Automatic Traffic Data Collection Using Surveillance Videos Cameras

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Presentation Outline

- Background
  - Introduction
  - Available approaches
- Methodology
  - VVDC1 : Video-based Vehicle Detection and Classification System, Version 1
  - VVDC2 : Video-based Vehicle Detection and Classification System, Version 2
  - Demo
- Conclusions

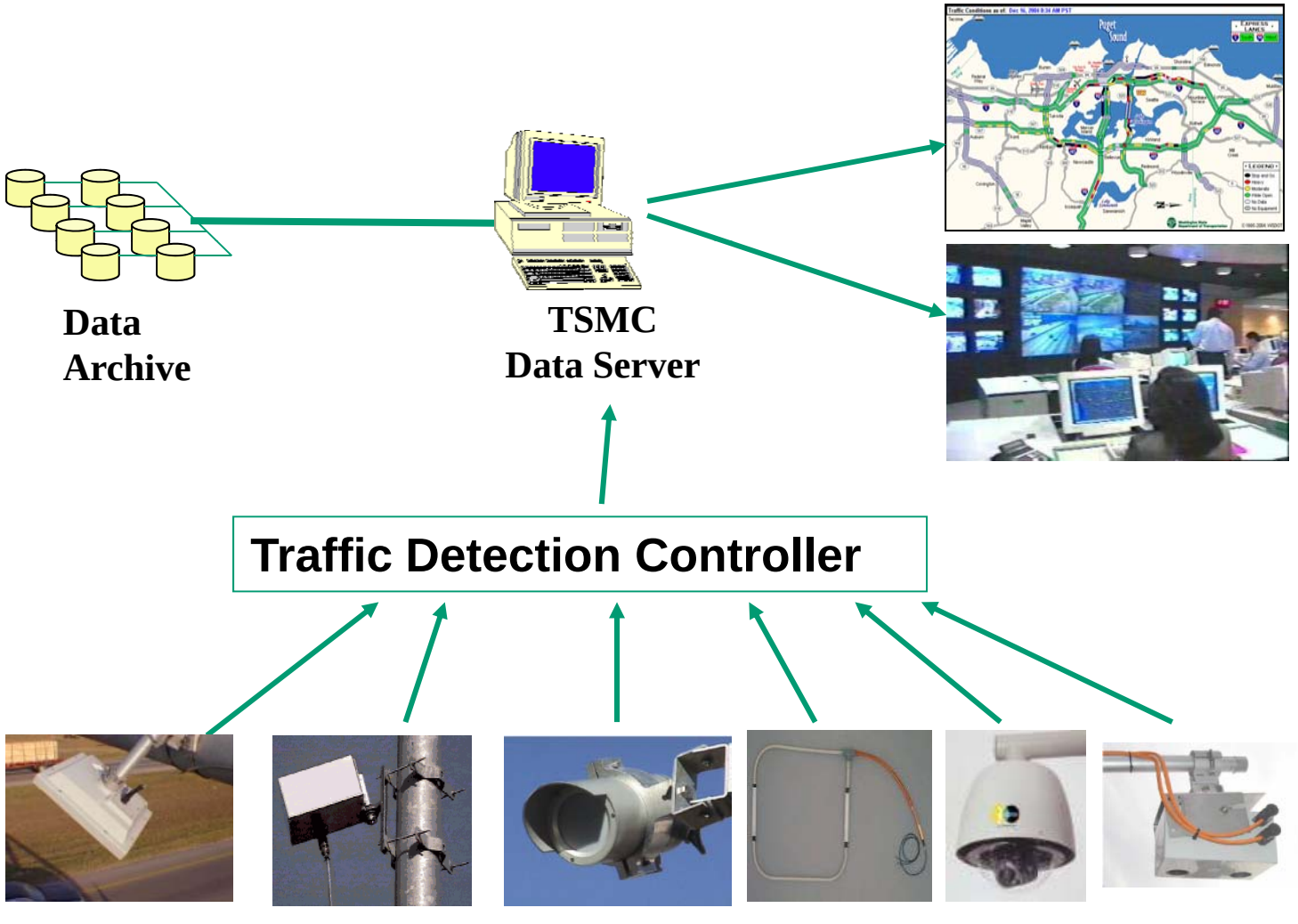
Introduction

- Manage Demand
  - Too many cars, not enough road
- Monitor Movements
  - Ensure a safe and mobile network
- Data Collection
  - Can't manage what you can't measure

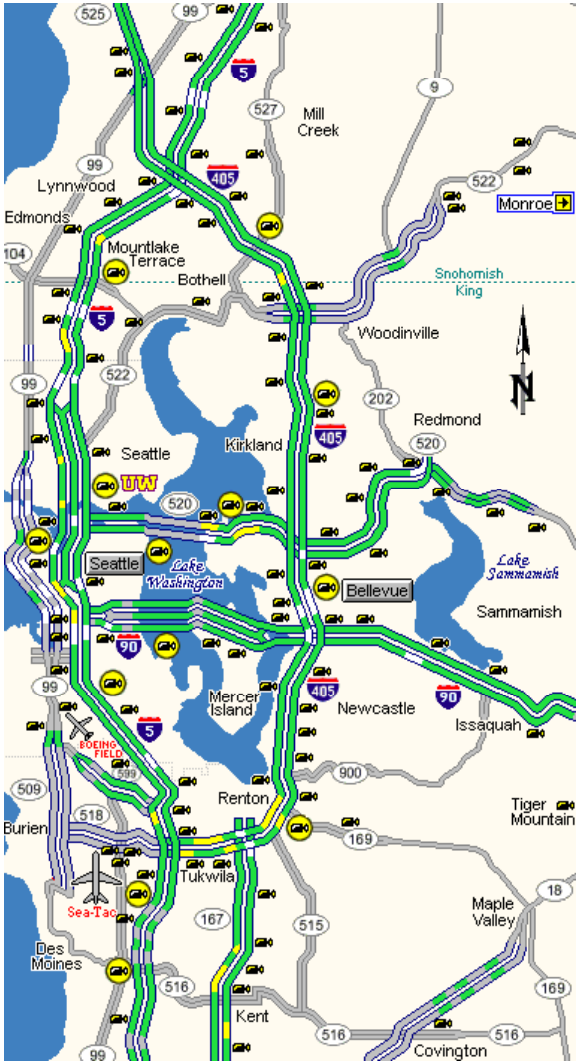
Data Collection Infrastructure

- Thousands of inductance loops
- Measure occupancy, volume
- Can classify cars and trucks
- Certain percentage malfunctioning
- Damage pavement
- Require lane closure for onsite maintenance

Data Collection Infrastructure



Surveillance Video Infrastructure



- Hundreds of available cameras
- Mainly used for traffic surveillance
- Low resolution
- Varying mounting angles
- Changing environments

Surveillance Video Cameras as Video Image Processors (VIP)

Surveillance video

Video Image Processor (VIP)

Source: http://www.metroactive.com/papers/metro/02.06.97/traffic-camera-9706.html
http://www.iteris.com/rs/products.html

Video Benefits

- Why Surveillance Video? Aren't loops and VIPs OK?
  - Cheap
    - Nothing proprietary, network already there
  - Easy
    - No pavement damage, lane closures
  - Verifiable
    - "See it in action"

Video Issues – Project Motivation

- Proprietary algorithms, equipment
  - High cost, limited deployment potential
- Extreme sensitivity to environmental impacts
  - Inconsistent error rates, depending on conditions
- Sensitivity to congestion
  - Occlusions between vehicles cause issues

DOT Benefits

- Collaboration with Washington State DOT (WSDOT)
  - Testbed evaluation
    - Future sensor studies
  - Live surveillance feeds through 2 fibers
- Benefits to WSDOT
  - Capability to collect volume data through surveillance cameras

Video Detection Basics

- Detection
  - Distinguish objects from background
- Classification
  - Determine which objects are of interest
- Tracking
  - Find these objects in the next frame

State of the Art

- Background Subtraction
- Motion Features
- Scan-line approaches

Background Subtraction

- Obtain background frame
  - Average, median, etc…
- Subtract background from current frame
  - Remaining pixels are thresholded to form binary image
  - Blobs are objects of interest
- Examine blobs for size/proportion to find vehicles
- Assume blobs do not change shape, size and color distributions and can be found nearby in the next frame

Background Subtraction

Background Subtraction Issues

- Blobs merge when objects get near or occlude one another
- Camera movement is interpreted as object movement
- Non-static noise is a source of error
  - Lighting, trees, shadows

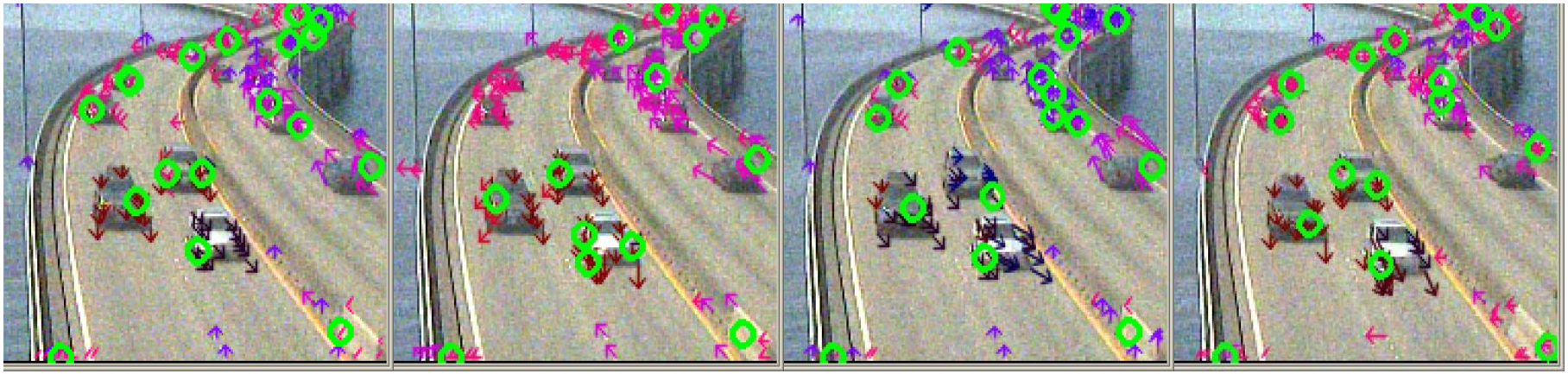
Motion Features

- Find unique points in an image
  - Gradient is high in both directions
- Assume small displacements
  - Assume the closest unique point in the next frame is the same point
- Cluster features to form objects

Motion Features

Motion Features Issues

- Clustering is difficult



- Several clusters may form per vehicle
- Clusters form on shadows, glare, etc…
- Speeds may be too similar

Scan-line Approaches

- Scan-lines simplify the scene significantly
  - Examines changes along a single, user-defined line
  - Background subtraction, 1D data analysis
  - Good example of relaying certain challenges to the user

Scan-line Issues

- 1D data does not take full advantage of available information
- Similar drawbacks to background subtraction
  - Sensitivity to environmental effects

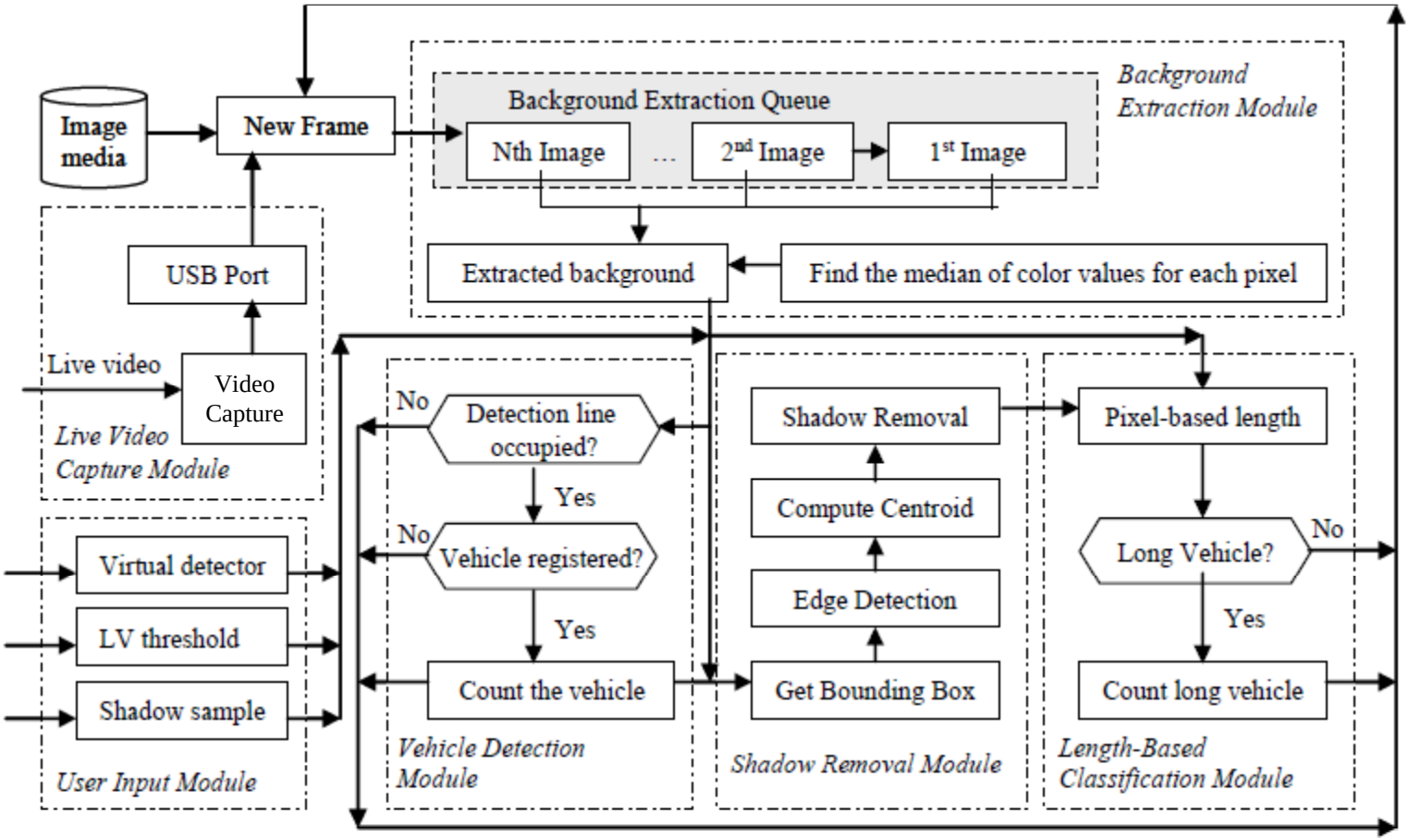
VVDC : Video-based Vehicle Detection and Classification System

