Distance estimation using mono camera at different altitudes and pitch angles

Author: Nurgeldy Praliyev (IEJTN2)

Supervisor: Viktor Remeli

Outline

- Motivation
- Literature Review
- Proposed Methods
- Experimental Setup
- Experimental Results
- Results and Discussion
- Conclusion and Recommendation

Motivation

- Minimization of number of traffic road accidents and develop the Automotive Driver Assistance Systems (ADAS)

- Development of cost-effective solutions for Autonomous Driver Assistance System (ADAS):
  - ✓ Distance estimation of target vehicle using a single camera

Literature Review

1. Bojian, L. & Pears, N. (2002) utilized a planar homography approach to estimate the height of the camera above the ground level considering world-camera coordinates relation.
2. Wu, X. et al. (2020) presented a passive ranging based on planar homography in mono camera vision where authors estimated the distance of horizontally positioned target objects.
3. Cheung, H. et al. (2012) claimed that selecting a proper tilt angle of the camera the distance estimation accuracy of the goal vehicle can be increased significantly.
4. Sh. Samuel, B. Joachim, E. Emil, K. Amrit, G. Karl, "Mono-Camera 3D Multi-Object Tracking Using Deep Learning Detections and PMBM Filtering," 2018 IEEE Intelligent Vehicles Symposium (IV), vol. 4, pp. 433-440, June 2018
5. Samuel, B. et al. (2018) developed a deep learning detection which estimates the distance of the vehicle(s), where bounding boxes' height and width are the key parameters
6. E. Mohamed et al. (2018) calculated the selected vehicle's distance from the camera using the information from the height and width of the boundary box, and their integration

