MATLAB EXPO

MATLAB 기반 딥러닝 모델을 활용한 감시 카메라 영상 내 차량 속도 분석 시스템 개발

최영수 감정관, 국립과학수사연구원 대전과학수사연구소

MathWorks

국립과학수사연구원(NFS)

국립과학수사연구원

진실을 밝히는 과학의 힘

The Power of Science to Reveal the Truth

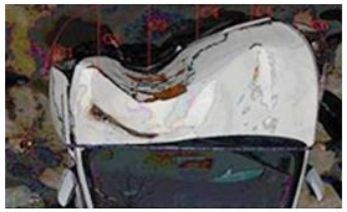
https://www.nfs.go.kr/site/nfs/main.do

국립과학수사연구원(NFS) : 교통과

교통사고 해석

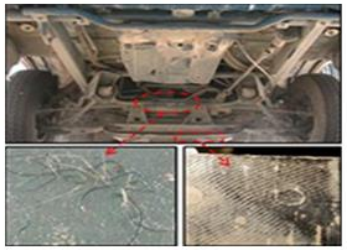
교통사고 원인 분석 및 사고 재현, 블랙박스 및 CCTV 영상에서 차량 속도 분석, 차대차 뺑소니, 보행자 충돌 및 역과 여부 분석

충돌지점, 충돌자세, 충돌속도 분석



파손된 차량 속도 분석

자전거에 부착된 도주차량 페인트



차량하부에 부착된 섬유와 흔적

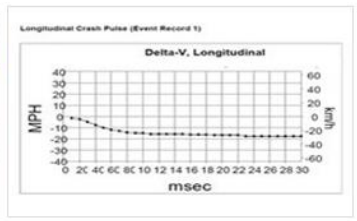
차량안전 검사

차량 결함 분석, 사고기록장치(EDR) 및 운행기록계 분석, 항공·철도·선박 사고 분석

엔진계통 및 샤시 계통 결함 분석

급발진 추정 사고분석

디지털운행기록계 분석 및 사고해석

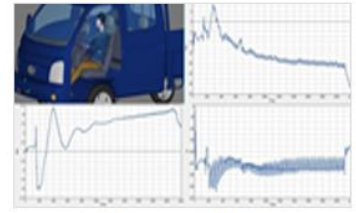


EDR 데이터 분석 및 사고해석

교통범죄 분석

교통 보험사기에 대한 운전자의 고의성 및 인지 분석, 보복 운전, 사고 위장 및 피해 과장 분석, 차량 탑승자 및 보행자의 인체거동해석

차량 탑승자 운동변화 분석



차량 탑승자 충격력 분석

진로변경 고의사고 분석

법규위반(꼬리물기) 고의사고 분석

https://www.nfs.go.kr/site/nfs/main.do

Contents

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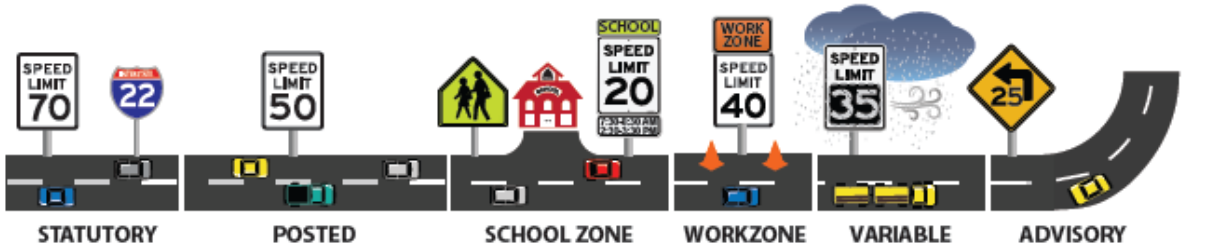
  - Module 4: Calculation of vehicle speed
- **Conclusion**

Brach, Matthew, James Mason, and Raymond M. Brach. *Vehicle accident analysis and reconstruction methods*. Sae international, 2022.

Introduction : Background

Importance of **vehicle speed** at the time of the accident

- Criteria for determining the cause and contributing factors of vehicle accident
  - Article 3 of the Act on Special Cases concerning the Settlement of Traffic Accidents (Overspeeding)
  - Traffic accident avoidability
- Used as initial input for car accident reconstruction, which affects the reliability of the reconstruction results.
- Provides critical information to evaluate the effectiveness of safety measures and identify potential areas for improvement
  - Safe Speed 5030 Campaign
  - Install speed bumps and speed cameras

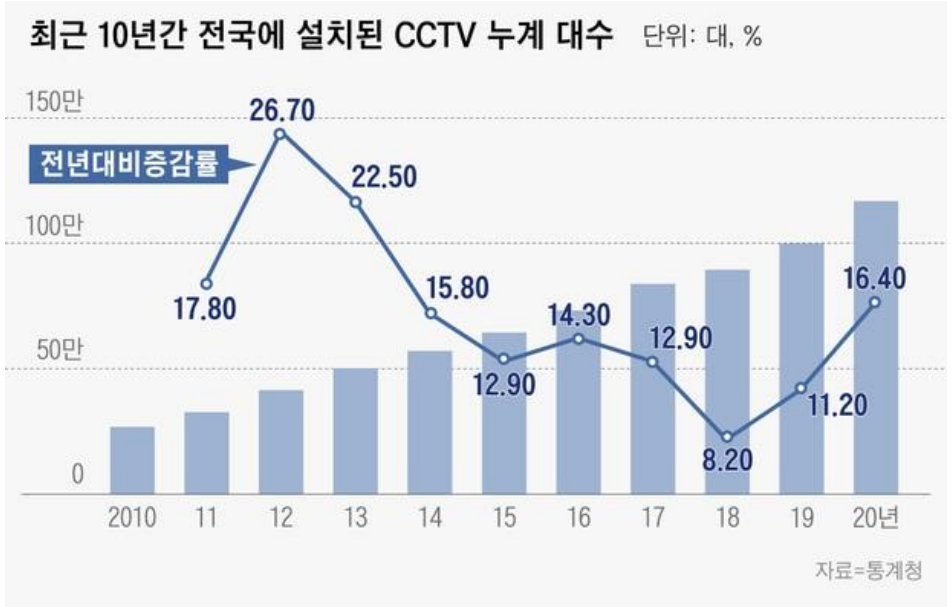


https://highways.dot.gov/safety/speed-management/speed-limit-basics

Introduction : Background

Importance of **surveillance camera** in accident analysis

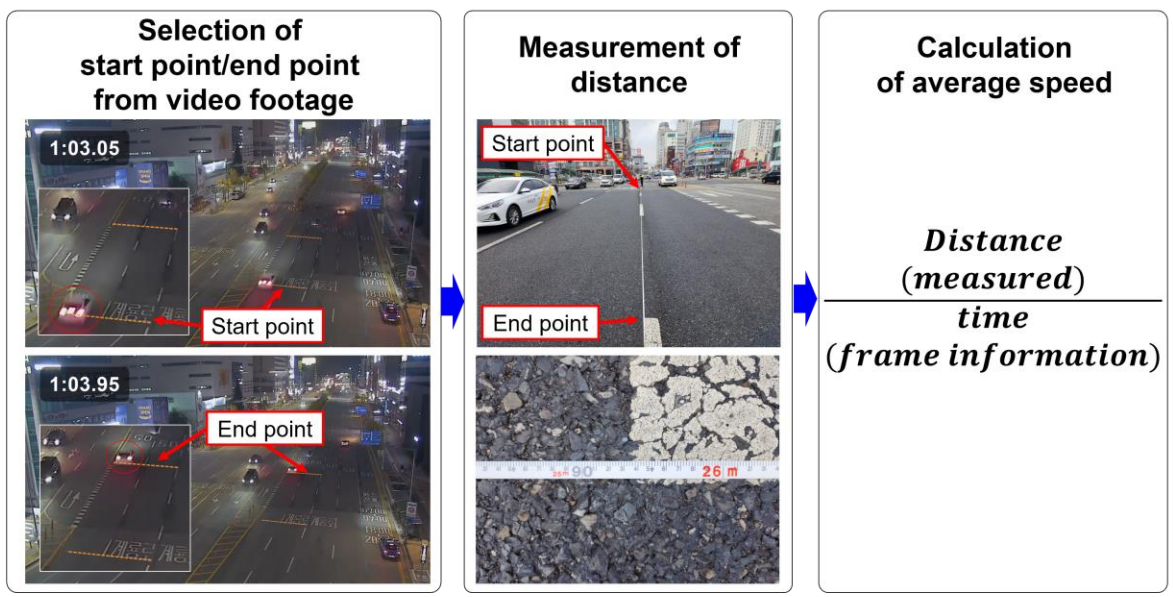
- Intuitive understanding of vehicle accident situations
  - Useful in determining the cause and circumstances of an accident
- Provide valuable information about the conditions at the time of the accident
  - Traffic conditions(vehicle position, direction)
- Surveillance camera installation status
  - Status of CCTV installations in public institutions
    (1,336,653 as of 2020)