- Development Guidelines
- Overview
- Shadow mitigation
- Vehicle Classification
- System Setup
- Demo
- Results

VVDC Version 1 Development

- Focus on:
  - Collect data such as volume, occupancy, headway, speed
  - Analyze traffic composition (LVs and SVs)
  - Shadow removal
- Ignore:
  - Occlusions
  - Night-time detection
  - Inclement weather
  - Camera vibration
  - Tracking

VVDC1 Overview



Shadow Mitigation

- Region growth shadow removal

- Explore low-texture areas between gradients

Shadow Mitigation

- Region growth shadow removal failure

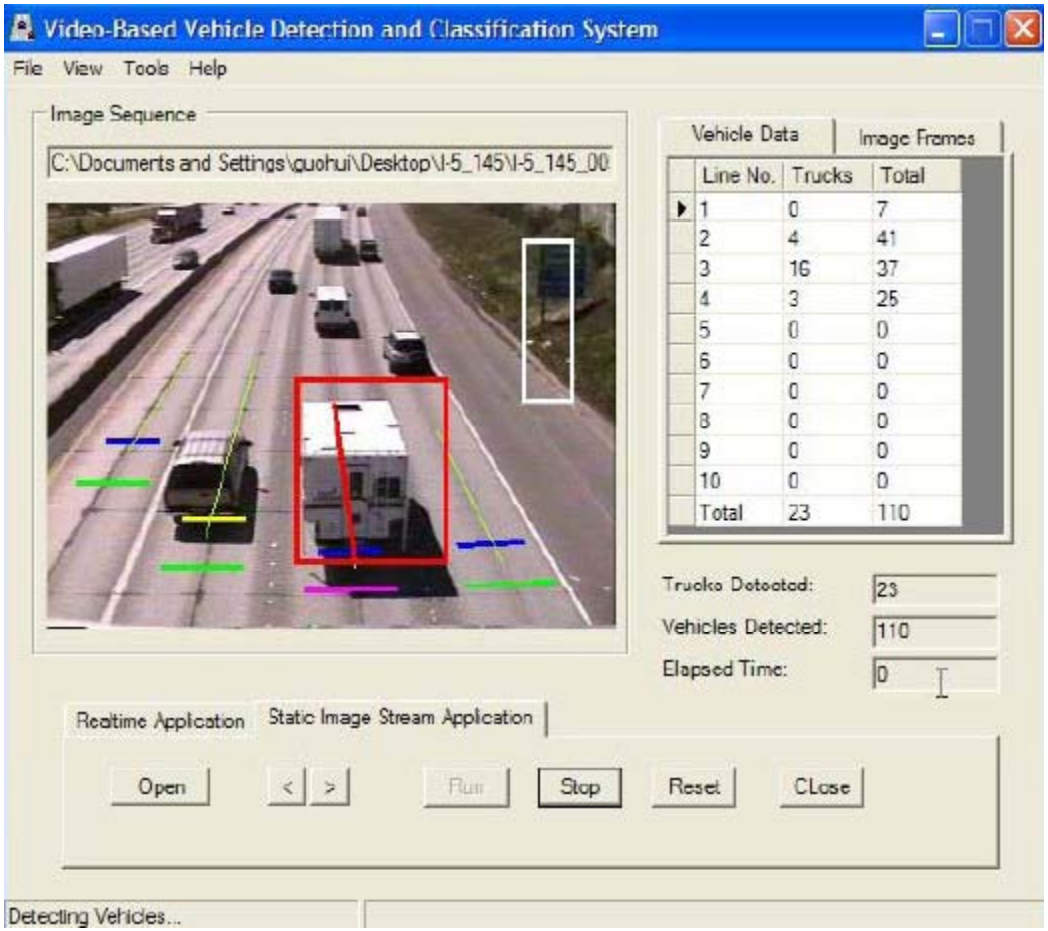
- Pavement texture prevents full removal

Shadow Mitigation

- Canny-edge based shadow mitigation

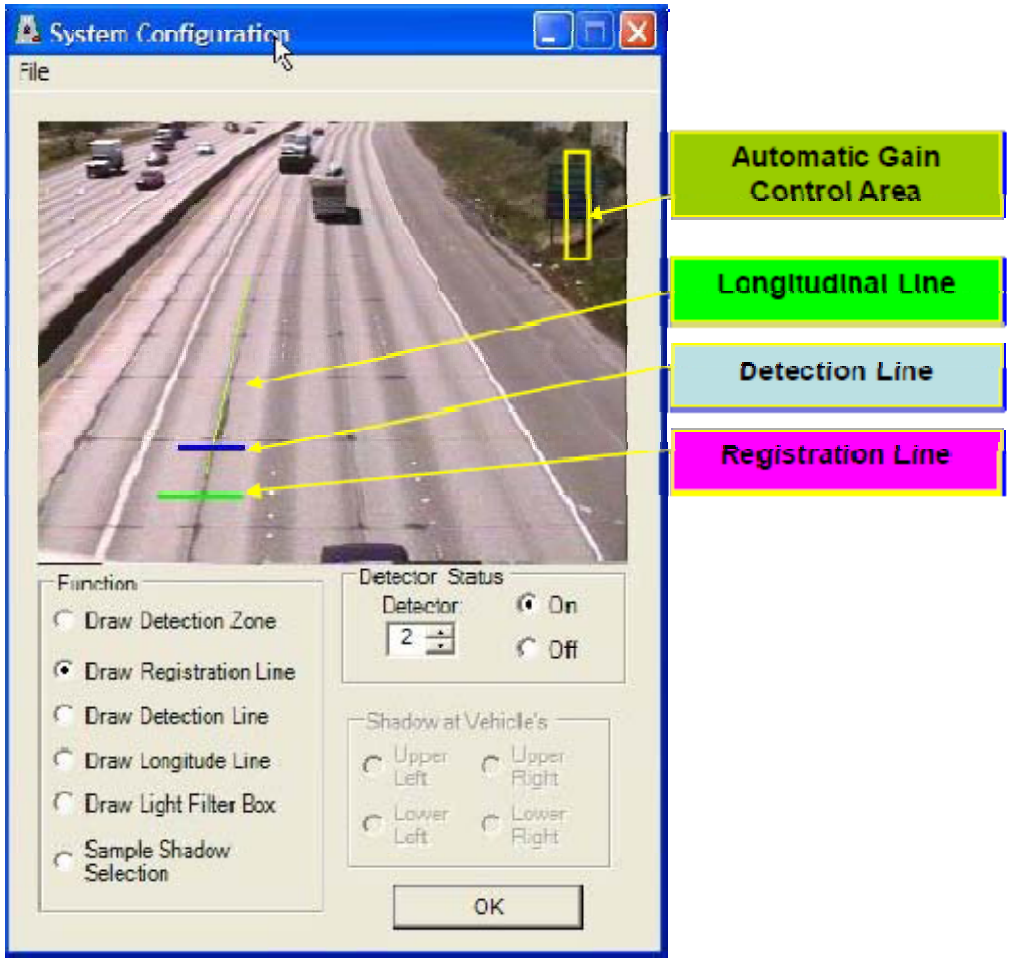
Vehicle Classification

- Length-based
- User-defined
- 2-bin system

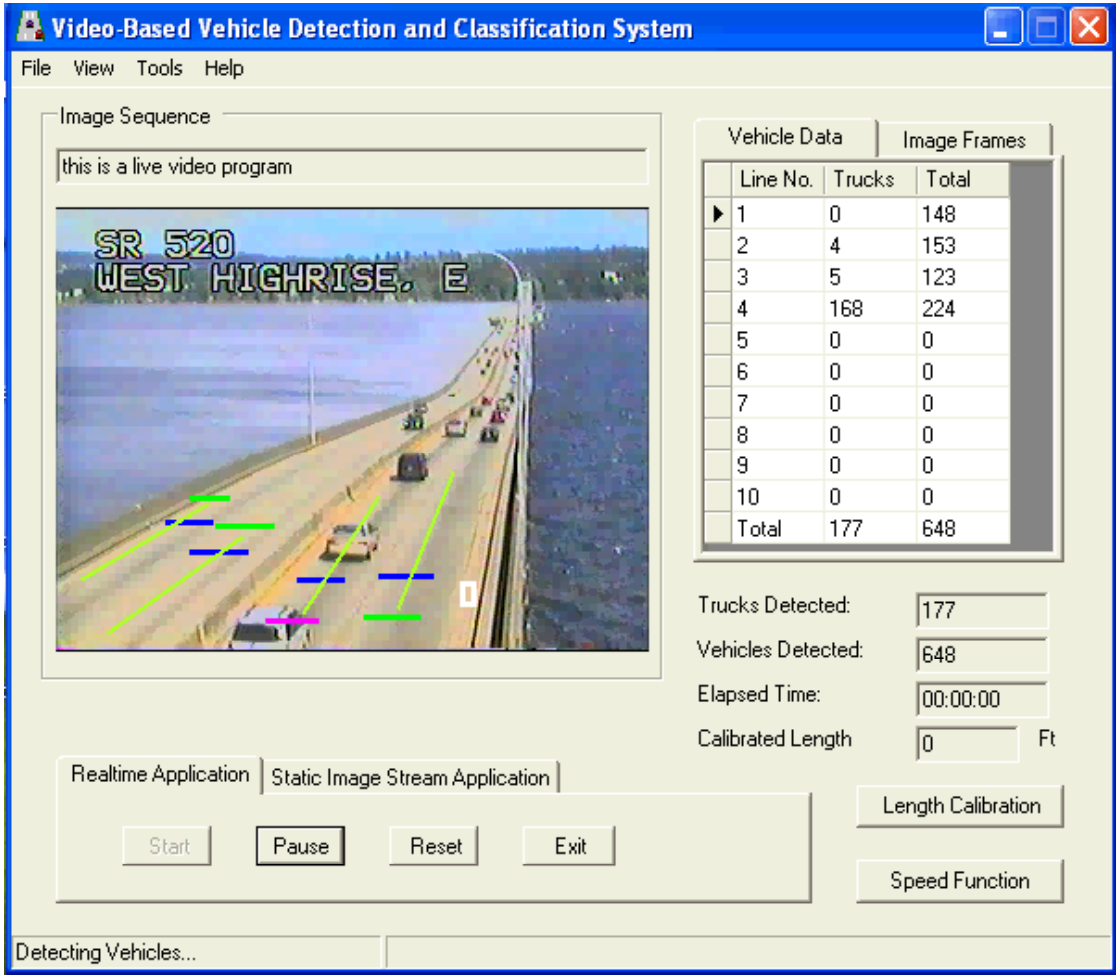


System Setup

- User defines detection lines
- User defines classification lines
- Selects gain area
  - For background adjustments



VVDC1 Demo


Video-Based Vehicle Detection and Classification System
File View Tools Help
Image Sequence
this is a live video program
SR 520
WEST HIGHRISE, E
Vehicle Data
Image Frames
Line No. Trucks Total
1 0 148
2 4 153
3 5 123
4 168 224
5 0 0
6 0 0
7 0 0
8 0 0
9 0 0
10 0 0
Total 177 648
Trucks Detected: 177
Vehicles Detected: 648
Elapsed Time: 00:00:00
Calibrated Length 0 Ft
Realtime Application
Static Image Stream Application
Start
Pause
Reset
Exit
Length Calibration
Speed Function
Detecting Vehicles...