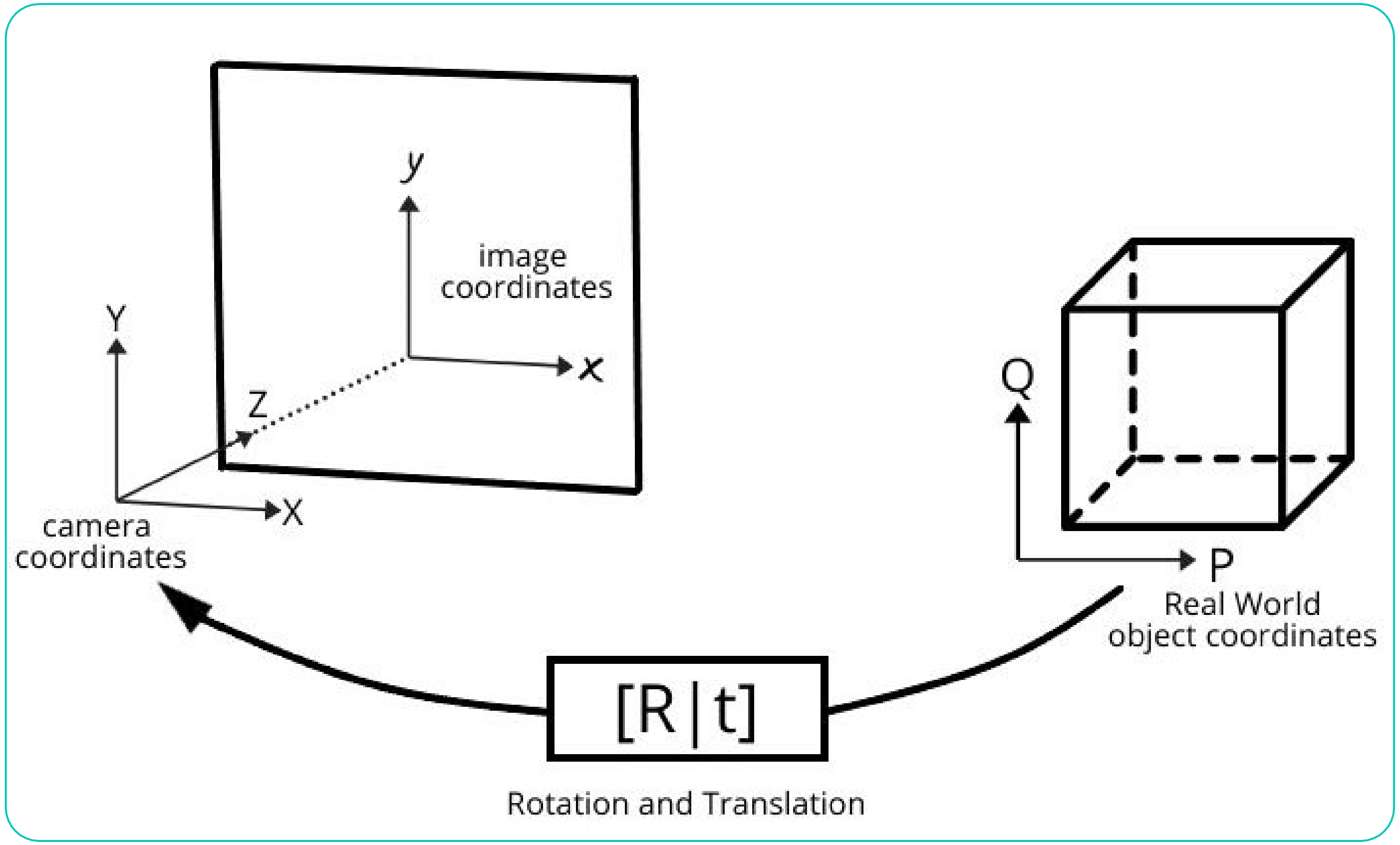

Fig. 1. Points on a planar surface: forward projection

Proposed Methods: Homography Based

Projective Equation

$$s\begin{bmatrix}x\\y\\1\end{bmatrix} \approx \begin{bmatrix}f_x & 0 & c_x\\0 & f_y & c_y\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}r_{11} & r_{12} & r_{13} & t_x\\r_{21} & r_{22} & r_{23} & t_y\\r_{31} & r_{32} & r_{33} & t_z\end{bmatrix}\begin{bmatrix}X\\Y\\Z\\1\end{bmatrix}$$

$$s\begin{bmatrix}x\\y\\1\end{bmatrix} \approx \begin{bmatrix}f_x & 0 & c_x\\0 & f_y & c_y\\0 & 0 & 1\end{bmatrix}\begin{bmatrix}r_{11} & r_{12} & t_x\\r_{21} & r_{22} & t_y\\r_{31} & r_{32} & t_z\end{bmatrix}\begin{bmatrix}X\\Y\\1\end{bmatrix}$$

Homography Equation

$$s\begin{bmatrix}x\\y\\1\end{bmatrix} \approx \begin{bmatrix}h_{11} & h_{12} & h_{13}\\h_{21} & h_{22} & h_{23}\\h_{31} & h_{32} & h_{33}\end{bmatrix}\begin{bmatrix}X\\Y\\1\end{bmatrix}$$