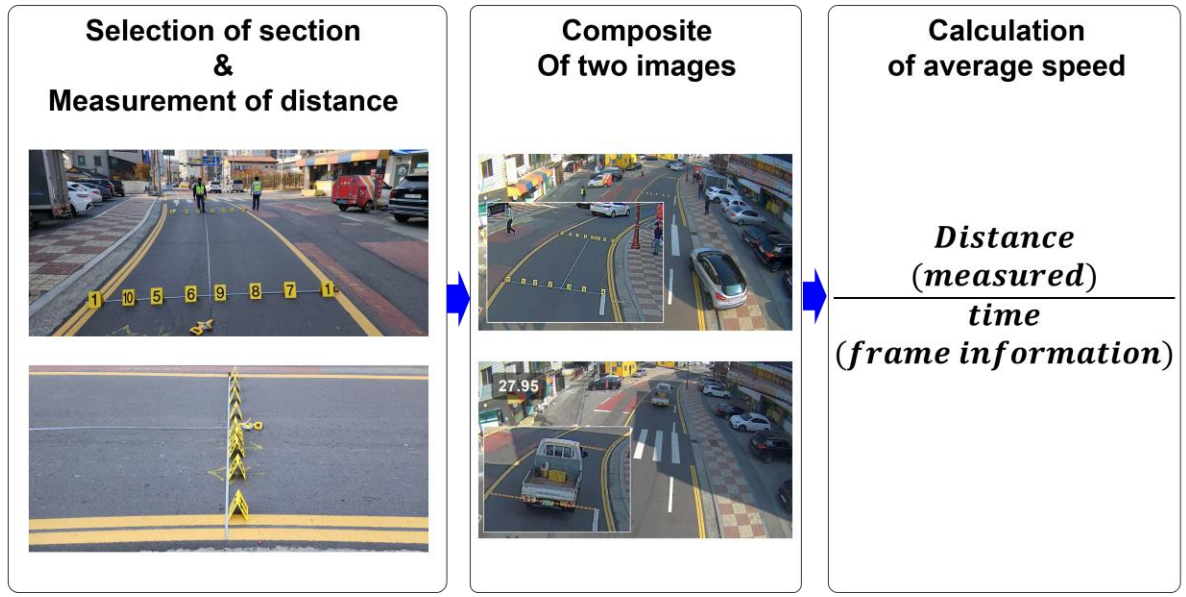


https://www.data.go.kr/data/15090247/fileData.do
https://biz.chosun.com/topics/topics_social/2021/10/25/FLLXZQCAHNAILDVV6QZCQZ2JTM/

Introduction : Limitations

Limitations of the existing method





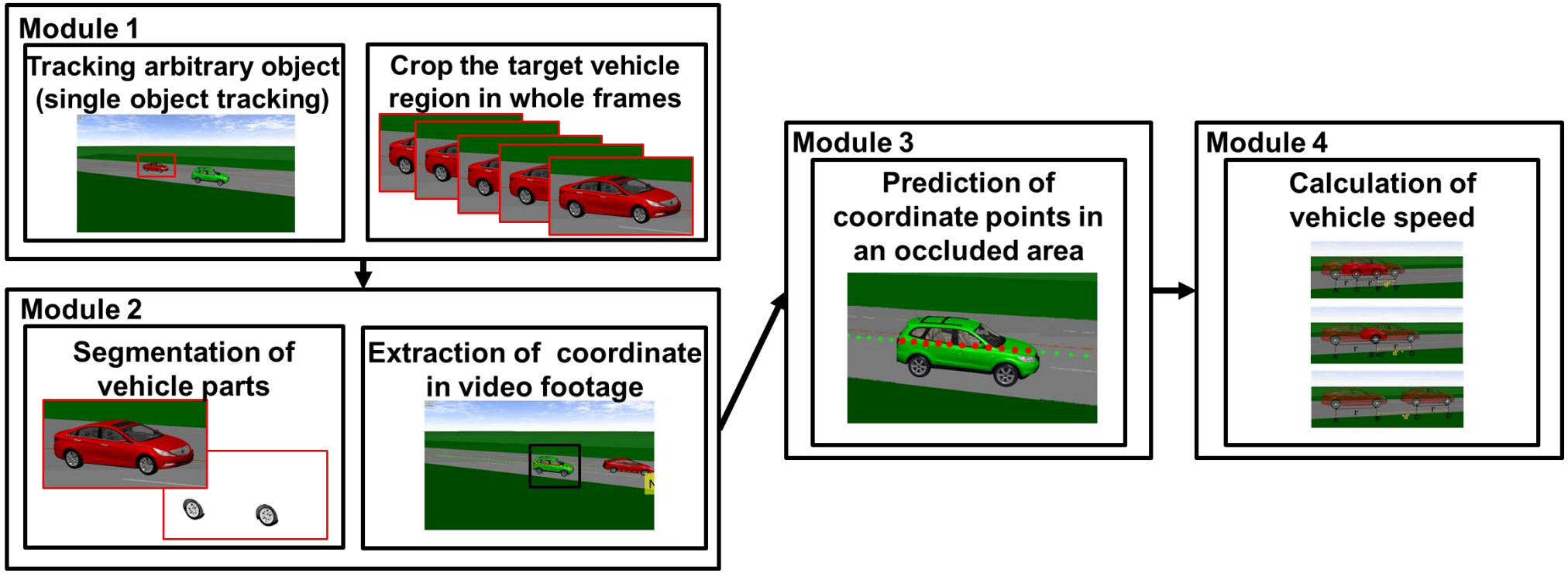
- A start and end point must exist
- Difficulty analyzing speed changes
- Too much on-site investigation

Project Overview

Goal : Vehicle speed analysis system in stationary camera

- Function to analyze instantaneous speed over time
- Function to automatically analyze the speed of a target vehicle in a video

Project pipeline



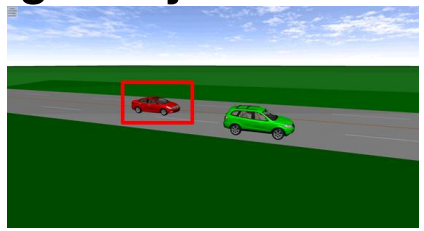
Methods : Module 1

Challenges

- Low resolution
- Occlusion
- Change the target shape
- Scale variation

Module 1

Tracking arbitrary object (single object tracking)



Crop the target vehicle region in whole frames

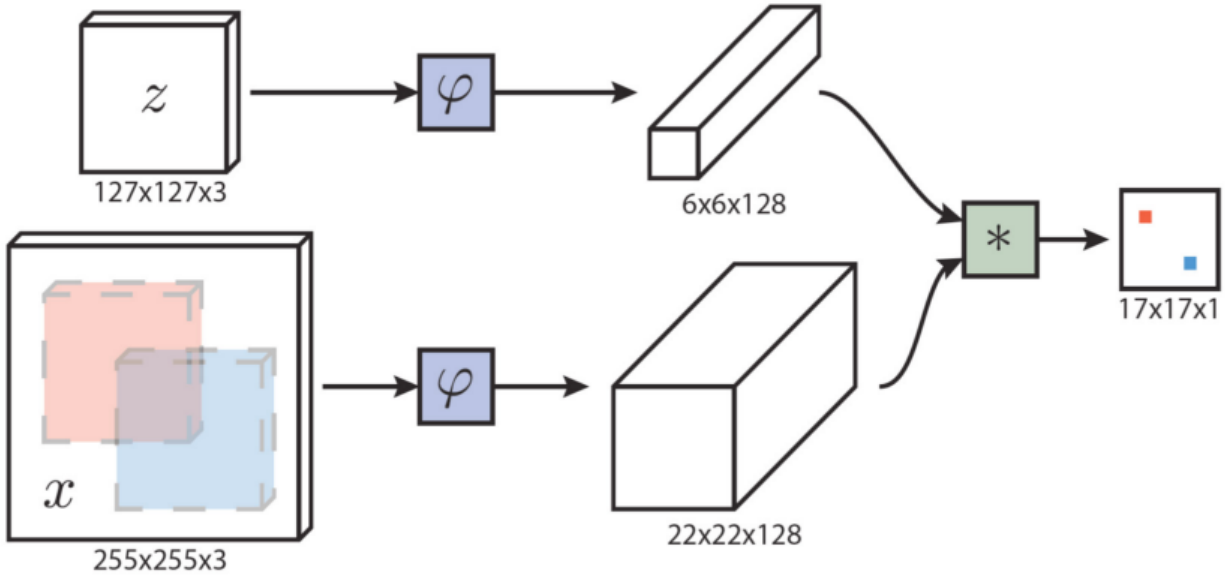
Existing methods for tracking by MATLAB

- MATLAB and Computer Vision Toolbox™ provides video tracking algorithms
  - CAMShift (Continuously Adaptive Mean Shift), KLT (Kanade-Lucas-Tomasi)

Proposal method

- Deep learning model : SiamFC(Siamese Fully Convolutional Networks)
  - Object tracking algorithm published in 2016
  - SiamFC uses a Siamese Network based on a Convolutional Neural Network (CNN) to track objects.