VVDC1 Testing

Test Site 1

Test Site 2

Test Site 3

VVDC1 System Test Sites

I-5 at NE 145th Street

Off-Line Test Results at the I-5 Test Location

Time Period 12 minutes		Location: Southbound I-5 near the over bridge									
		Lane 4		Lane 3		Lane 2		Lane 1		Subtotal	
Ground-truth	Trucks	5		4		37		12		58	
	Total vehicles	149		409		335		244		1136	
System Detected	Trucks	5		4		35		12		56	
	Total vehicles	154		412		335		245		1146	
Comparison Error	Trucks	0[a]	0[b]	0	0	2	5.41%	2[c]	16.67 %	4	6.89%
	Total vehicles	5	3.36%	3	0.73 %	0	0	3[d]	0.82%	10	0.88%

[a] absolute error, [b] relative percentage error, [c] one was missed and one was over-counted. [d] two cars missed and one truck over-counted.

I-5 at NE 145th Street

Error Cause Investigation for the I-5 Test Location

Lane	Error descriptions	Explanations
Lane 4	Five vehicles over-counted	Both Lane 3 and Lane 4 had false alarms. These false alarms were likely caused by the reflection of vehicle head lights from Northbound I-5 traffic.
Lane 3	Three vehicles over-counted	
Lane 2	Two trucks missed	The two false dismissals were because of that the colors of the two trucks were too similar to the background to have its length properly measured. Figure 5-5 shows one of the two trucks to illustrate the problem.
Lane 1	1. One truck missed 2. One truck over-counted 3. Two vehicle missed	1. The reason was the same for that of Lane 2. 2. A truck occupied both Lane 1 and Lane 2 was counted by both the Lane 1 and Lane 2 detectors. A snapshot of this truck is shown in Figure 5-6. 3. Two lane-changing vehicles did not trigger any of the two virtual loops. See the black car in the lower right corner of Figure 5-7 for example.

SR-99 at NE 41st Street

Off-Line Test Results at the SR-99 Test Location

Time Period 12 minutes		Location: Northbound SR-99 near the							
		Lane 3		Lane 2		Lane 1		Subtotal	
Ground-truth	Trucks	8		7		15		30	
	Total vehicles	270		244		192		706	
System Detected	Trucks	7		6		15		28	
	Total vehicles	270[c]		245		194		709	
Comparison Error	Trucks	1[a]	12.5%[b]	1	14.28%	0	0	2	6.67%
	Total vehicles	2	0.74%	1	0.41%	2	1.04%	5	0.41%

[a] absolute error, [b] relative percentage error, [c] one vehicle missed and one over-counted.

I-5 at NE 92nd Street

Test Results for Test Site Three

Time Period 12 minutes		Location: Southbound I-5 near the 92nd Street Over Bridge									
		Lane 4		Lane 3		Lane 2		Lane 1		Subtotal	
Observation Results	Trucks	13		36		5		5		59	
	Total vehicles	388		378		380		170		1316	
System Results	Trucks	14		37		6		5		62	
	Total vehicles	397		387		389		173		1346	
Comparison Error Results	Trucks	1[a]	7.69%[b]	3[c]	8.33%	1	20%	0	0	5	8.47%
	Total vehicles	9	2.31%	9	2.38%	9	2.36%	3	1.76%	30	2.27%

[a] absolute error, [b] relative percentage error, [c] one truck missed and two trucks double counted.

I-5 at NE 145th Street

These vehicles generated errors. Why?

a) Adjacent lane overlap

b) Missed lane-changing vehicle

I-5 at NE 145th Street

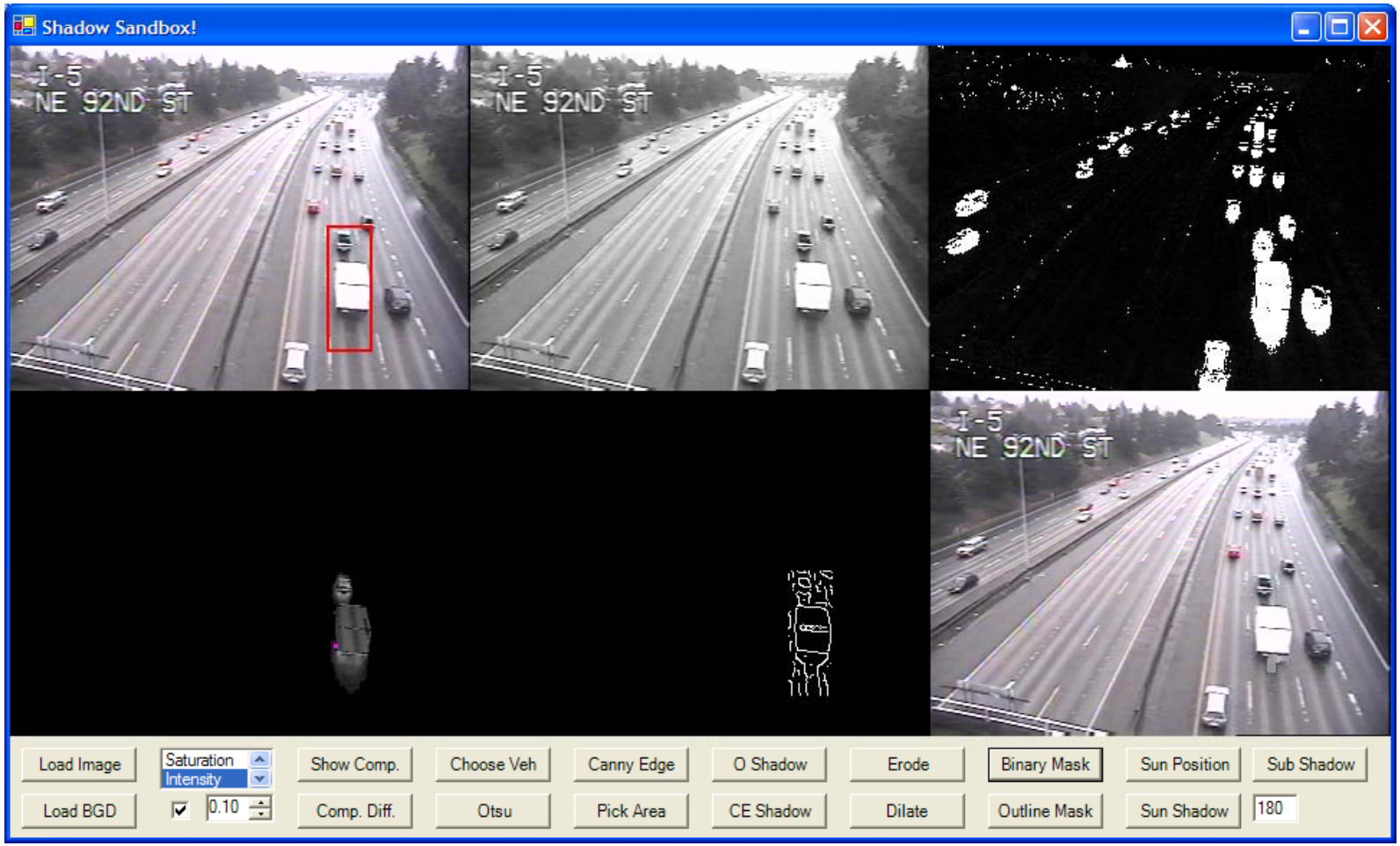
These vehicles generated errors. Why?

a) Fragmentation

b) Containers counted separately

I-5 at NE 145th Street

These vehicles generated errors. Why?



a) Occlusion error

VVDC1 Conclusions

- The VVDC1 system demonstrated that surveillance cameras can be used for traffic data collection
- Detection error rarely exceeds 3% and is suitable for planning and analysis purposes
- Length-based vehicle classification is acceptable, error rate below 10% at the test sites
- The VVDC program provides a good base from which to expand

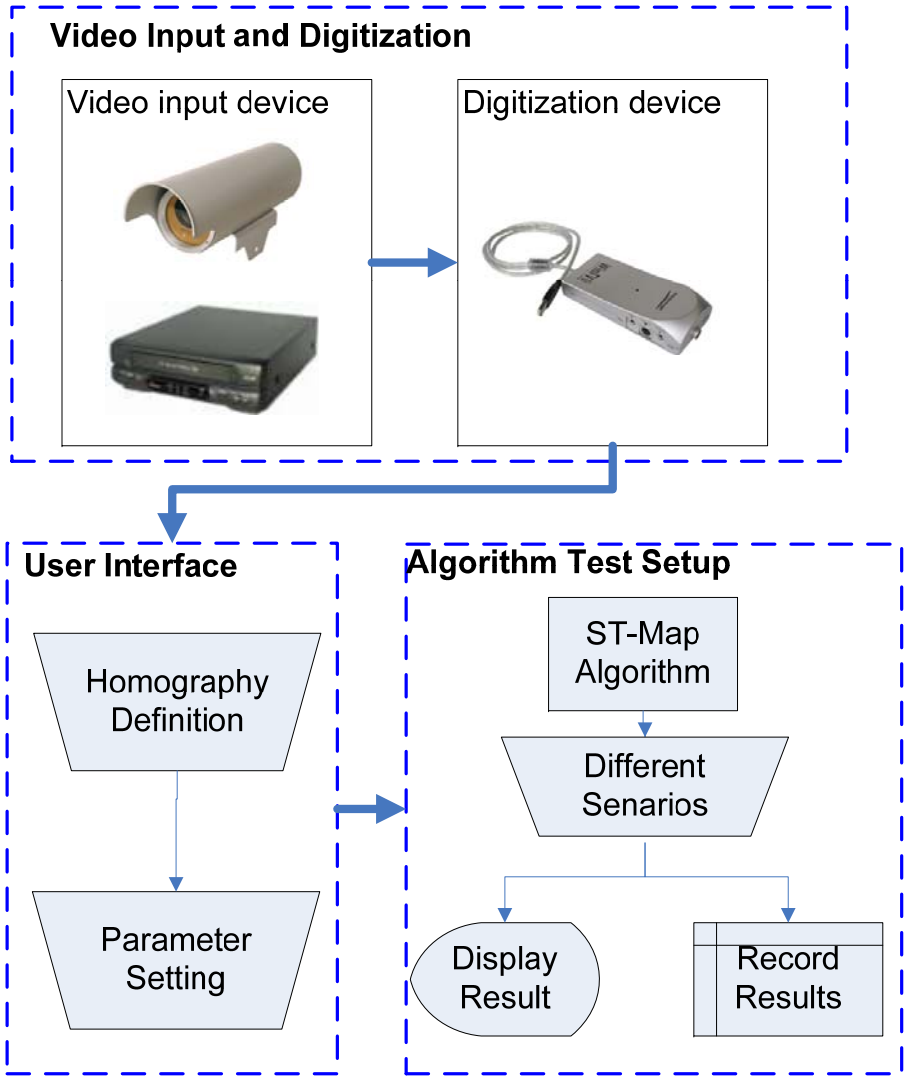
VVDC Version 2

- Development Guidelines
- Overview
- Spatiotemporal Maps
- Perspective Transformation
- Hough Transform
- Graph Based Clustering

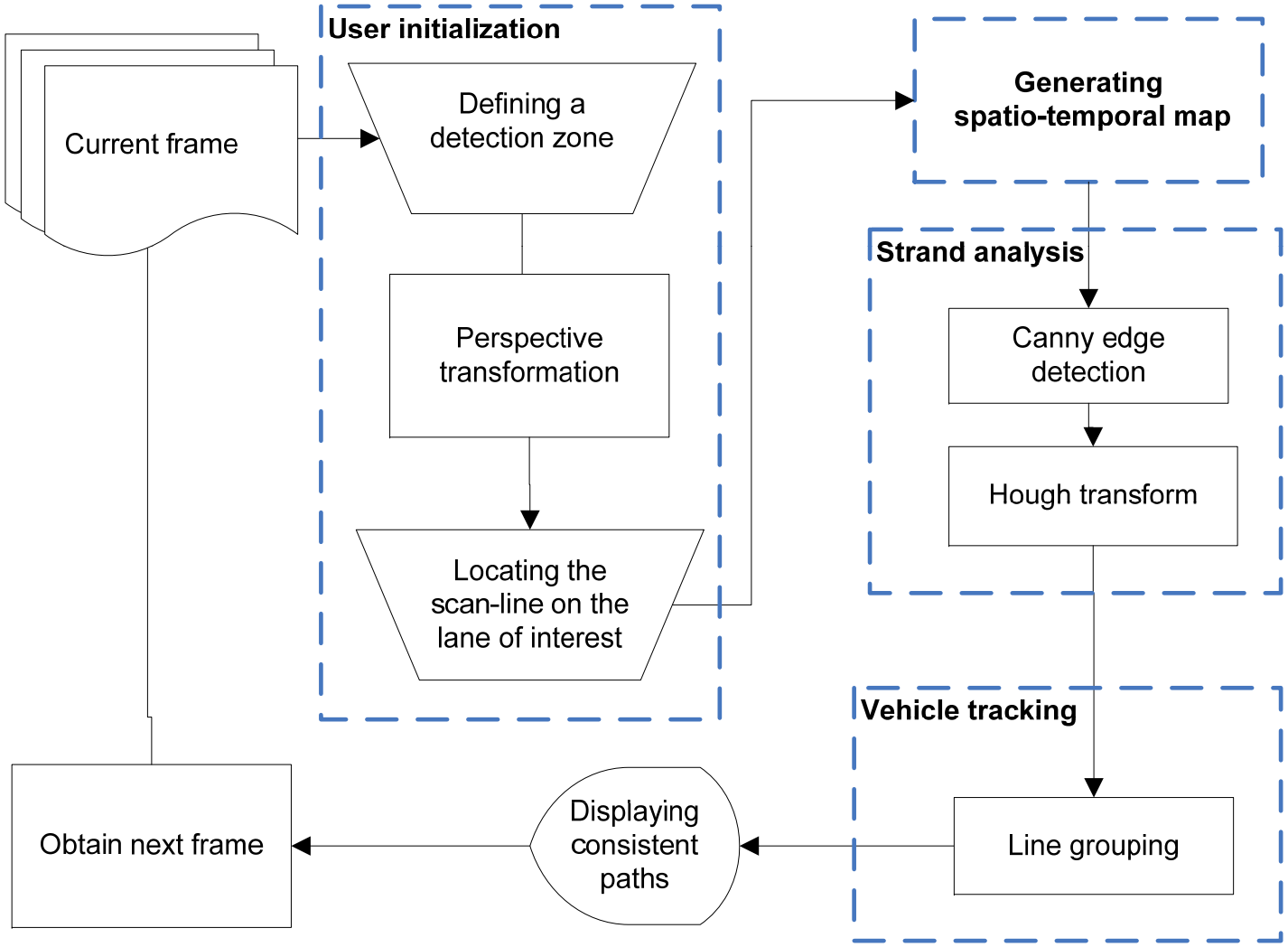
VVDC Version 2 Development

- Focus on:
  - Counts
  - Occlusions
  - Night-time detection
  - Inclement weather
  - Camera vibration
  - Tracking
- Ignore:
  - Classification
  - Volume/Occupancy
  - Headway
  - Speed