Proposed Methods: Real-Time Distance Detection

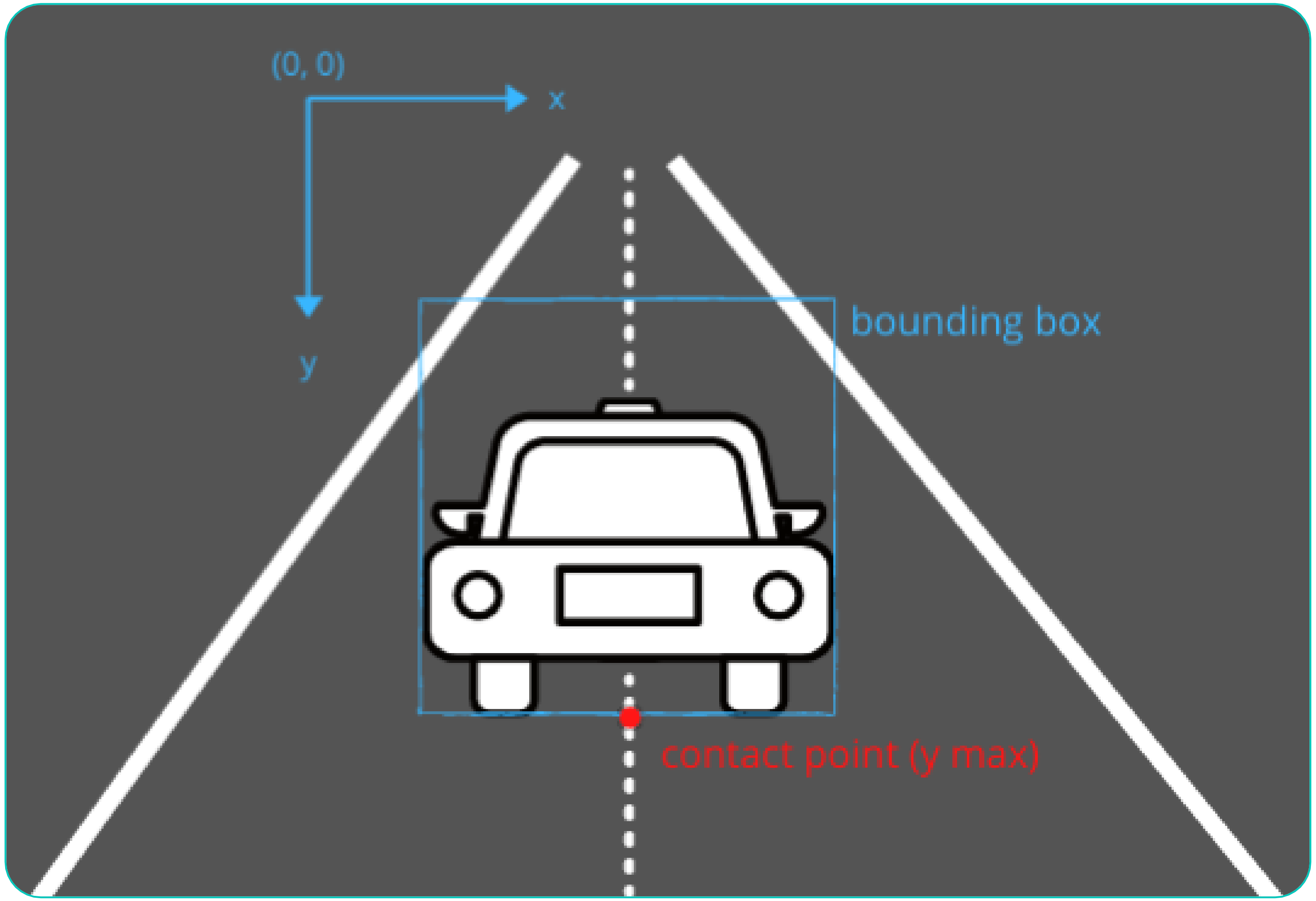

Fig. 2. Contact point between car and road

- Single Shot Detection (SSD) model in Tensorflow on the COCO dataset
- Target vehicles: car, truck, bus
- Contact point is the maximum y of BB
- Assumption: The contact point is the bottom point of the BB

Experimental Setup

- Camera: HikVision DS-2CD2043G0-I IP

TABLE I. EXPERIMENTAL SETUP PARAMETERS

Camera Height [m]	2.40	2.00	1.60	1.20
Tilt Angle β [deg]	64.2	68.2	72.26	76.5

- The center of the camera view is always fixed at 3.0 meters (shown with red dash line in Fig. 3).