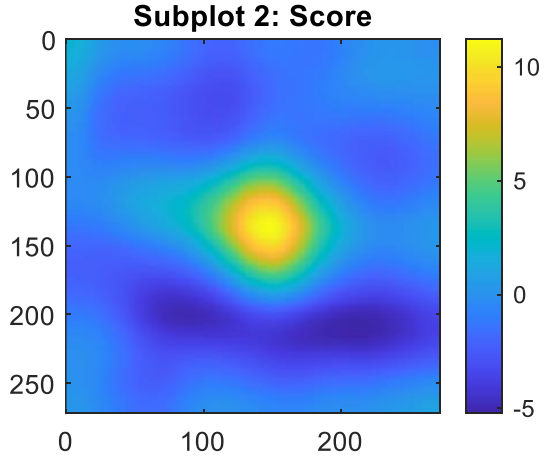
Methods : Module 1



Subplot 1: X_crops

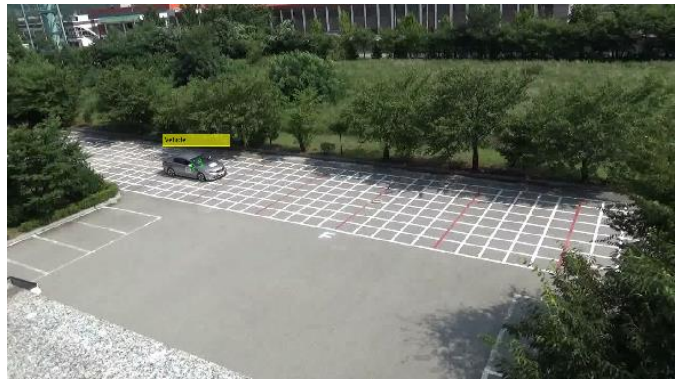
Z

*



X

Subplot 3: Image



Bertinetto, Luca, et al. "Fully-convolutional siamese networks for object tracking." *Computer Vision–ECCV 2016 Workshops: Amsterdam, The Netherlands, October 8-10 and 15-16, 2016, Proceedings, Part II 14*. Springer International Publishing, 2016.

Methods : Module 1

Improvement : Apply a Kalman filter

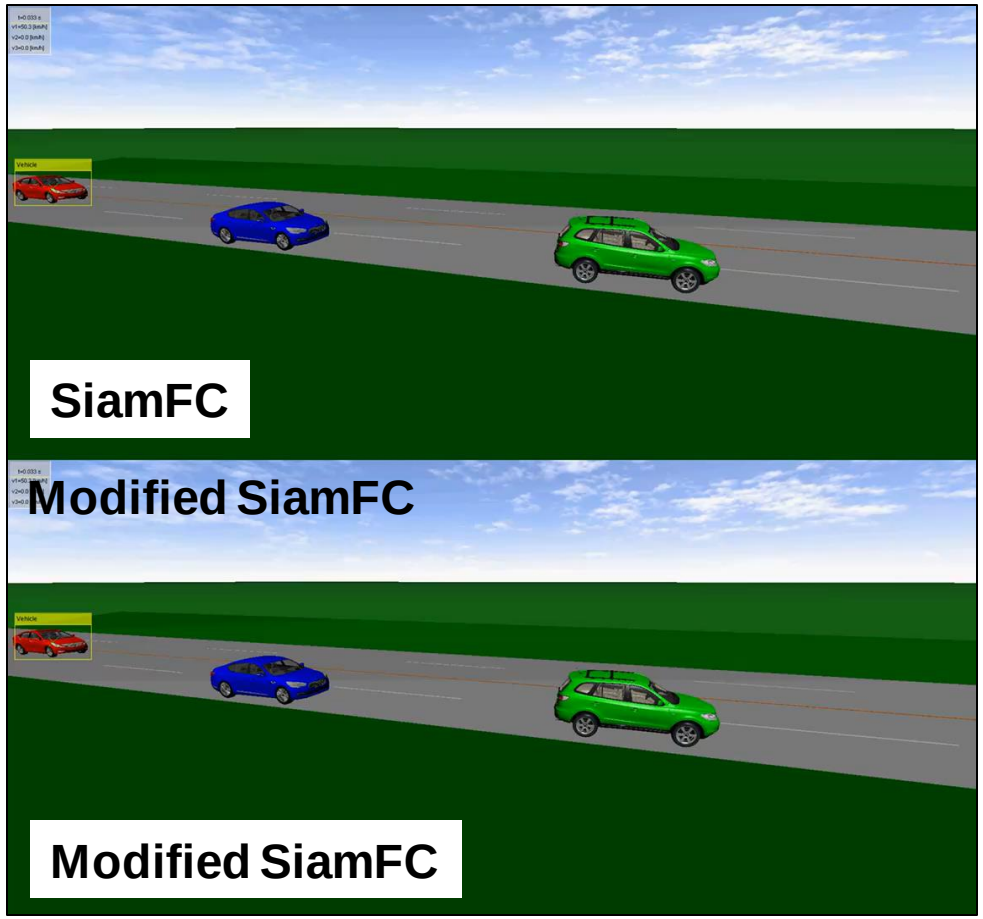
function [newTargetPosition, bestScale, score, response_size] = tracker_eval(dlnetArea, s_x, exemplarFeatures, x_crops, targetPosition, window, adjust, numScale, scalePenalty, wInfluence, scoreSize, responseUp, totalStride, instanceSize)

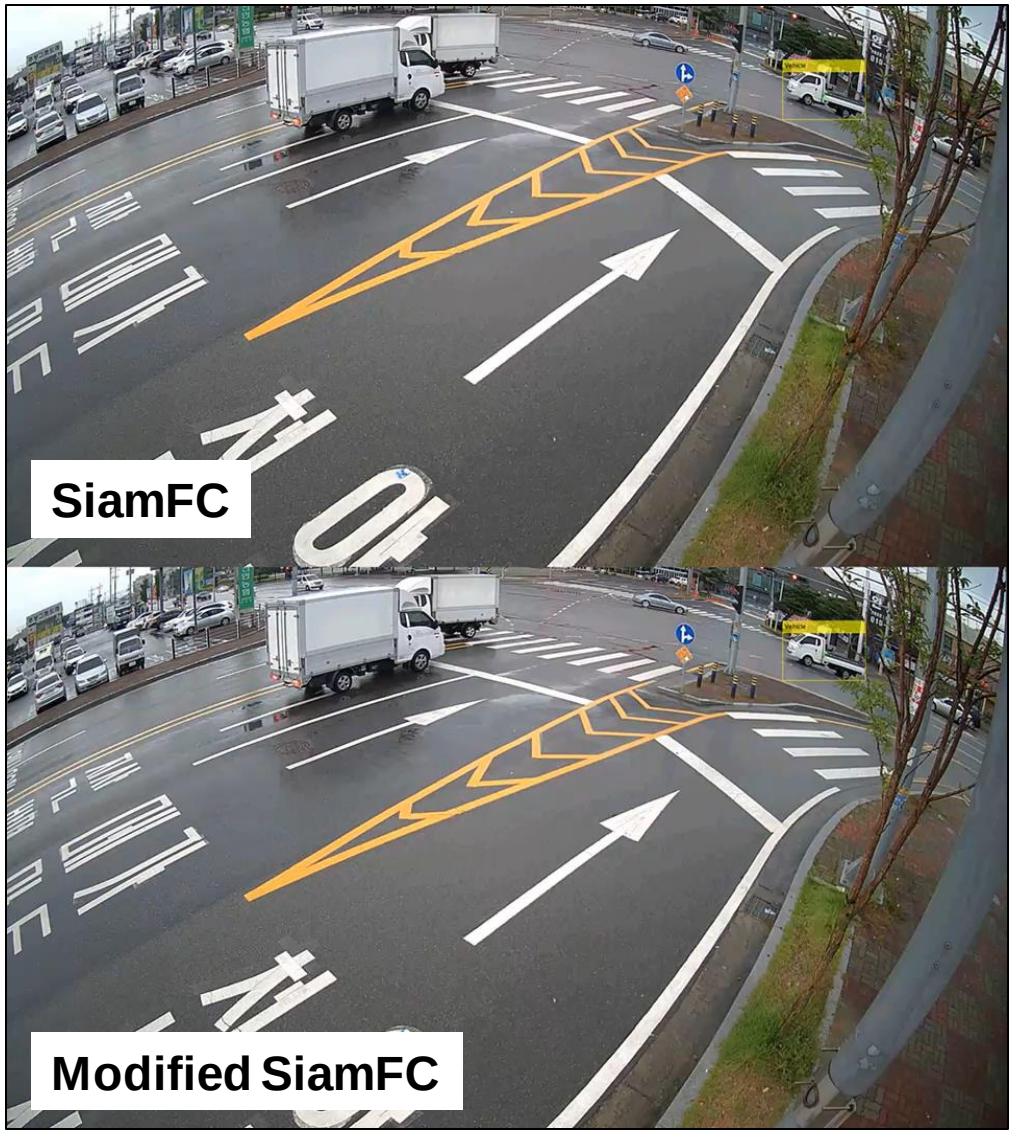
```
if score_max <= 3
    targetPosition_cor = predict(filter);
    targetPosition = targetPosition_cor;

else
    predict(filter);
    targetPosition_cor = correct(filter,targetPosition);
    targetPosition = targetPosition_cor;
end
```