VVDC2 Overview

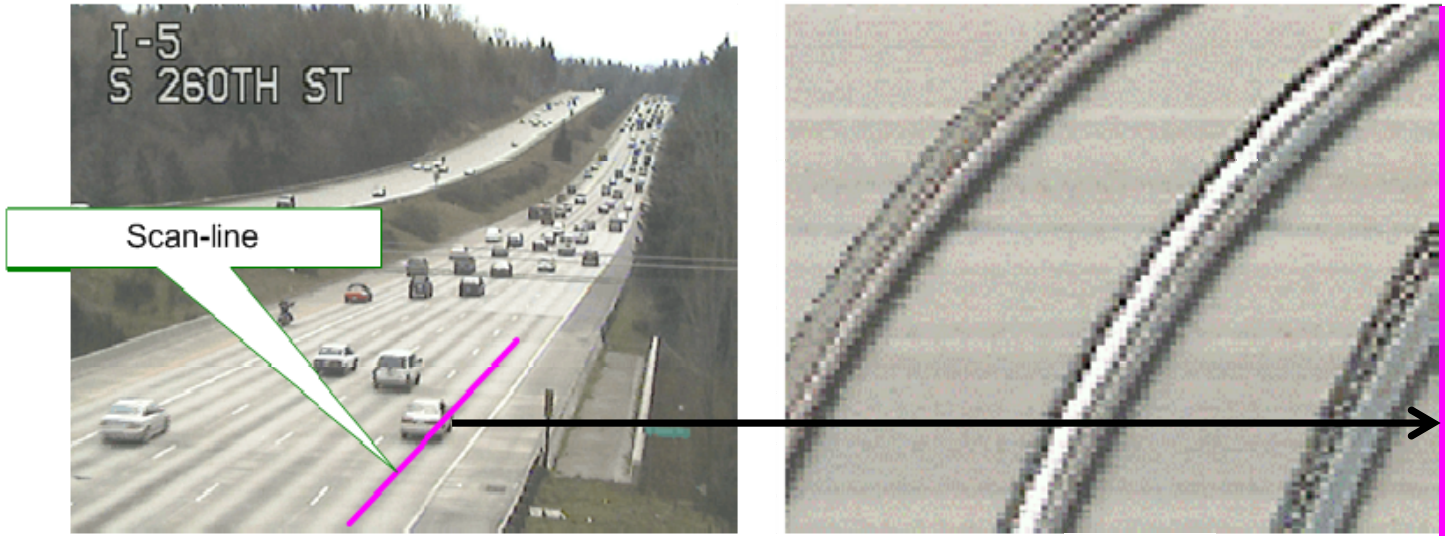


VVDC2 Overview



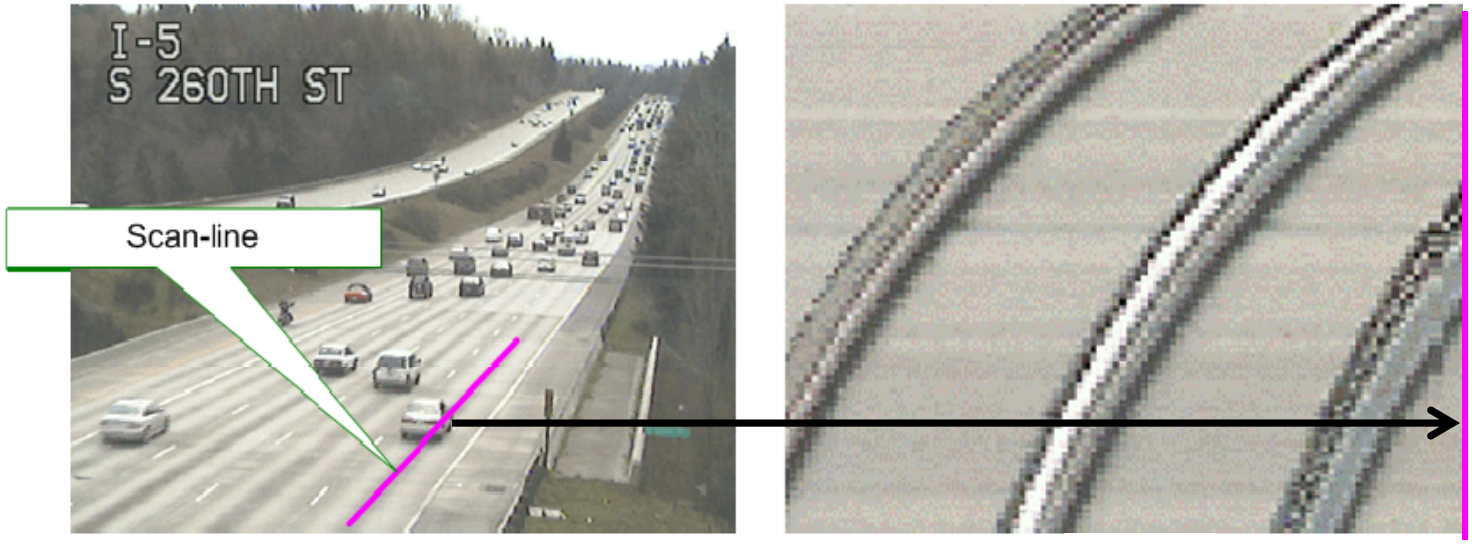
Spatiotemporal Maps

- Capture pixels along scan-line



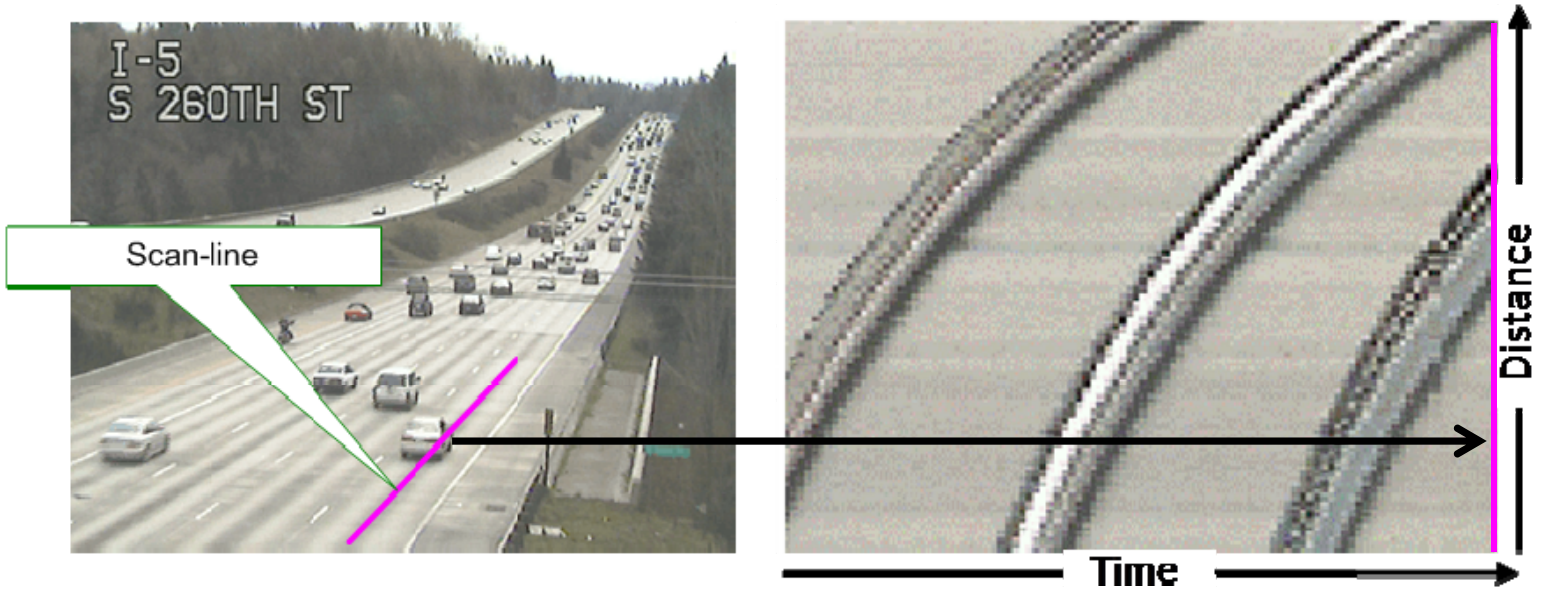
Spatiotemporal Maps

- Append to previous captured scan-line pixels



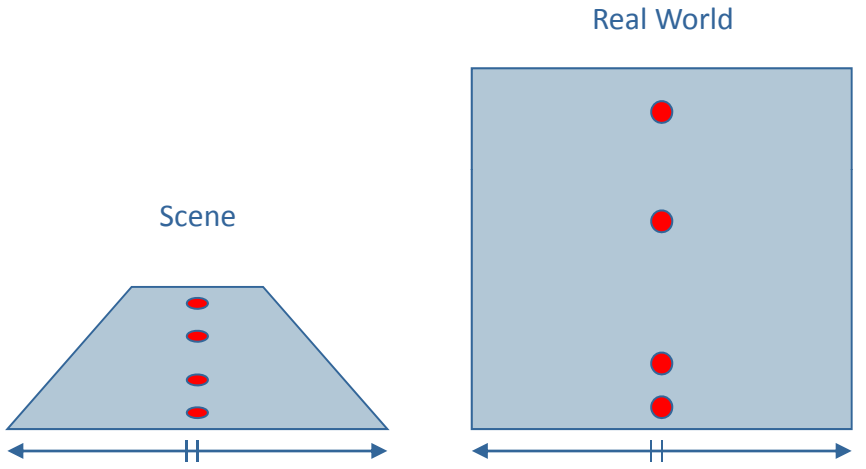
Spatiotemporal Maps

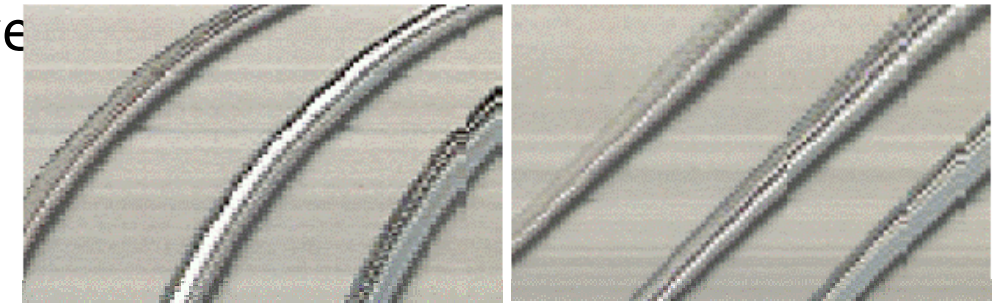
- Vertical scan-lines accumulated every frame

