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To cite this article: Shuaihui Qi *et al* 2019 *J. Phys.: Conf. Ser.* **1237** 022120

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# Short-term and Fast Tracking Algorithm of Vehicle with Distance Information

Shuaihui Qi<sup>1</sup>, Zhiyuan Li<sup>1</sup>, Jianfeng Ma<sup>1</sup>, Qinghui Zhang<sup>1</sup> and Shasha Xu<sup>1</sup>

<sup>1</sup> National University of Defense Technology, Xi'an, ShanXi, 710106, China

18883381539@163.com, 2484908@qq.com, 13566701@qq.com,  
158290815@qq.com and 20376272@qq.com

**Abstract.** To solve the contradiction between speed and performance in vehicle tracking, this paper designs a short-term and fast tracking algorithm which integrates vehicle distance information. Millimeter wave radar is used to get accurate range information to optimize the scale of vehicle, so as to achieve fast and accurate vehicle tracking. The effectiveness of the algorithm in scale optimization is proved by experiments.

## 1. Introduction

In autonomous driving, target tracking algorithm can track moving objects and predict their position and speed in the future. It can automatically analyze and extract trajectory to make up for the shortcomings of target detection, effectively remove false alarms and compensate for missed objects, then provide effective information for further behavior analysis.

Before correlation filter, classical tracking methods, such as mean-shift [1], particle filter [2], kalman filter [3] and TLD [4] are used in tracking field. Until MOSSE [5] is raised, tracking methods based on correlation filter are introduced into tracking field. It collects image samples and trains filters to generate filter template, which convolute the image to obtain the maximum output response and update filter online. The advantage of correlation filter is rapidity realized by fast fourier transform. P. Martins et al. propose CSK [6], which is a kernel tracking method based on cyclic matrix, and it solves the problem of dense sampling perfectly. In 2014, P. Martins propose KCF [7]. It takes CSK as baseline. Multi-channel features are utilized and ridge regression in linear space is introduced into non-linear space to generate target detector and it achieves better result than CSK. However, MOSSE, CSK and KCF can not solve the problem of scale. After that, Martin Danelljan et al. propose DSST algorithm [8]. Two-dimensional displacement filter and one-dimensional scale filter are learned to solve the problem of target offset and scale change in tracking. In 2015, Ma C et al. propose LCT algorithm [9] based on DSST. By introducing the detection mechanism of TLD, the cumulative tracking error can be effectively corrected. Due to highly computation, tracking speed is slightly slower than DSST. In the VOT2016, C-COT algorithm [11] based on correlation filter combined with multi-layer deep features ranked first. Taking C-COT as baseline, Martin Danelljan raise ECO algorithm [12], which achieved better performance and tracking speed. ECO is the best correlation filter algorithm at present. However, the tracking algorithm based on correlation filter does not perform well in fast deformation and motion. In non-scale tracking algorithm, because of low computation, it can achieve a highly speed, but the performance is poor. In tracking algorithm with scale, the computation increases and leads to low speed.



Combined with the application of target tracking in unmanned driving, a short-term and fast vehicle tracking algorithm based on distance information is proposed. To keep high speed, this paper takes non-scale tracking algorithm as baseline, combined with accurate distance information of vehicle by radar to correct the scale of vehicle in real time, so as to achieve fast and better tracking.

## 2. Short-term and Fast Tracking Algorithm of Vehicle with Distance Information

In order to track the vehicle quickly and perfectly, we take the MOSSE, CSK and KCF as baseline, the vehicle scale optimization is realized by introducing the distance information of millimeter wave radar.

According to the principle of correlation filter in [5], correlation filter is used for tracking by learning the optimal filter in real time, and then convolute the filter with the image to get the position of the maximum response as the tracking center. Therefore, the center of the tracking result obtained by the tracking algorithm based on correlation filter is basically maintained on the center of the target. Taking the above three algorithms as an example, the results after tracking 15 frames are shown in figure 1. '+' indicates the actual center of the vehicle, 'o' indicates the center after tracking. Combining with Table 1, we can see that the KCF tracking algorithm works best. When the proportion of the center error occupying the diagonal line of bounding box of the vehicle is taken as the evaluation criterion, the error is 1.0804%, and the result of MOSSE algorithm is the worst, the error is 8.2761%, but the speed of KCF is much lower than MOSSE, and the performance of CSK tracking algorithm is between KCF and MOSSE. From figure 1, it is found that although the three tracking algorithms can not solve the vehicle scale problem, the center of the vehicle will not change much after tracking 15 frames, and the center of vehicle can be obtained quickly and accurately, we call it invariance of center.