Methods : Module 1

Result : Tracking video example

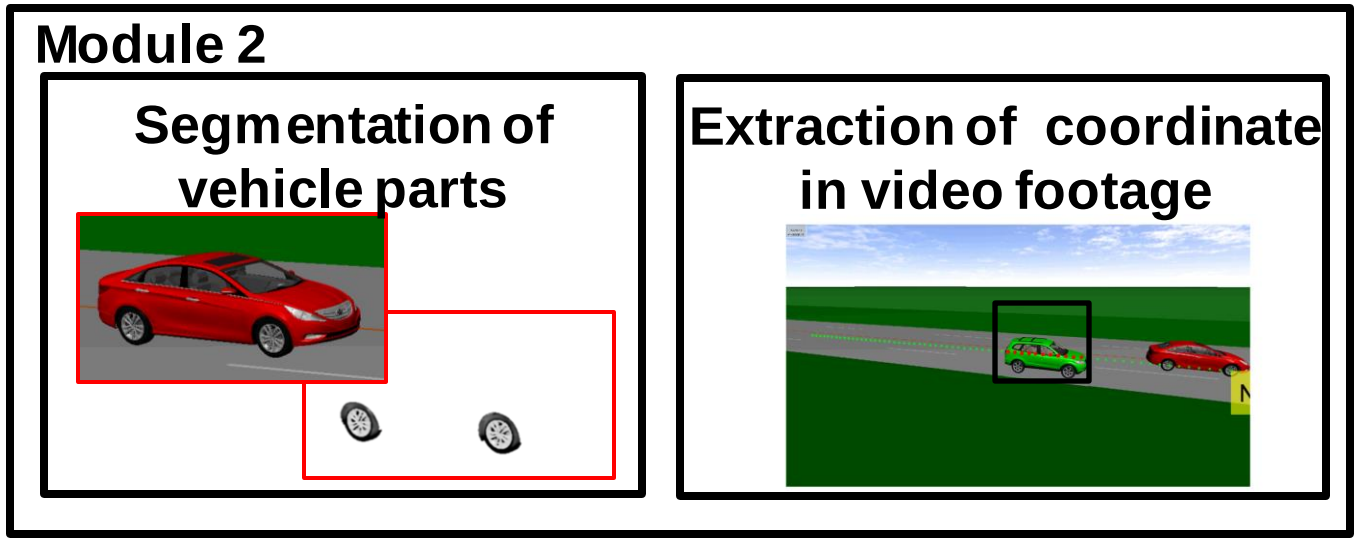




Methods : Module 2

Challenges

- Low resolution
- Change the target shape
- Scale variation



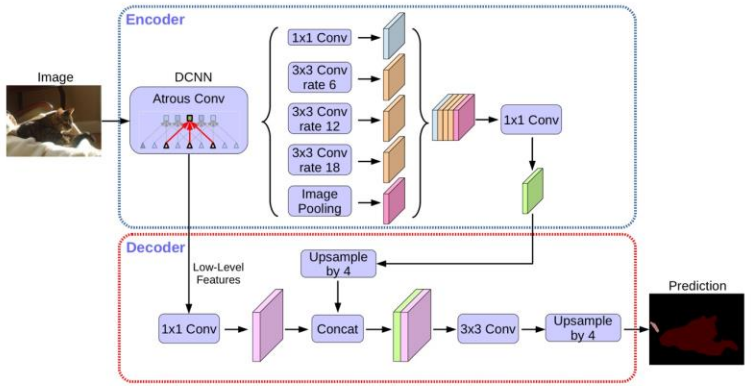
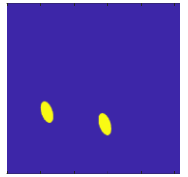
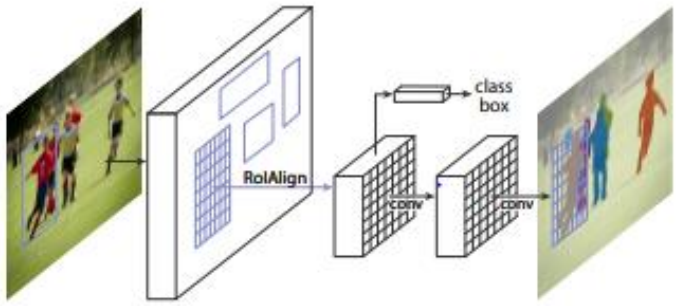
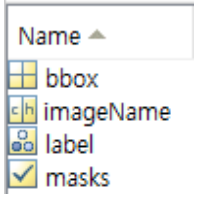
Existing methods for segmentation by MATLAB

- MATLAB and Image Processing Toolbox™ provides Various image segmentation techniques
  - binarization, clustering, graph-based segmentation, and region expansion
- Deep Learning Toolbox™ provides a framework for designing and implementing deep neural networks using algorithms, pre-trained models, and apps

Proposal method

- Deep learning model : Deeplabv3+, Mask R-CNN

Methods : Module 2

Model	Output	Input(training)	Difference
DeepLabV3+ 	Semantic segmentation  Semantic Map	CamVid dataset type  image  Label	❖ Models based on Fully Convolutional Network (FCN) ❖ Perform per-pixel categorization and segmentation ❖ Perform pixel-by-pixel classification and segmentation for the entire image
Mask R-CNN  Figure 1. The **Mask R-CNN** framework for instance segmentation.	Instance segmentation  Classification Label Bounding Box Pixel Classification	COCO dataset type  image  Label	❖ Models based on Faster R-CNN ❖ Models that perform object detection and segmentation simultaneously ❖ Predict the bounding box of an object and perform object segmentation in that area

He, Kaiming, et al. "Mask r-cnn." *Proceedings of the IEEE international conference on computer vision*. 2017.
Chen, Liang-Chieh, et al. "Encoder-decoder with atrous separable convolution for semantic image segmentation." *Proceedings of the European conference on computer vision (ECCV)*. 2018.