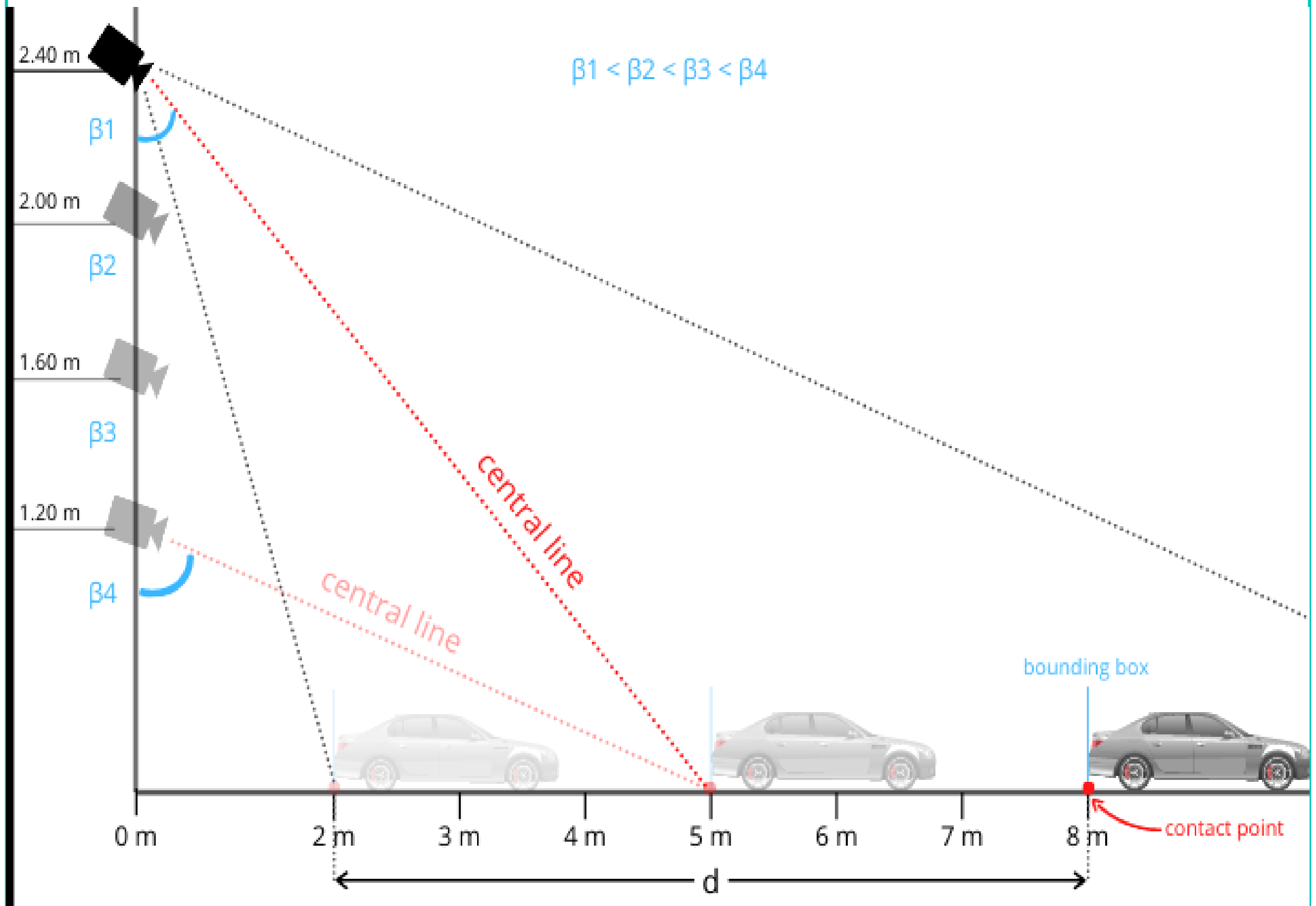

Fig. 3. Experimental Setup

Homography experiment

1. Import an undistorted image with tennis balls located with 1 meter apart

2. Export pixel coordinates (x, y, z = 1) selecting tennis balls

$$s \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \approx \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix}$$