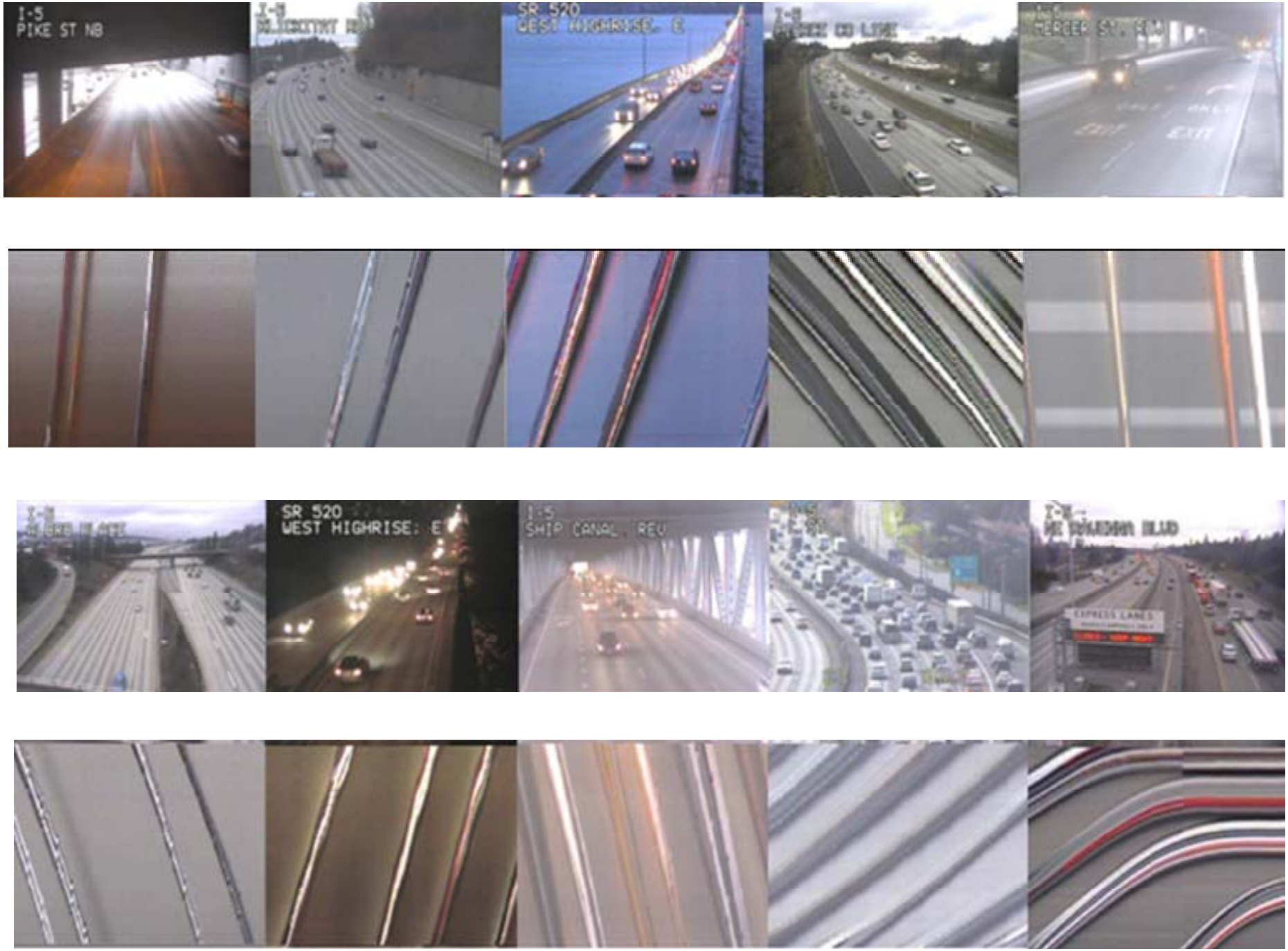


Perspective Transform

- Perspective distorts relative spatial relationships
- Only four user-defined points are necessary for transformation
- Transformation does not have to be exact





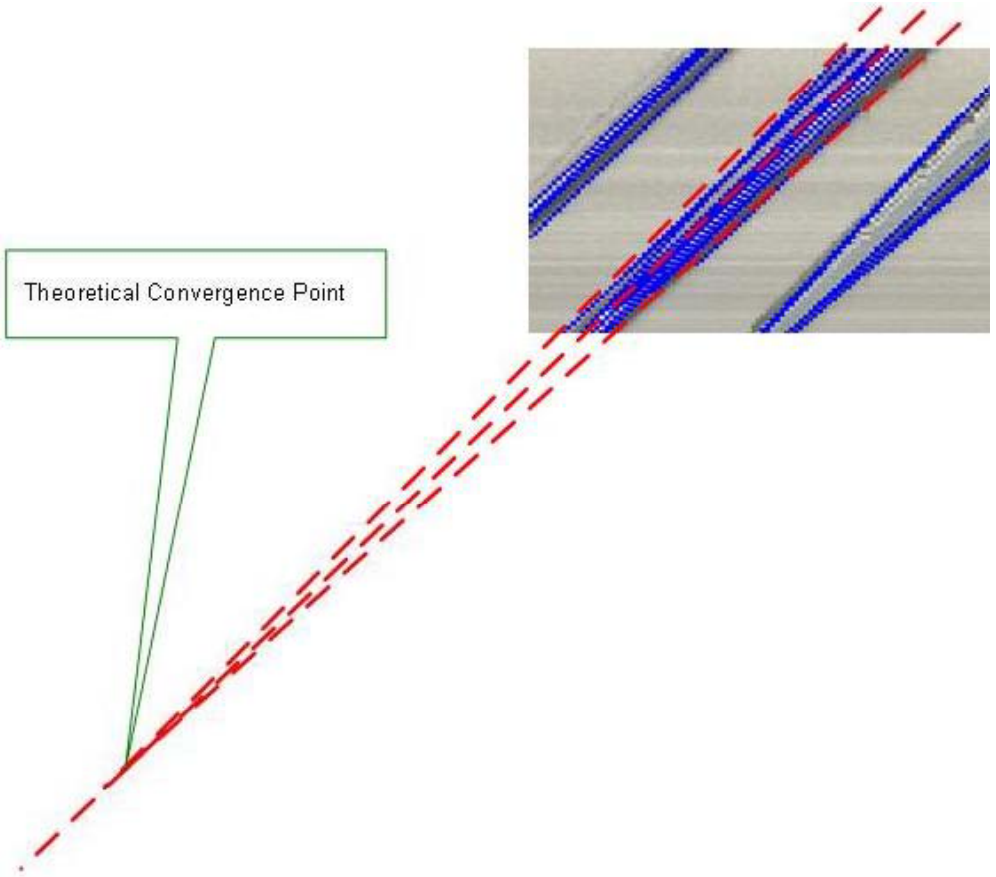

I-5
PIKE ST NB
SR 520
WEST HIGHRISE: E
I-5
SHIP CANAL, REV
SR 520
WEST HIGHRISE: E
I-5
SHIP CANAL, REV

Assumptions

- Constant speeds
  - Linear strands
- Gaps between following vehicles
  - Varying speeds
  - Camera mounting
- Lane changing vehicles require additional scan-lines

Hough Transform

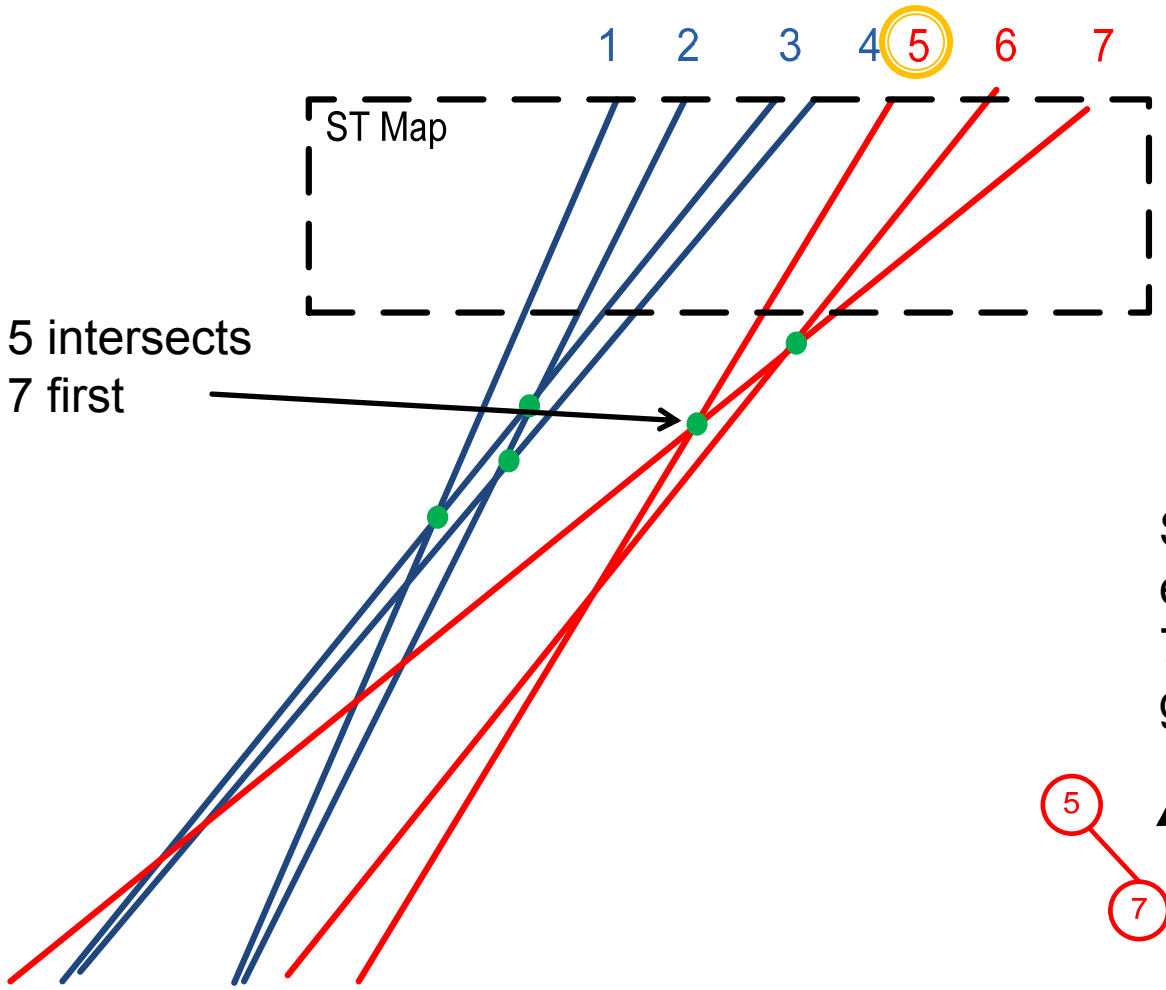
- Finds parameterized lines in images
- Lines indicate traces left by the vehicles
- Lines converge due to height distortion



Graph Based Clustering

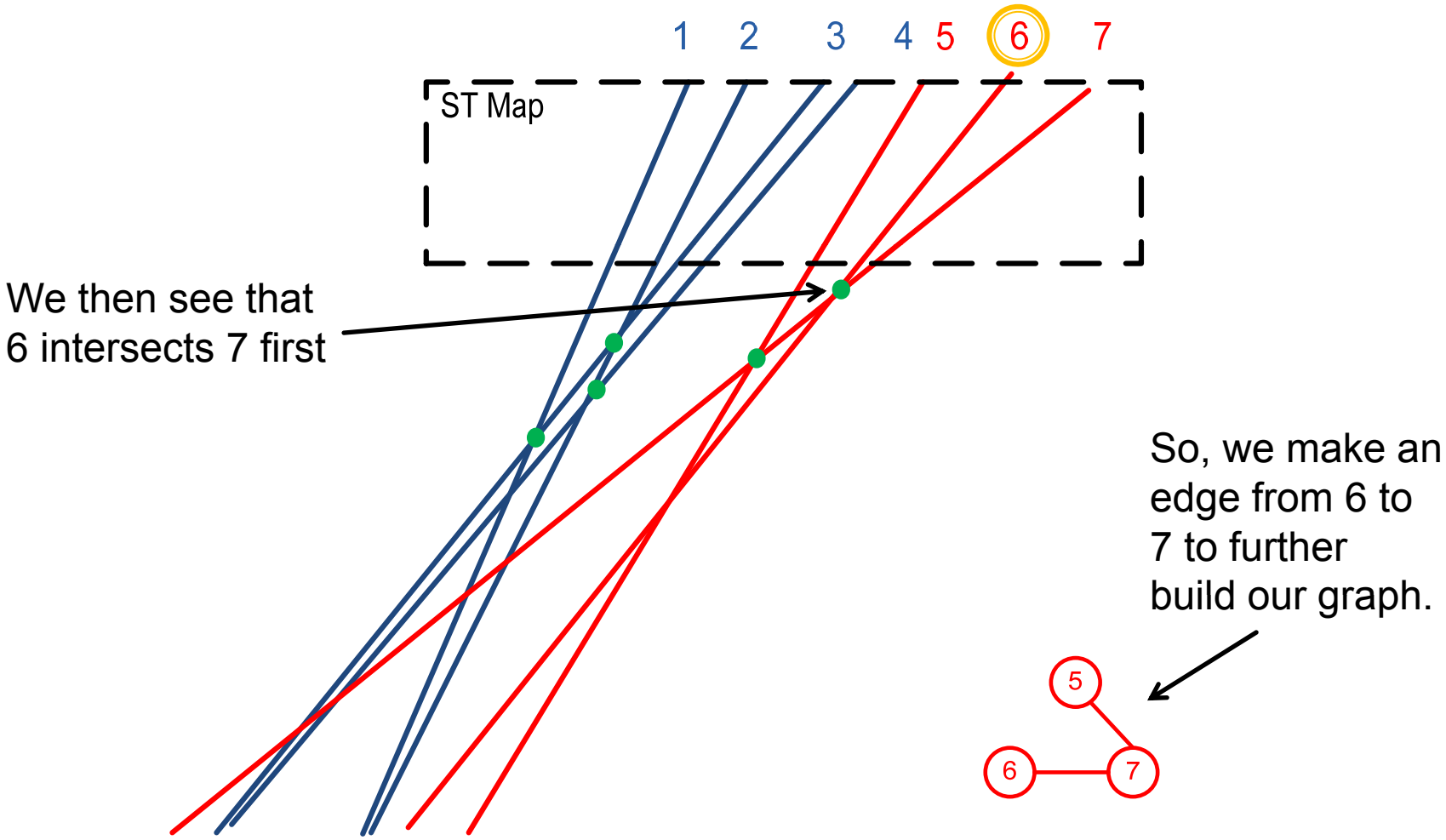
- Use the first intersection as metric
  - For each line, the first intersection is the first line that is encountered from the bottom of the ST-map
- Construct graph based on the first intersection relationship
- Search for connected components