Methods : Module 2

Improvement : Prepare new dataset(train:421, val:105)

Data labeling

Image Segmenter

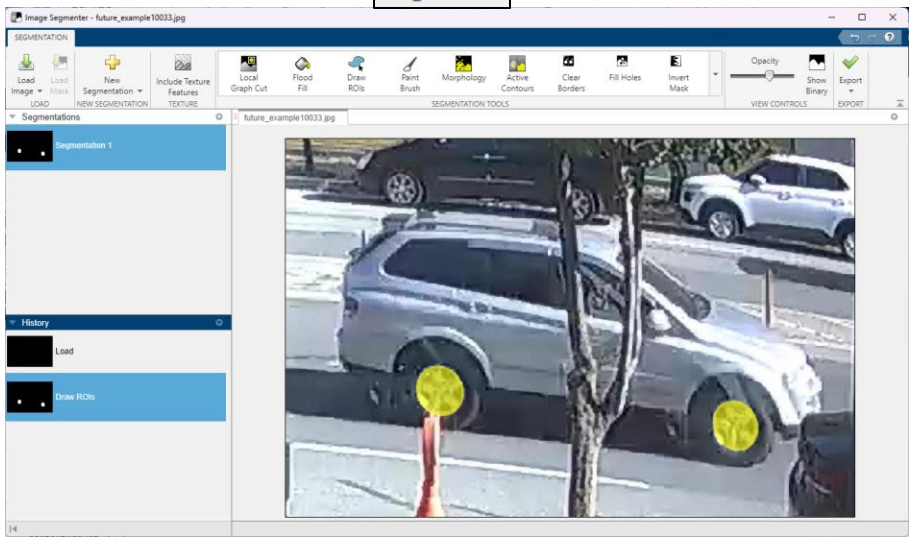
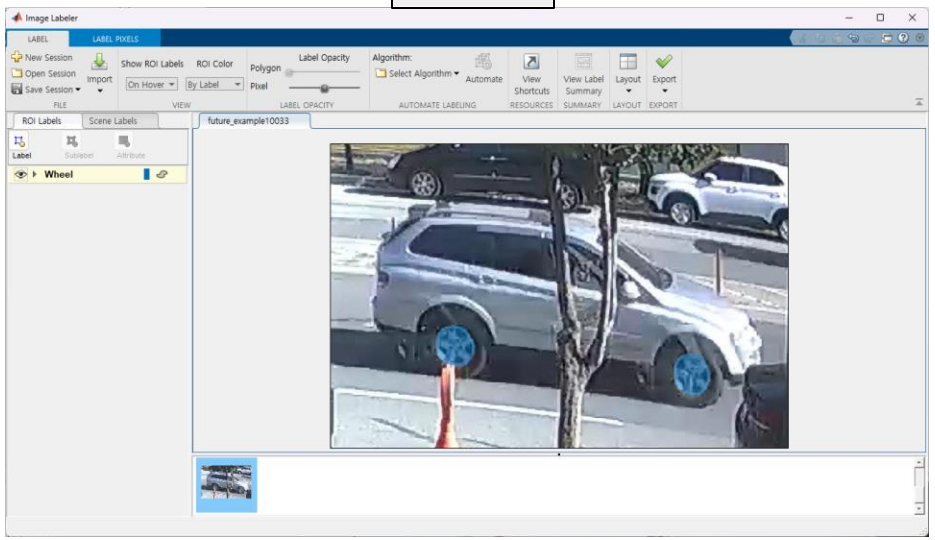
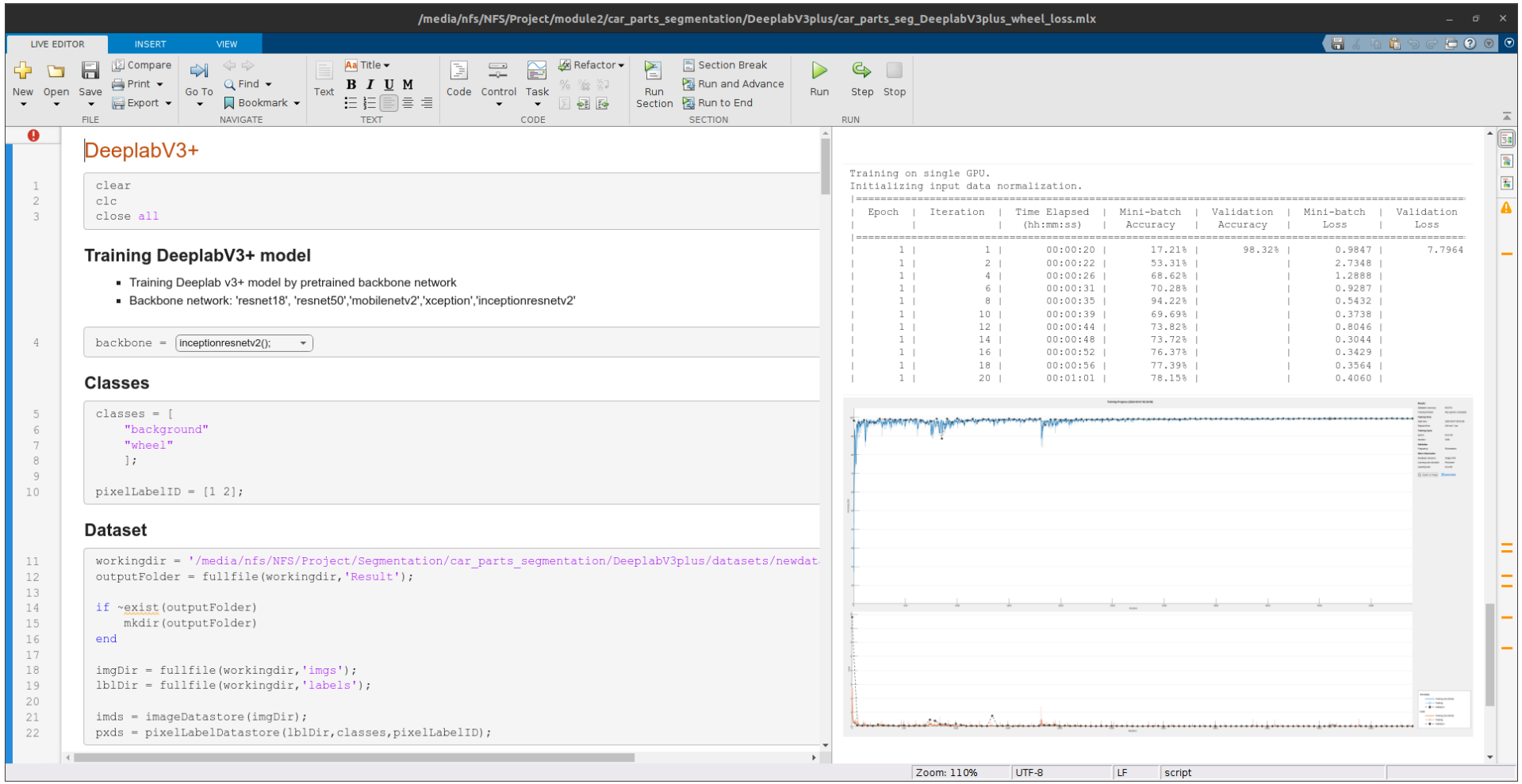