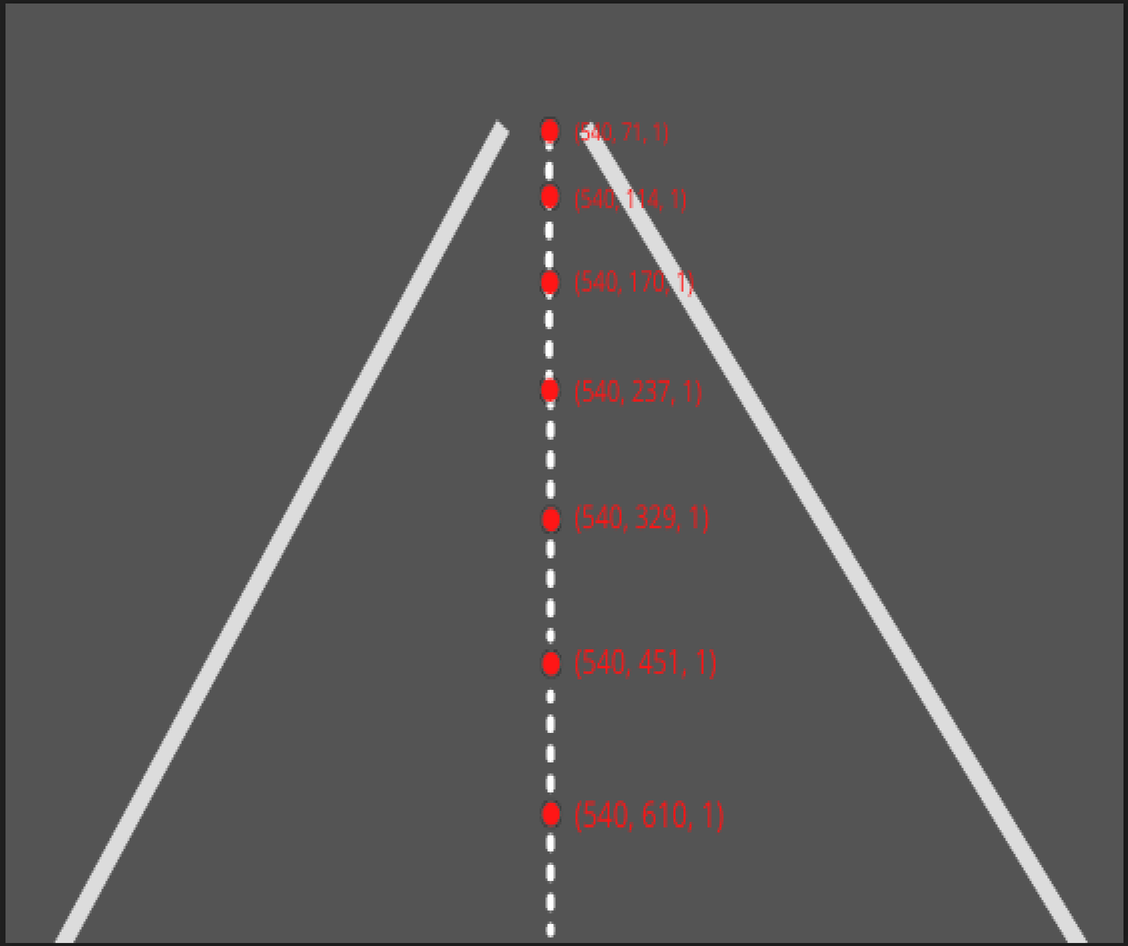

Fig. 4. Experimental Setup

Real-Time Distance Detection Experiment

$$\arctan(\theta_2) = \frac{true\ distance_1 + 2}{H_c}$$

$$true\ distance_1 = \frac{projected\ distance_1}{\sin(90 - \theta_2)} + 2$$
$$= \frac{projected\ distance_1}{\cos(\theta_2)} + 2$$

$$true\ distance_2 = \frac{projected\ distance_8}{\sin(90 - \theta_8)} + 2$$
$$= \frac{projected\ distance_8}{\cos(\theta_8)} + 2$$