Graph Building Example

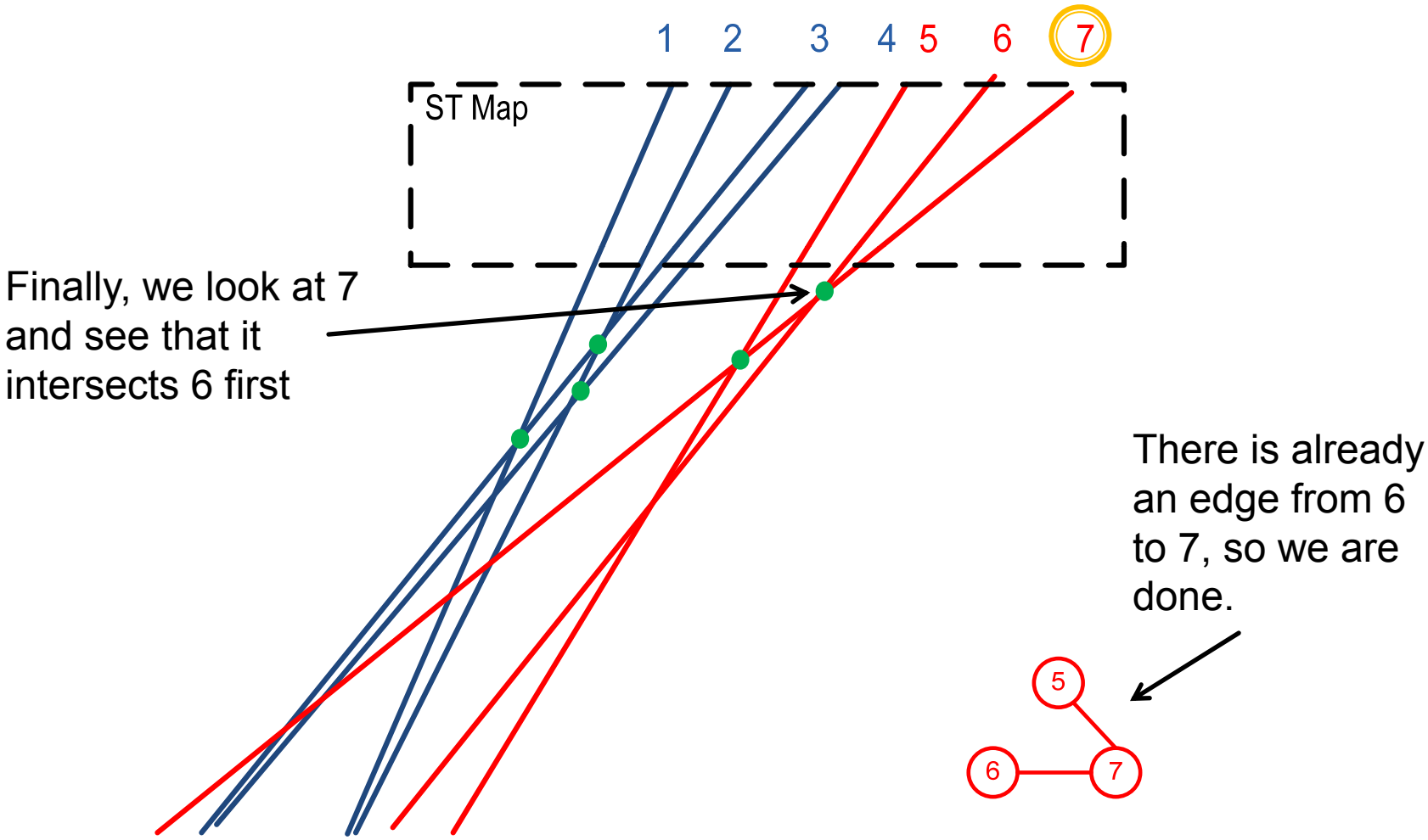


So, we make an edge from 5 to 7 to make a graph.

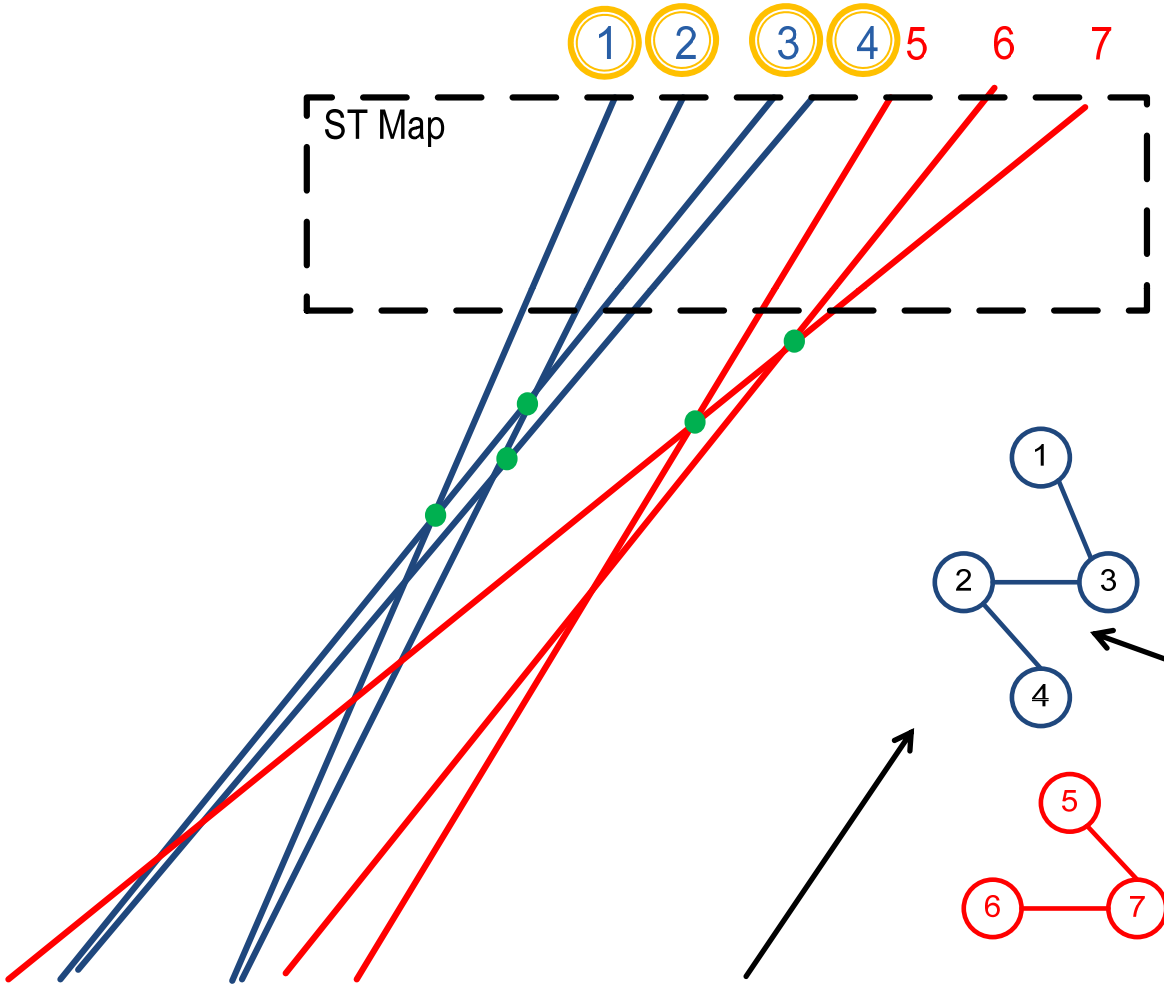
Graph Building Example



Graph Building Example



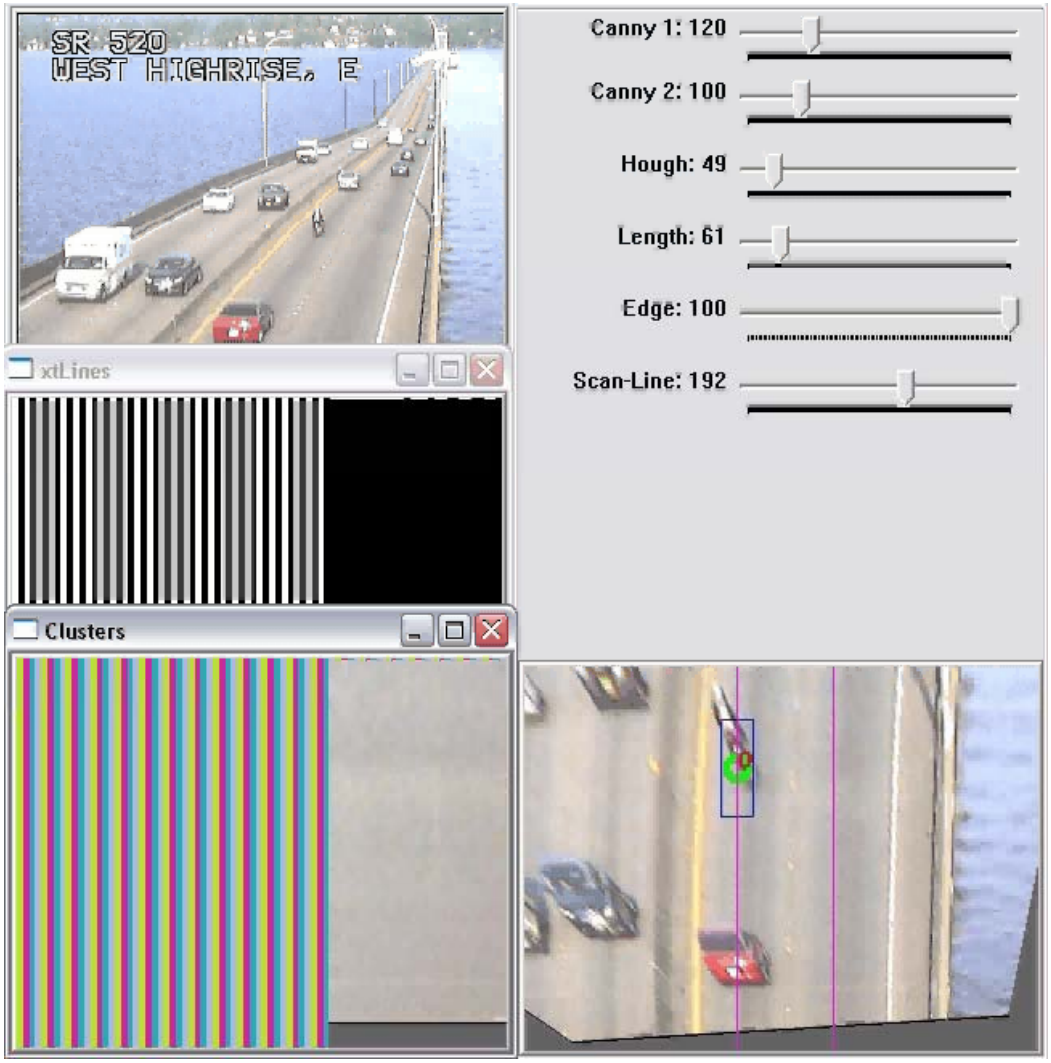
Graph Building Example



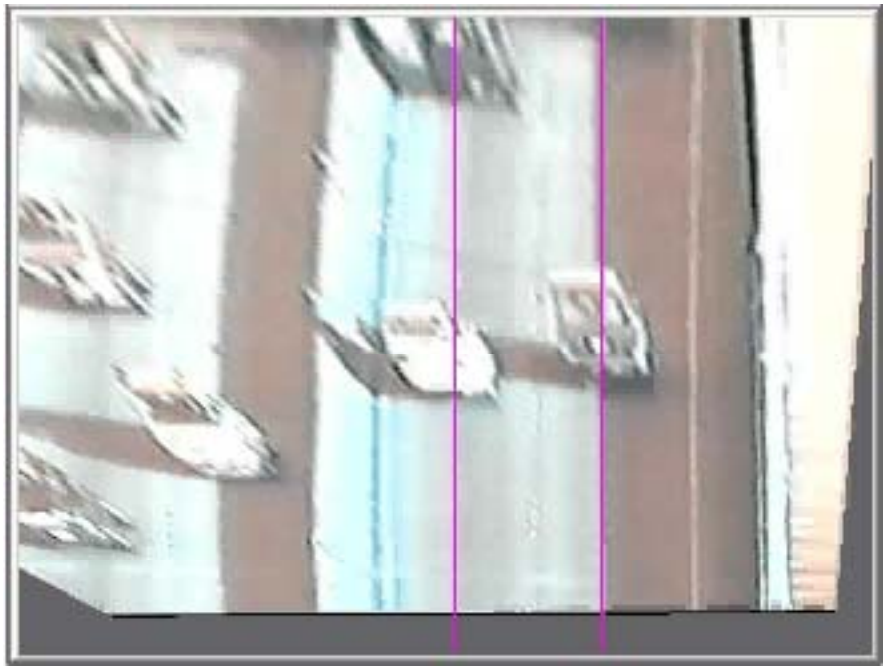
Repeating the same procedure for other lines in the ST map provides this graph.