Image Labeler



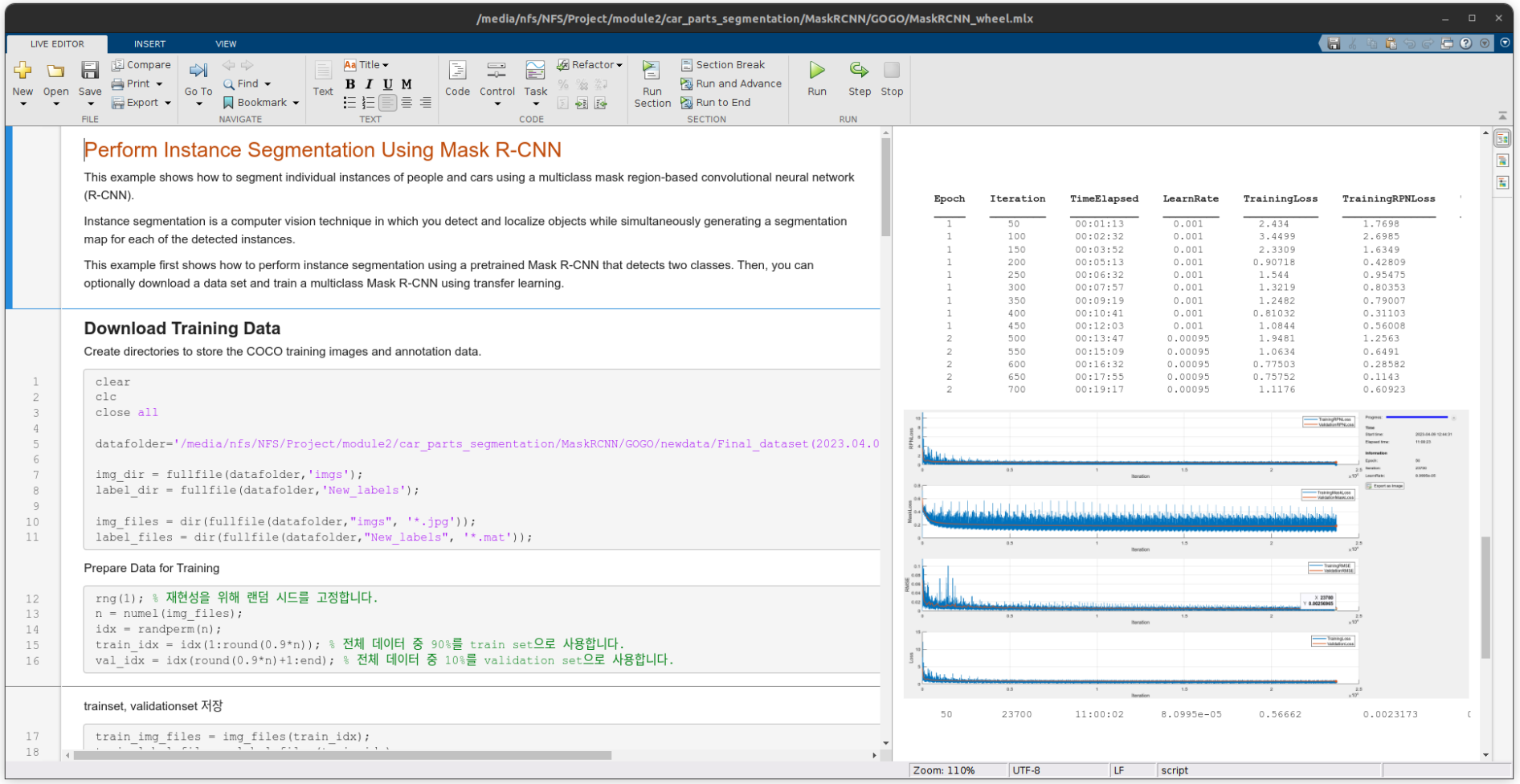
Methods : Module 2

Training : DeeplabV3+



Methods : Module 2

Training : Mask R-CNN



Methods : Module 2

Result : Comparison between DeepLabv3+ and Mask R-CNN

Model inference

DeepLabV3+

Half

Good

Good

Mask R-CNN

Half

Good

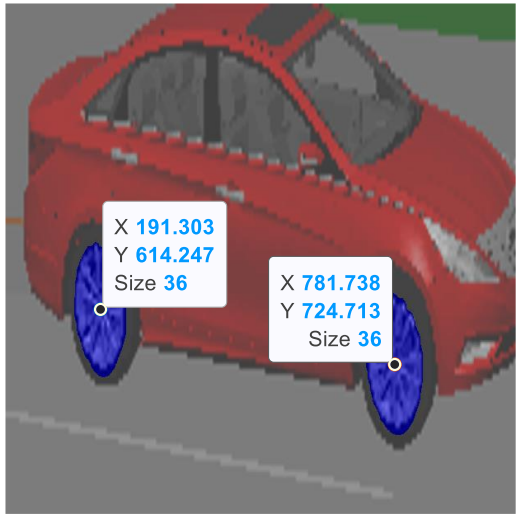
Missing

Methods : Module 2

Result : Extracting coordinates, imposing them on the original image

Cropped image

Resize **Extraction**

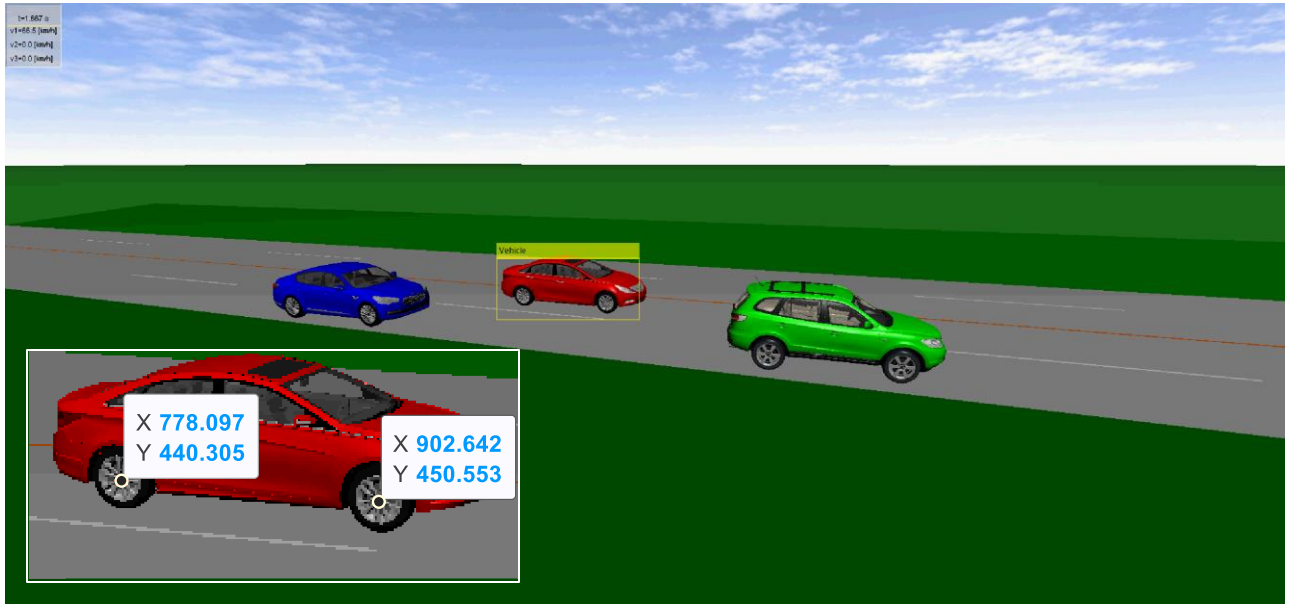


Imposing

regionprops

Measure properties of image regions

measures properties such as area, centroid, and bounding box, for each object (connected component) in an image.



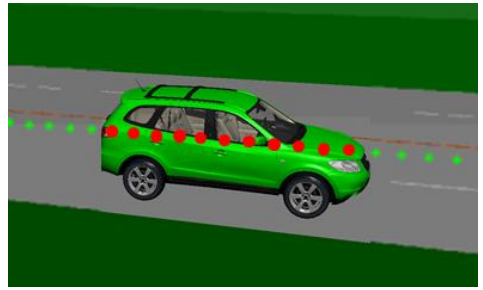
Methods : Module 3

Challenges

- Missing coordinates
- Inaccurate coordinate data

Module 3

Prediction of coordinate points in an occluded area



Existing methods for estimation by MATLAB

- MATLAB and Automated Driving Toolbox™ provides Various Kalman filter techniques
  - Alpha-Beta filter, Linear Kalman filter, Extended Kalman filter, Unscented Kalman filter
- MATLAB provides ‘Preprocessing Data'
  - anymissing, ismissing, fillmissing, rmmissing, standardizeMissing functions