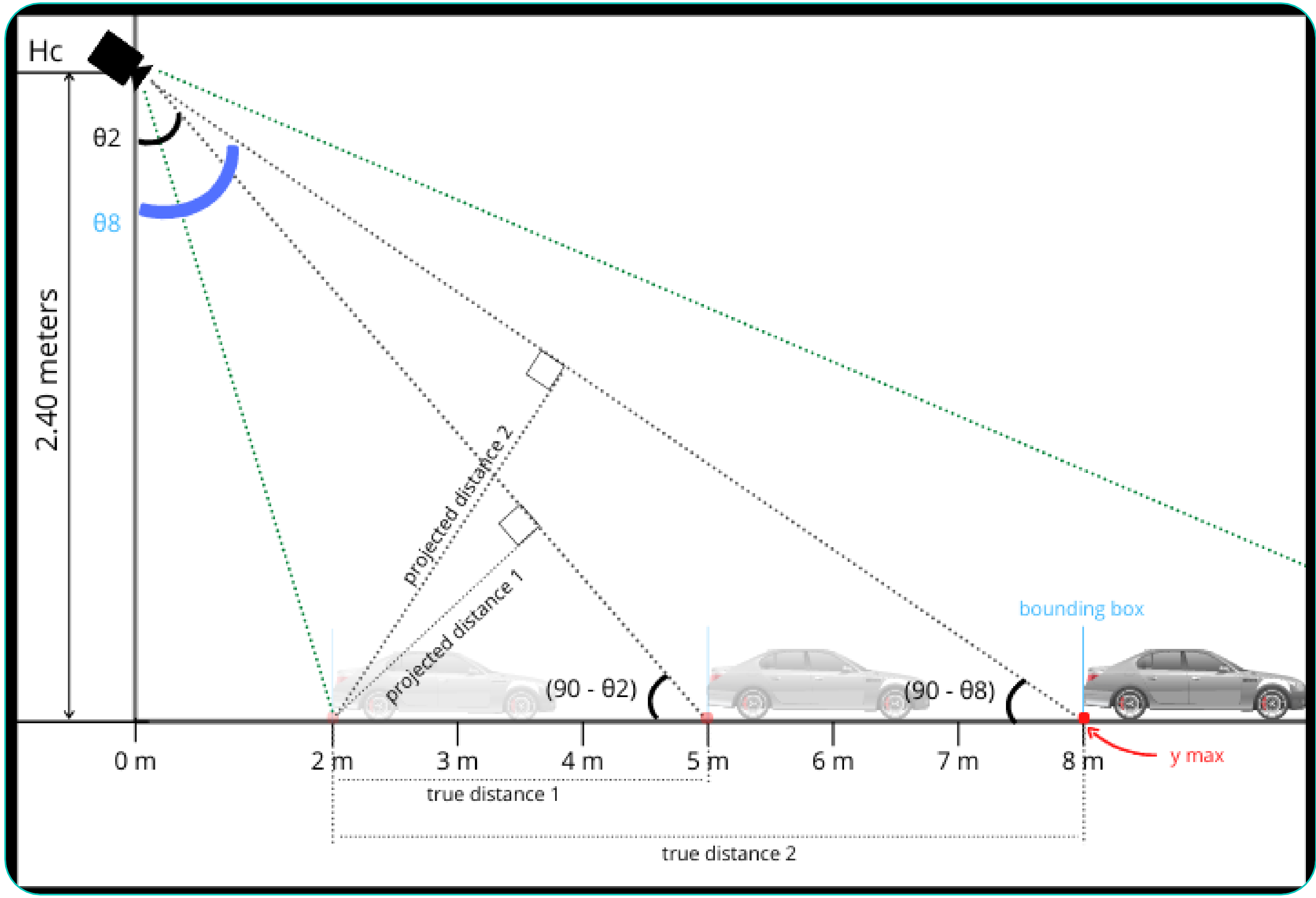

Fig. 5. Distance estimation using ymax of the bounding box

Homography experimental results

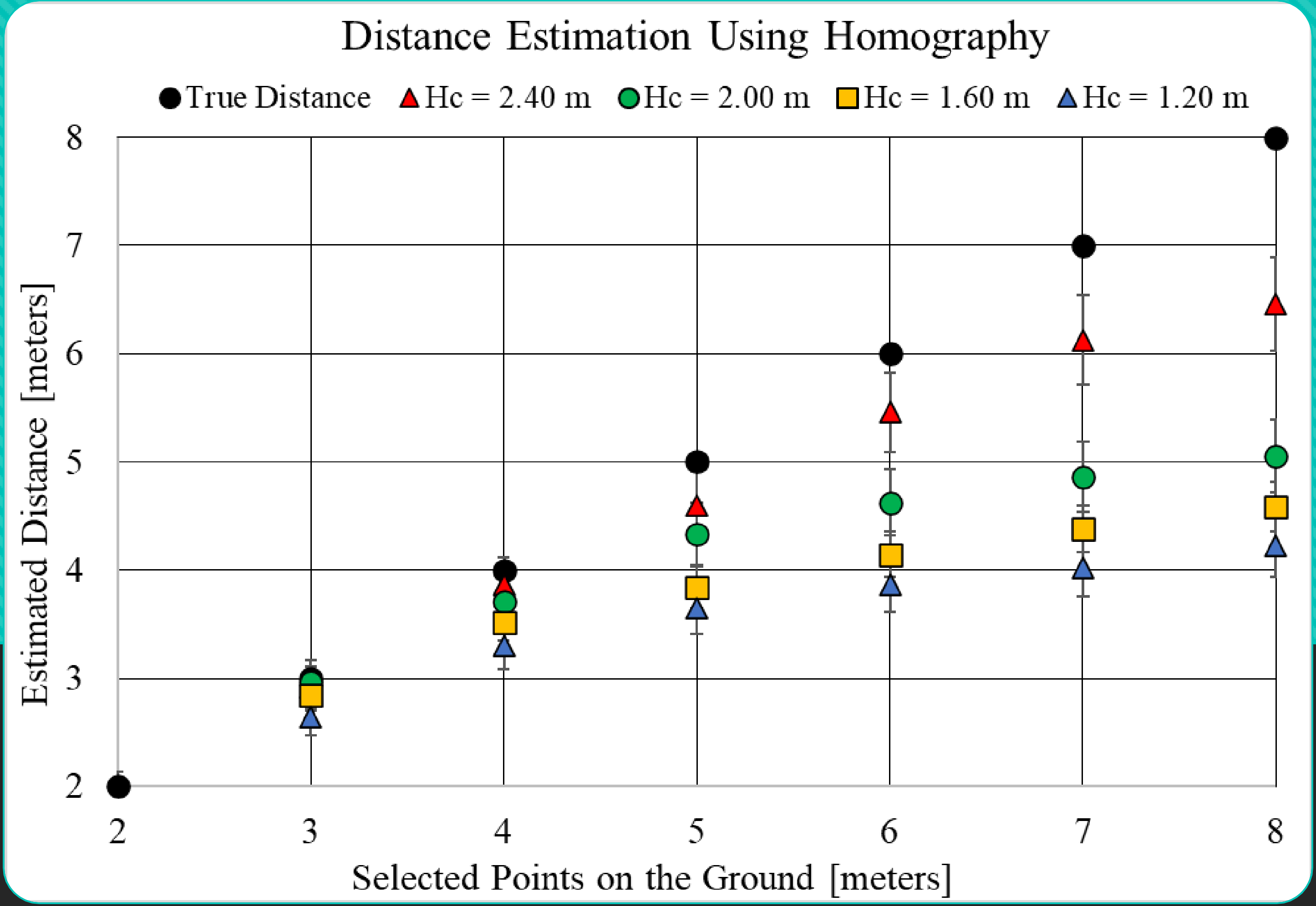

Fig. 6. Experimental results

True Distance [m]	Average Estimated Distance at Hc = 2.40 m	RMSE	Average Estimated Distance at Hc = 2.00 m	RMSE
2.0	1.9988	0.001	1.9530	0.047
3.0	2.9153	0.085	2.9642	0.036
4.0	3.8590	0.141	3.7025	0.298
5.0	4.6027	0.397	4.3316	0.668
6.0	5.4569	0.543	4.6247	1.375
7.0	6.1265	0.873	4.8614	2.139
8.0	6.4561	1.544	5.0496	2.950
True Distance [m]	**Average Estimated Distance at Hc = 1.60 m**	**RMSE**	**Average Estimated Distance at Hc = 1.20 m**	**RMSE**
2.0	1.9724	0.028	1.9141	0.086
3.0	2.8454	0.155	2.6454	0.355
4.0	3.5210	0.479	3.3010	0.699
5.0	3.8406	1.159	3.6474	1.353
6.0	4.1463	1.854	3.8681	2.132
7.0	4.3808	2.619	4.0204	2.980
8.0	4.5858	3.414	4.2198	3.780

