object**, and its **velocity** and moving **direction**
    - However, **moving object size** is **implicit**, and require further process for retrieval
    - Doubt on whether there is a method that could cater both **azimuth** and **range** motion

7 Own opinion (2)

- Spaceborne vs Airborne SAR
  - Requirement ground sampling distance equal or smaller than typical vehicle size
  - E.g. TerraSAR-X
    - StripMap (GSD: 3.3m)
    - ScanSAR (GSD: 18.5m)
    - SpotLight (GSD: 1.7m)
  - More feasible using airborne sensor
- Opinion on validation scheme
  - Hard to compare performance and result
    - Lack of standard dataset
    - Lack of statically meaningful detection result
    - Only demonstration detection ability of the algorithm
  - Instead of correctness/completeness, more papers prefer showing performance in terms of signal-to-clutter-and-noise ratio (SCNR)
    - Hard to discuss possible false alarm
    - Less intuitive

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