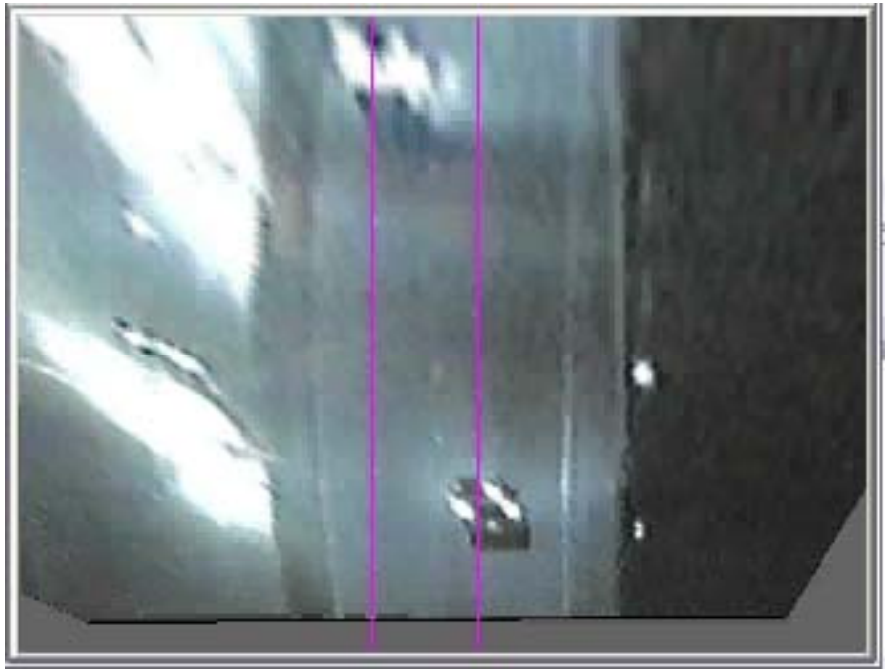
There are two connected components, so we have two vehicles. Their trajectories are the average slopes of all the Hough lines in the group.

VVDC2 Ideal Conditions



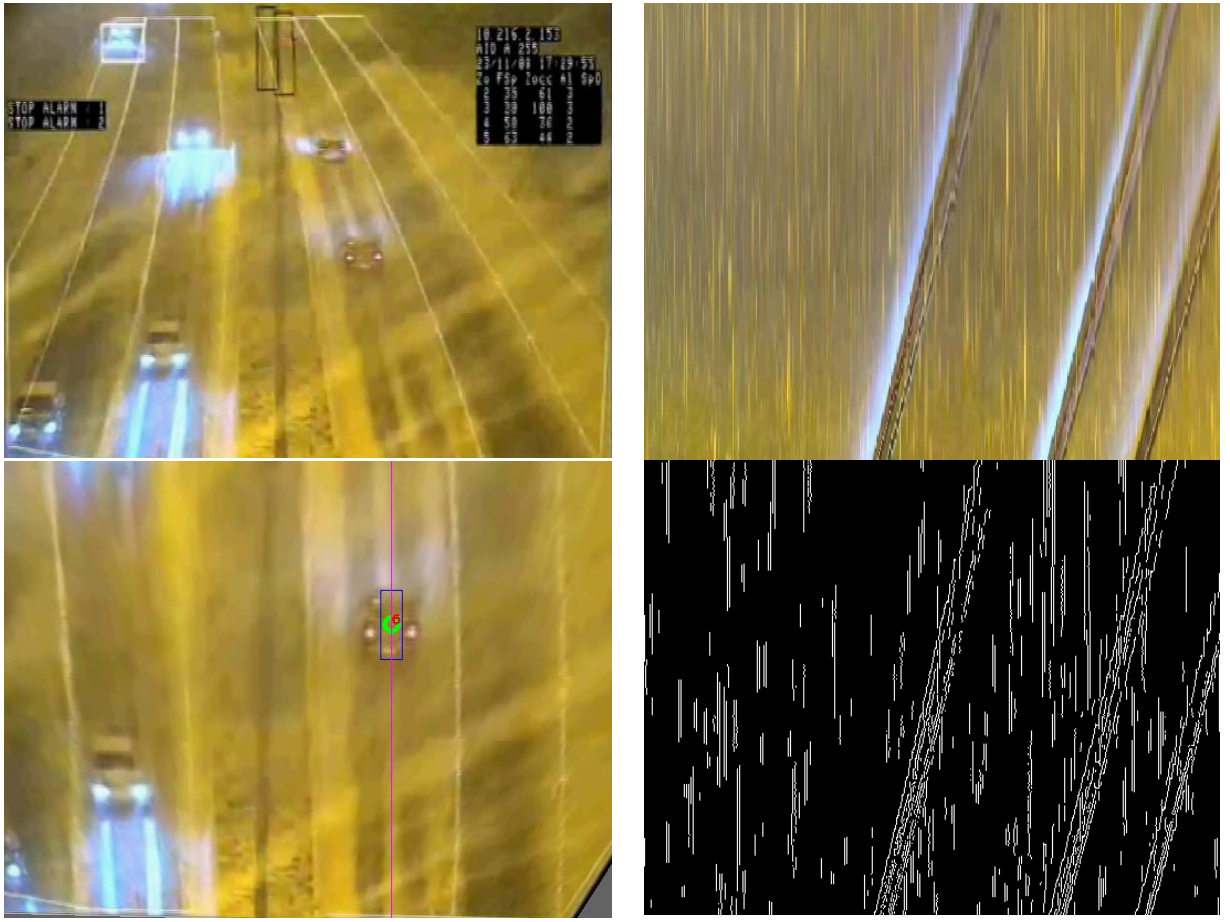
VVDC2 Adverse Conditions





More Adverse Conditions

- Snow + Incline
  - No difference due to incline
  - Noise
  - Blurs some edges
  - Snow like heavy rain



Original snow video courtesy of Trafficon Inc.

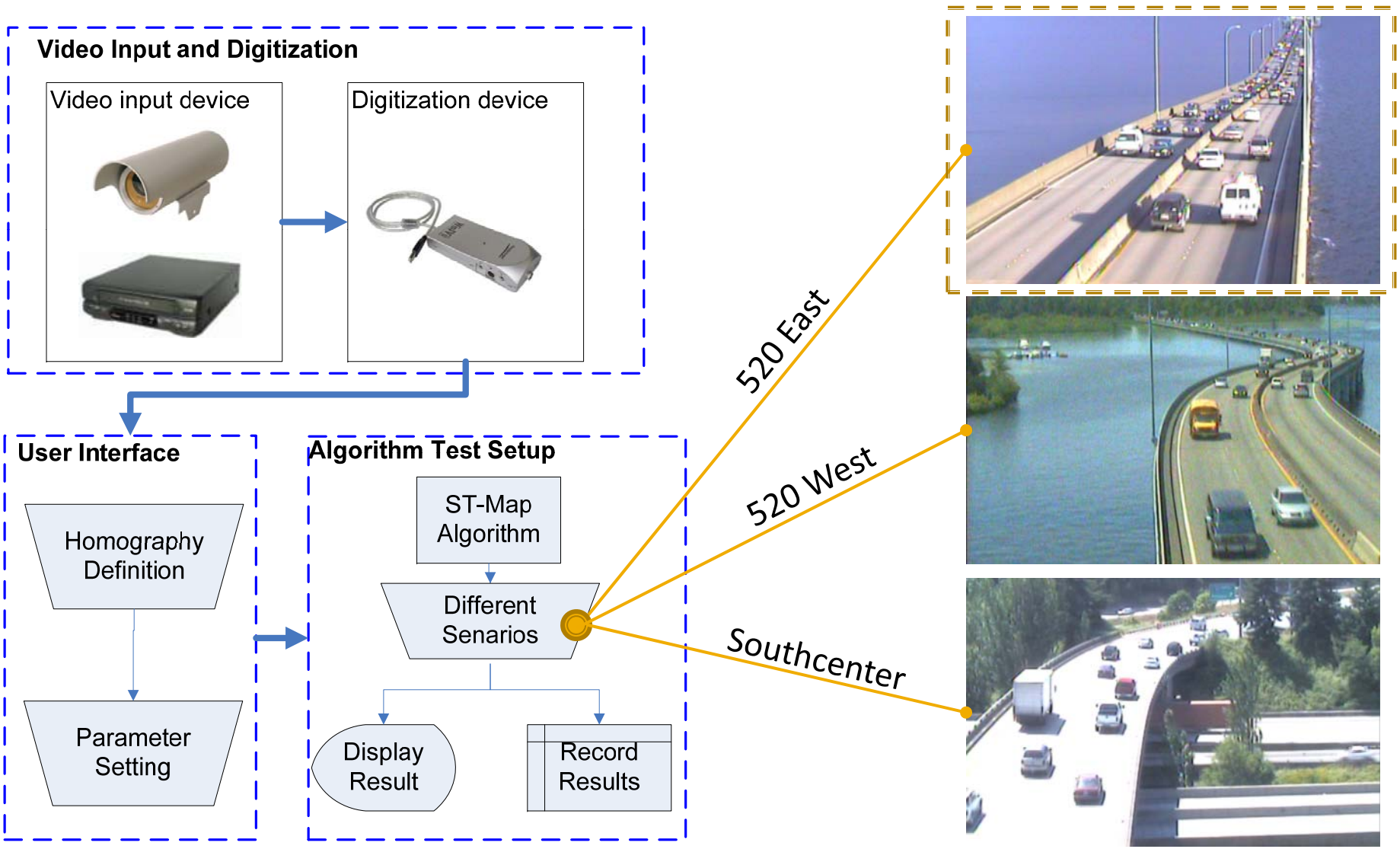
Effects of Adverse Conditions

- Weather Effects
  - Inconsistent noise trajectories
  - Blurring of certain edges
    - Dense fog or snow
    - Sensitivity must be adjusted if too blurred
- Camera effects
  - Small perturbations in vehicle trajectories
    - Usually not enough to change overall linearity

Experimental Results

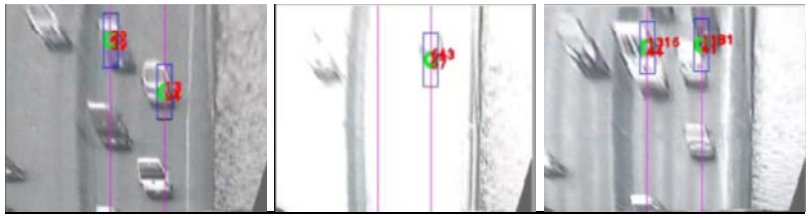
- Experiment Setup
- Hour-long Tests
- 10-minute Tests
- Findings

Experiment Setup



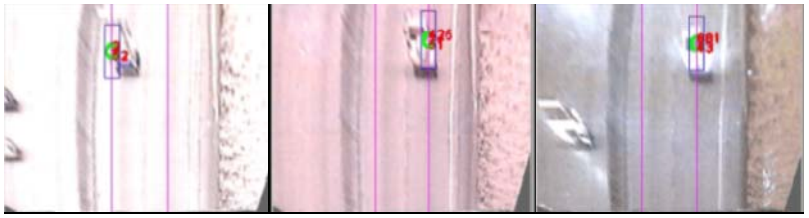
Hour-Long Tests

11:30 pm – 12:30 pm, June 4, 2008



Performance measure	Left lane	Right lane
Manual count	1556	1302
ST-map count	1328	1194
Error rate	14.7%	8.3%

8:30 pm – 9:30 pm, June 4, 2008



Performance measure	Left lane	Right lane
Manual count	871	841
ST-map	882	833
Error rate	-1.3%	1.0%

4:30 pm – 5:30 pm, October 27, 2008

Performance measure	Left lane	Right lane
Manual count	1944	1499
ST-map count	1949	1588
Error rate	-0.26%	-5.94%