Table II. RMSE of results

Real-Time distance estimation experimental results

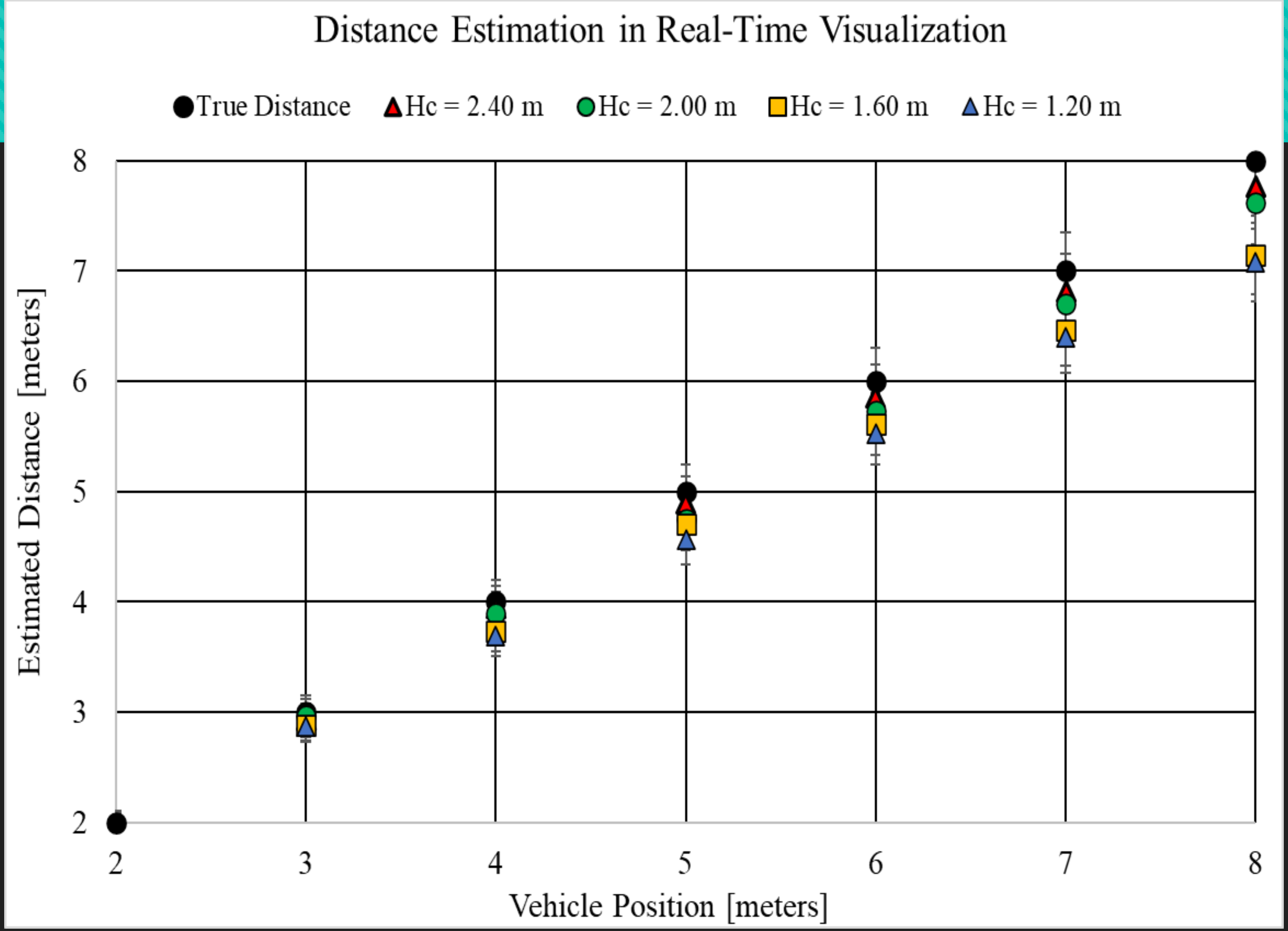

Fig. 6. Experimental results

True Distance [m]	Average Estimated Distance at Hc = 2.40 m	RMSE	Average Estimated Distance at Hc = 2.00 m	RMSE
2.0	1.9965	0.003	1.9829	0.020
3.0	2.9255	0.075	2.9711	0.025
4.0	3.9440	0.056	3.8995	0.201
5.0	4.8944	0.106	4.7519	0.248
6.0	5.8573	0.143	5.7342	0.266
7.0	6.8198	0.180	6.7048	0.295
8.0	7.7695	0.230	7.6224	0.378
True Distance [m]	**Average Estimated Distance at Hc = 1.60 m**	**RMSE**	**Average Estimated Distance at Hc = 1.20 m**	**RMSE**
2.0	1.9807	0.019	1.9267	0.073
3.0	2.8846	0.115	2.8751	0.125
4.0	3.7335	0.266	3.6921	0.308
5.0	4.7019	0.298	4.5684	0.432
6.0	5.6105	0.389	5.5213	0.479
7.0	6.4645	0.536	6.3993	0.601
8.0	7.1427	0.857	7.0830	0.917

Table III. RMSE of results

Conclusion

- Both tested methods showed the best performance with highest camera altitudes (Hc = 2.40 meters) and tilt angle of 64.2^o
- Distance accuracy increases with decreasing camera position respect to the ground level
- Real-time distance detection method has much more reliable outcomes compared to the homography at 2.40 and 2.00 meters with only 0.230 and 0.378 maximum RMSE
- The vehicles with the mono camera mounted at certain height (in this case more than 2.00 meters) can estimate the distance of target front vehicle
- These methods can improve autonomous and driving assistance functions and decreases the level of road risk
- Proposed solutions are economically beneficial since it does not demand high-priced technologies
- Research work will be extended by testing those distance estimation methods at higher camera heights and in extensive test area

Reference List

1. B. Liang, N. Pears, "Visual Navigation using Planar Homographies," Proceedings 2002 IEEE International Conference on Robotics and Automation, vol. 1, pp. 205-210, May 2002
2. X. Wu, F, Guan, A, Xu, "Passive Ranging Based on Planar Homography in a Monocular Vision System," Journal of Information Processing Systems, vol. 1, pp. 155-170, February 2020
3. H. Cheung, W. Siu, L. Steven, Ng. Chiu-Shing, "Accurate Distance Estimation Using Camera Orientation Compensation Technique for Vehicle Driver Assistance System," 2012 IEEE International Conference on Consumer Electronics (ICCE), pp. 227-228, January 2012
4. Sh. Samuel, B. Joachim, E. Emil, K. Amrit, G. Karl, "Mono-Camera 3D Multi-Object Tracking Using Deep Learning Detections and PMBM Filtering," 2018 IEEE Intelligent Vehicles Symposium (IV), vol. 4, pp. 433-440, June 2018
5. E. Mohamed, M. S. Ahmed, M. M. Mostafa, R. M. Hassan, H. A. Munim, M. Ghoneima, M. S. Darweesh, H. Mostafa, "Real-Time Car Detection-Based Depth Estimation Using Mono Camera," In 2018 30th International Conference on Microelectronics (ICM), pp. 248-251, December 2018