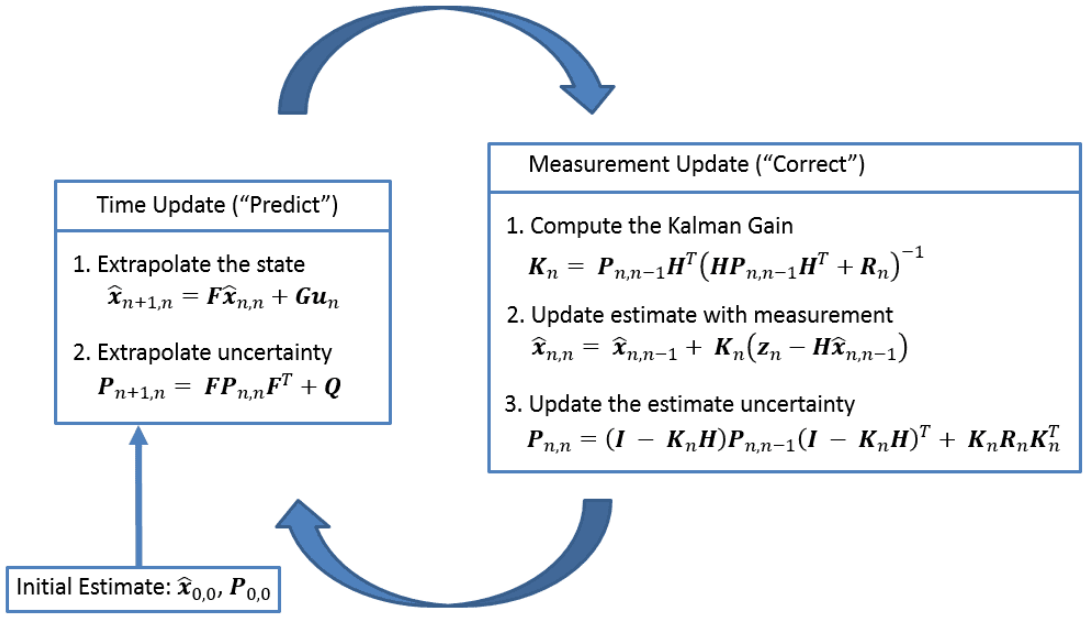
Proposal method

- **Kalman filter with smoothing**

Methods : Module 3

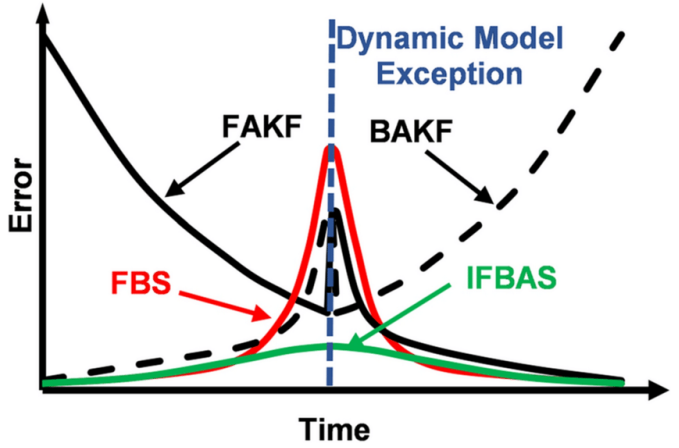
What is Kalman filter

- Prediction(system model) and Update(measurement)
- Recursive algorithm
- Real time operation



Improvement : Smoothing

- Forward pass and Backward pass
- Use the state estimated by the Kalman filter and the error covariance to estimate the final state, taking into account all observations from past time periods.

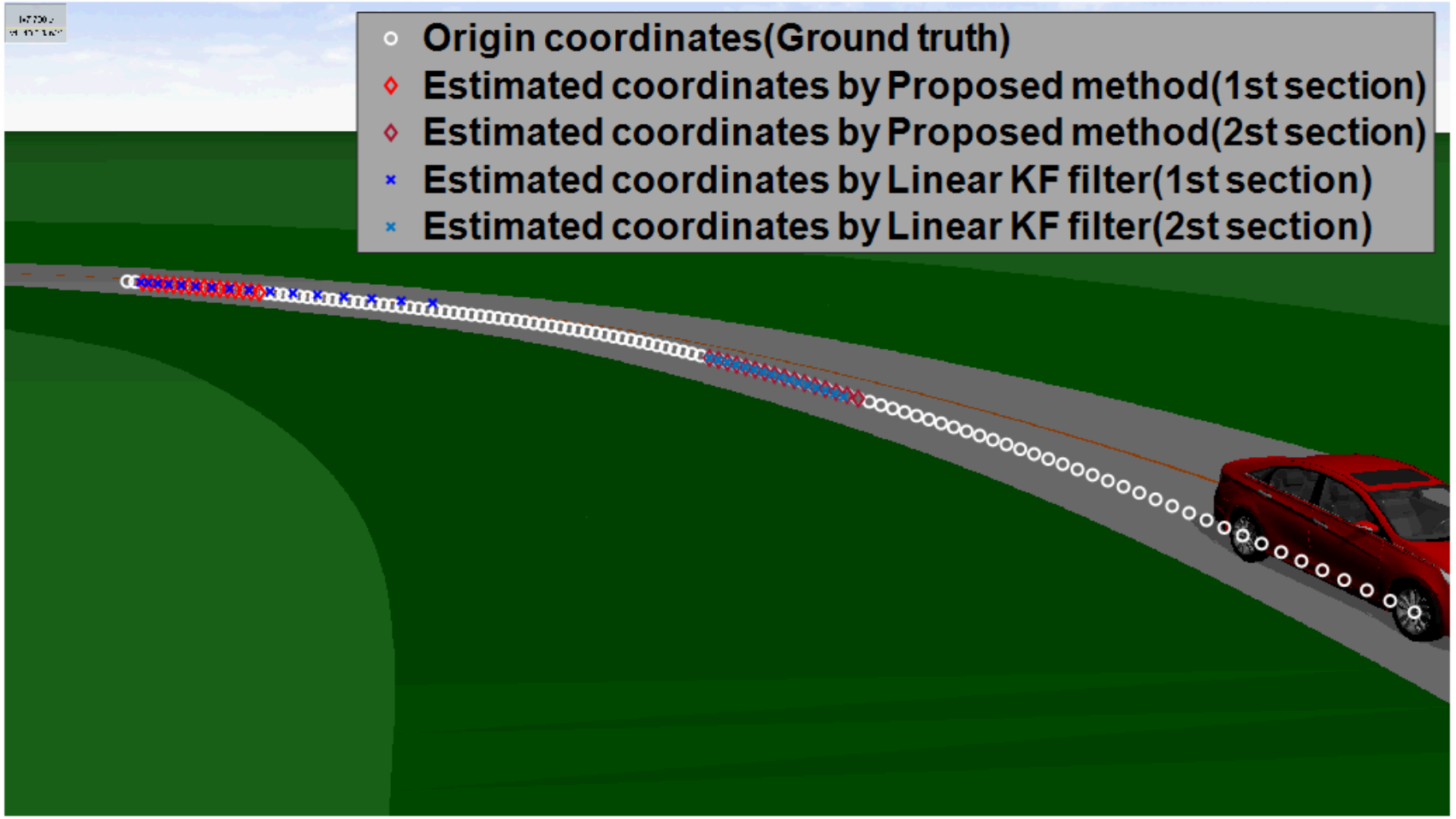


https://www.kalmanfilter.net/multiSummary.html

Lin, Xu, et al. "Improved forward and backward adaptive smoothing algorithm." Gps Solutions 26 (2022): 1-13.

Methods : Module 3

Result : Estimation of missing data



Methods : Module 4

Challenges

- Using known information (Vehicle specification)
- Reflection the geometry of Cross-Ratio

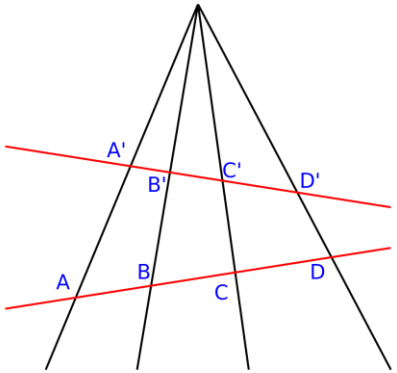
Implementation in MATLAB

- Function to automatically calculate the speed of a vehicle
- Function to analyze how a vehicle' speed changed over time

What is Cross-ratio?

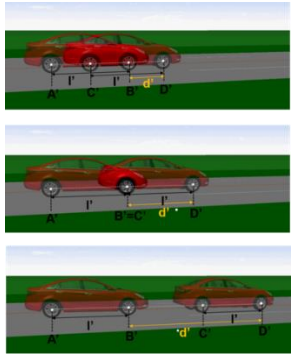
- Invariant value

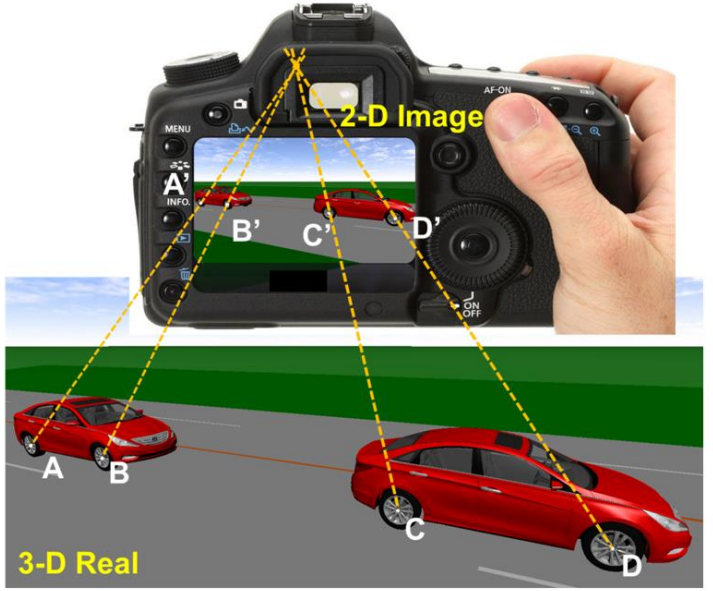
$$(A, B; C, D) = \frac{AC \cdot BD}{BC \cdot AD}$$



Module 4

Calculation of vehicle speed





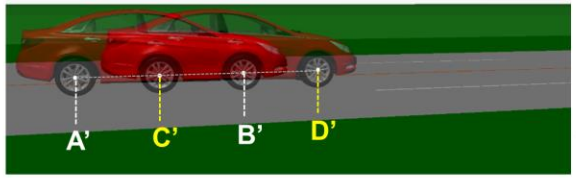
https://en.wikipedia.org/wiki/Cross-ratio

Methods : Module 4

How to calculate vehicle speed?