8:30 pm – 9:30 pm, October 27, 2008

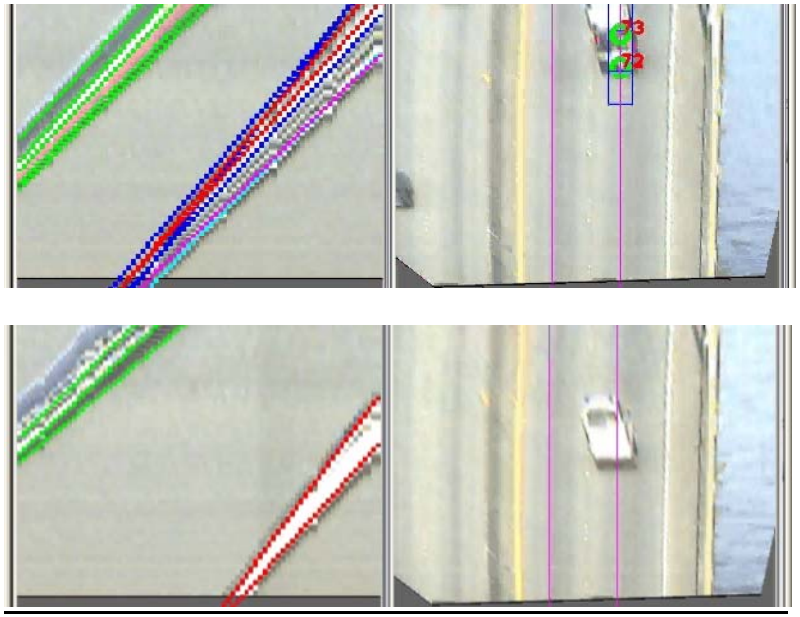
Performance measure	Left lane	Right lane
Manual count	760	822
ST-map count	687	827
Error rate	9.61%	-0.61%

Hour-Long Tests Summary

- Significant errors are usually undercounts
- Conditions did not affect accuracy
- Volume seemed to have an adverse affect
- Latitudinal occlusions (extending from left lane to right lane) did not have big effect

10-minute Tests

SR 520 East during 6:30 pm - 6:40 pm, on July 6, 2008



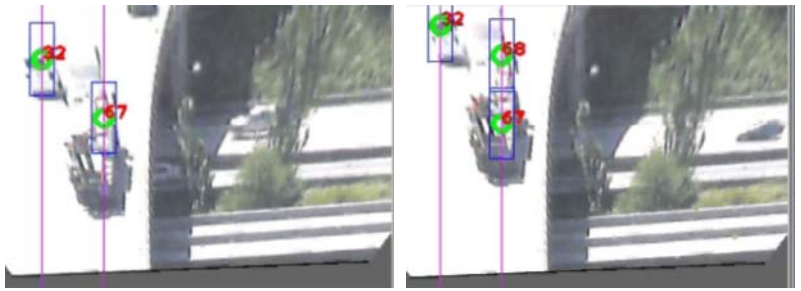
Performance measure	Left lane	Right lane
Under-count	21	12
Over-count	1	3
Lane Changes	1	2
ST-Map Count	191	178
Manual Count	212	189
Overcount Rate	0.47%	1.59%
Missed Rate	9.86%	6.28%

10-minute Tests

SR-520 West during 1:30 pm – 1:40 pm, on July 7, 2008

Performance measure	Left lane	Right lane
Under-count	17	34
Over-count	7	3
Lane Changes	1	1
ST-Map Count	222	234
Manual Count	233	266
Overcount Rate	3.00%	1.13%
Missed Rate	7.26%	12.73%

I5 Southcenter during 2:00pm – 2:10pm, July 7, 2008



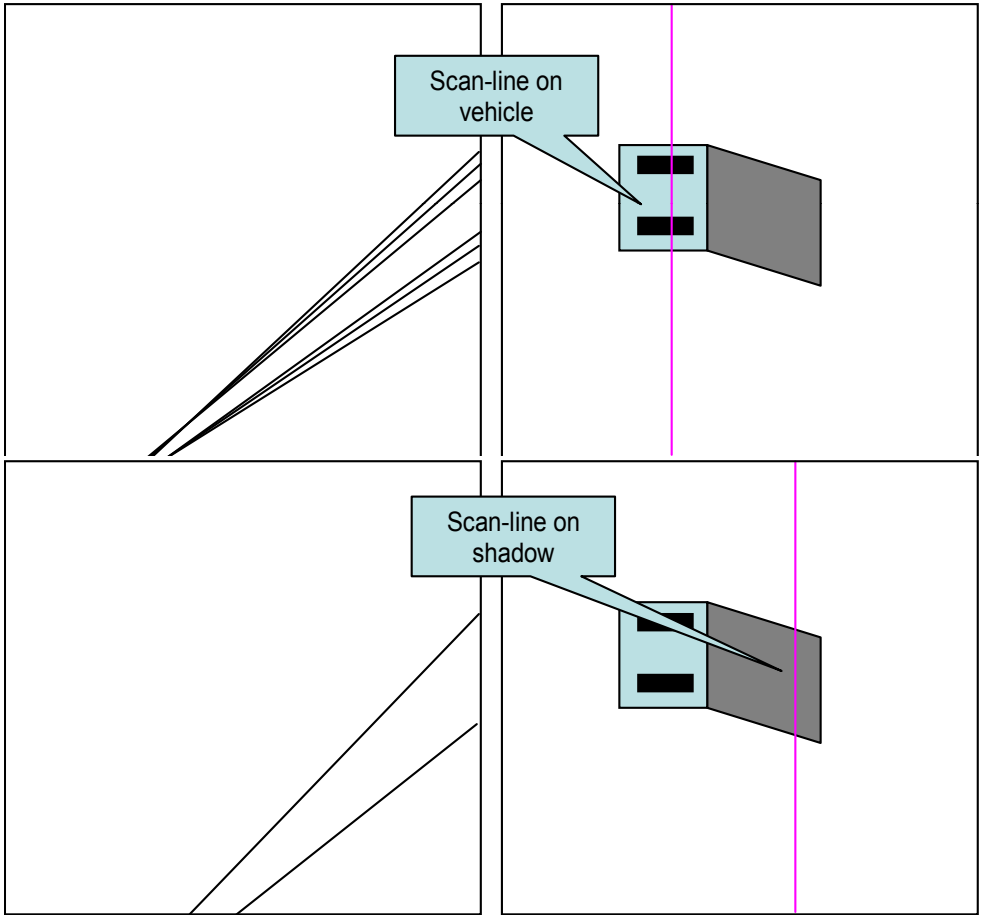
Performance measure	Left	Right
Under-count	9	13
Over-count	11	19
Lane Changes	0	1
ST-Map Count	147	280
Manual Count	145	275
Overcount Rate	7.59%	6.91%
Missed Rate	6.21%	4.71%

Findings: Occlusions

- Occlusions
  - Lateral occlusions are mitigated
    - Scan-line placement can be manipulated
  - Longitudinal occlusions are more difficult
    - Hard to distinguish where one vehicle begins and another ends
  - Need additional information to reason through occlusions

Findings: Environmental Effects

- Shadows
- Headlights
- Vibration
- Lighting
- Water trails



VVDC2 Conclusions

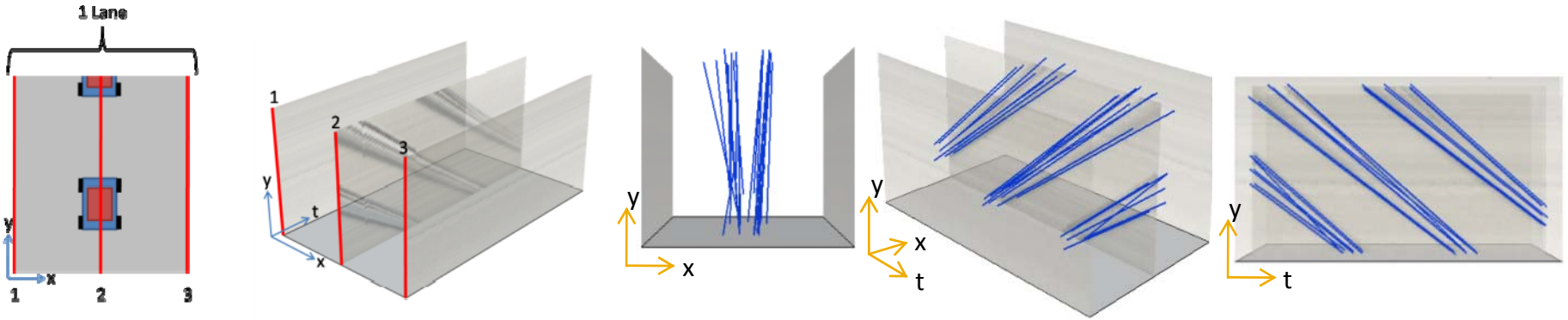
- ST-maps provide a standardized way to view vehicle movement.
- Interpreting ST-maps is simpler than entire frames.
- Relying on Hough transforms to interpret ST-maps results prevents many common errors.
- Interpretation of ST-maps through Hough line intersection graphs is a novel concept.
- A variety of conditions were tested, with resulting in error rates from 1 to 15%.

Applicability to Rural Settings

- Major strength of approach is robustness to environmental factors.
- Works best in low-volume situations.
- Ideal for rural applications.

Further Work – VVDC3

- Accuracy loss in high volumes
- Stop and go traffic
- Information redundancy for occlusions
  - Texture Model
  - Combine feature points with ST-maps
  - Add third dimension

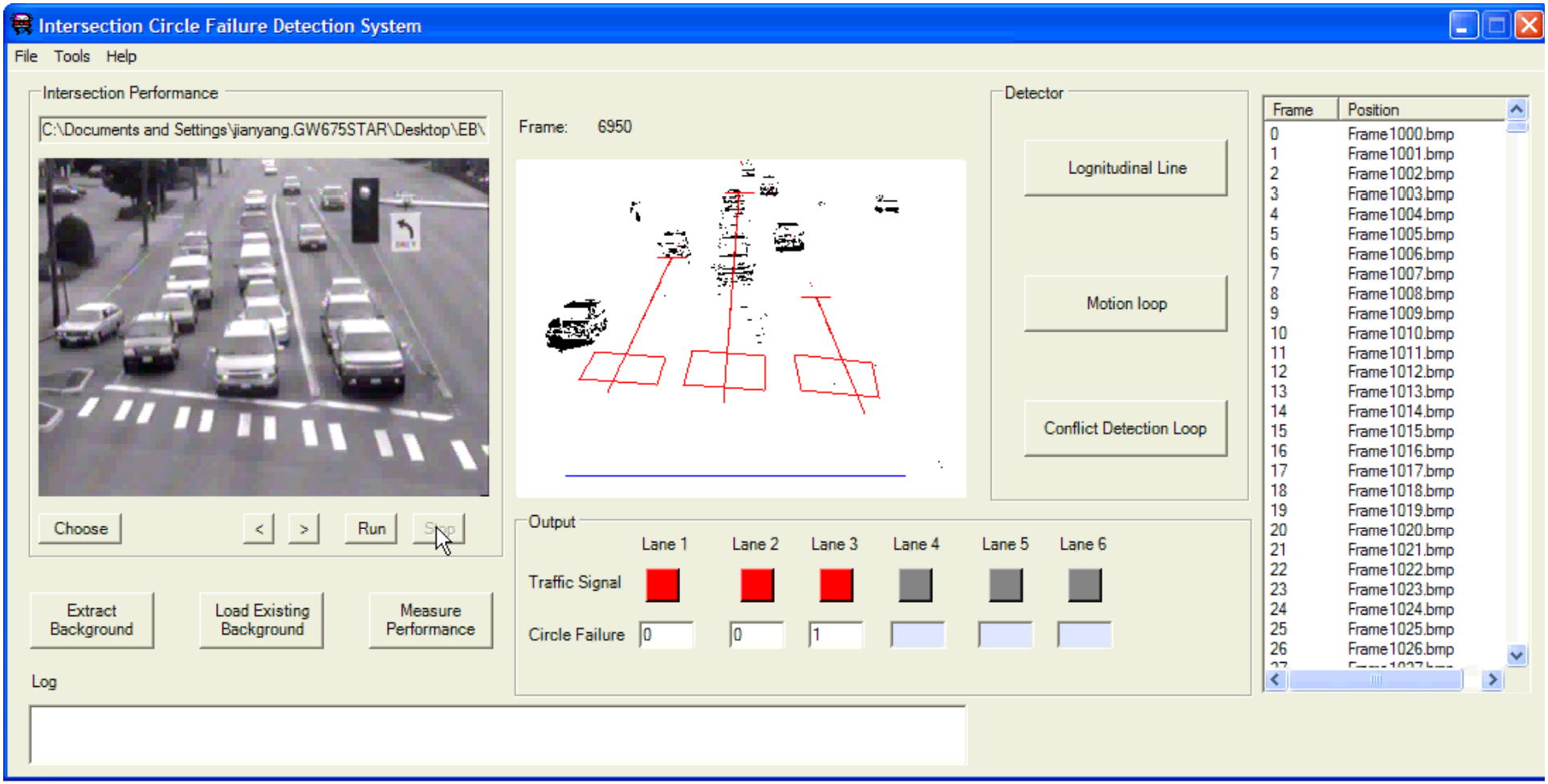


Potential Applications at WSDOT

Additional Directions

- Cycle Failure
  - Determine potential cycle failures
- PBTrack
  - Track pedestrians and cyclists
  - Determine waiting and crossing times

Cycle Failures



PBTrack

Summary

- VVDC1
  - Accurate
  - Speed and classification info
  - Sensitive to environmental effects
- VVDC2
  - Robust to environmental factors
  - Reasonable accuracy
- Video Detection
  - Many applications, great potential