- Using invariant property
- Using vehicle' wheel length

Case 1: |A'B'|>|A'C'|

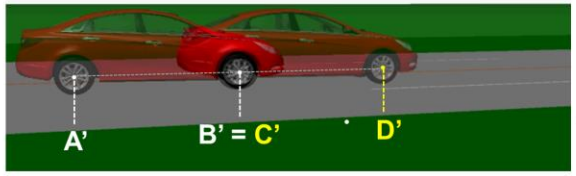


$$CR(Cross-ratio) = (A'C'B'D') = \frac{|A'B'| \times |C'D'|}{|A'D'| \times |B'C'|}$$

$$d_{i,j}(distance) = \sqrt{l^2 - \frac{l^2}{CR}}$$

$$v_{i,j}(speed) = \frac{d_{i,j} \times FPS}{|i-j|}$$

Case 2: |A'B'|=|A'C'|

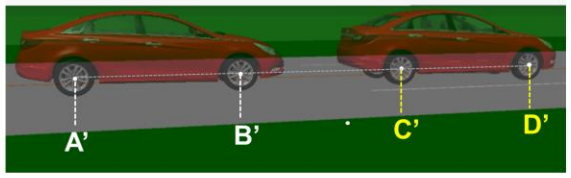


$$CR(Cross-ratio) = \infty$$

$$d_{i,j}(distance) = l$$

$$v_{i,j}(speed) = \frac{d_{i,j} \times FPS}{|i-j|}$$

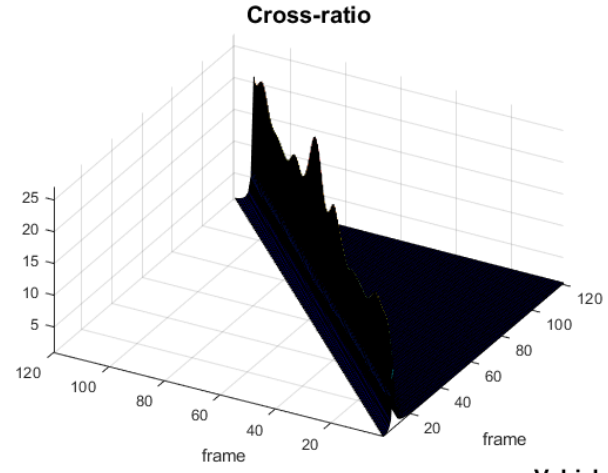
Case 3: |A'B'|<|A'C'|

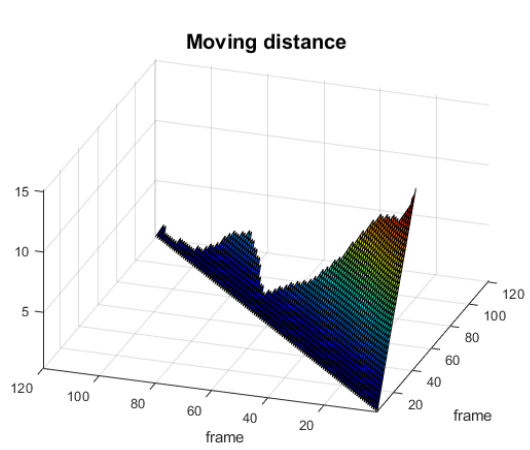


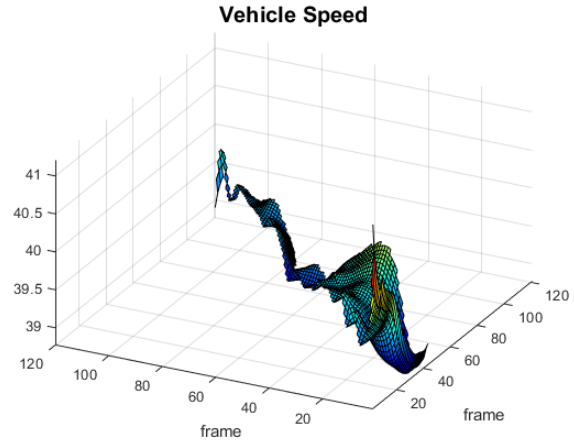
$$CR(Cross-ratio) = (A'B'C'D') = \frac{|A'C'| \times |B'D'|}{|A'D'| \times |B'C'|}$$

$$d_{i,j}(distance) = \sqrt{\frac{CR}{(CR-1)}l^2}$$

$$v_{i,j}(speed) = \frac{d_{i,j} \times FPS}{|i-j|}$$

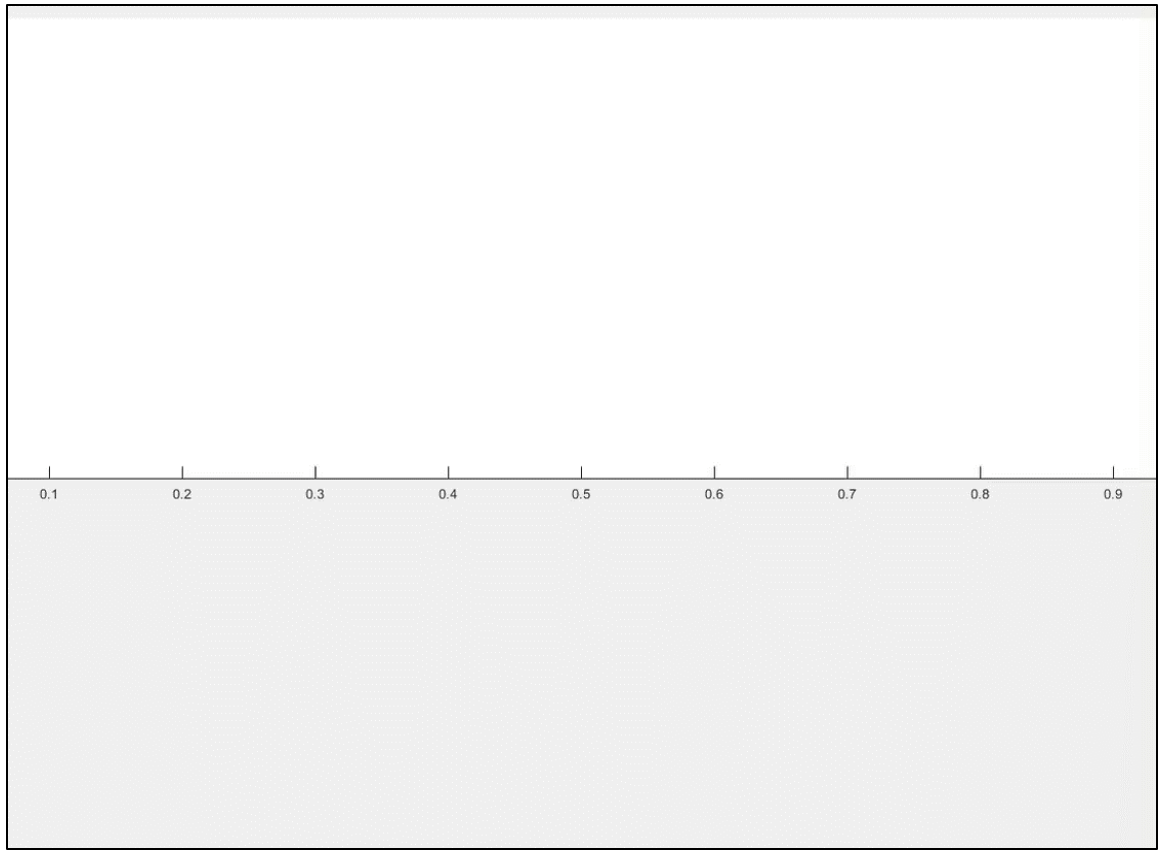






Methods : Module 4

Result : Estimation of vehicle speed over time



Conclusion

- **Vehicle speed and Video** are important factors in accident analysis
- Analyze the speed of a vehicle using the **vehicle's specs**, not the on-site investigation
- Analyze the Instantaneous speed of a vehicle in a video "**automatically**" and "**over time**"
- Implement functional modules
  - Single object tracking, Segmentation based on Deep Learning
  - Kalman filter technique, Cross-ratio
- Implement the functionality of all modules as a MATLAB and Toolbox
  - Plenty of useful examples on the MathWorks website
  - **Deep engagement** project with **MathWorks Korea**

MATLAB EXPO

Thank you