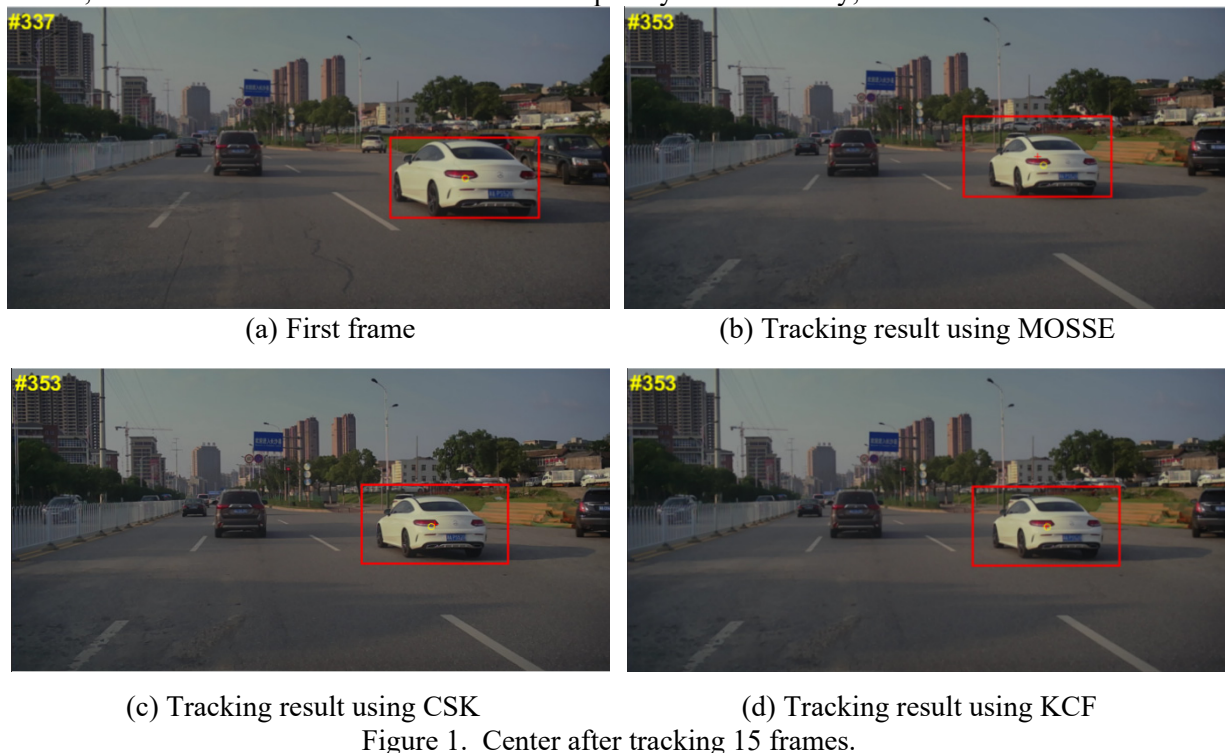


Figure 1. Center after tracking 15 frames.

Table 1. Center error of tracked vehicle.

Tracker	MOSSE	CSK	KCF
Speed	1112fps	911fps	167fps
Center error	8.2761%	3.3299%	1.0804%

According to [13], the width of vehicle in image is inversely proportional to the forward distance of the vehicle. That is mean that the larger the forward distance of vehicle, the smaller the size of the

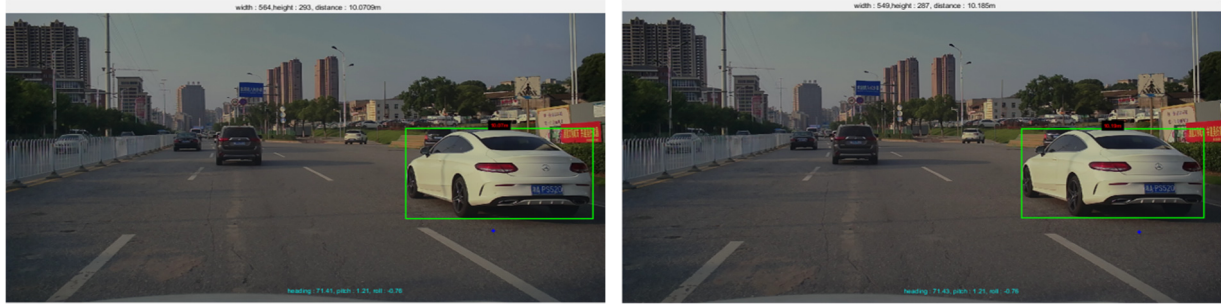
bounding box, and the smaller the forward distance of vehicle, the larger the size of the bounding box. So the distance information given by millimeter wave radar can be used to estimate the scale of bounding box, so that the size of bounding box can be obtained more accurately.

Because captured rate of camera is 20 fps and the vehicle changes little between adjacent frames, the width **W** of the bounding box of can be approximately inversely proportional to forward distance **D** of vehicle.

$$C = W * D \quad (1)$$

Where **C** denotes a constant.

As shown in figure 2, the result of bounding box between adjacent frames and forward distance information are shown. From table 2, we can know that the calculation error of constant term **C** between adjacent frames is 1.56%, which can be neglected approximately.



(a) Current frame

(b) Next frame

Figure 2. Change of the same vehicle in adjacent images.

Table 2. width and distance of the same vehicle in adjacent images.

	<b>W</b>	<b>D</b>	<b>C</b>	error
<b>Current frame</b>	564	10.0709m	5679.9876	1.56%
<b>Next frame</b>	549	10.185m	5591.565	

This paper synthesizes the above two aspects of information: the rapidity of the tracking algorithm and the accuracy of tracking center. According to the relationship between the size of the vehicle and the distance, a fast tracking algorithm integrating millimeter wave radar information is proposed, which is convenient to get the accurate position of vehicle.

$[x_1, y_1, w_1, h_1]$  represents the bounding box of vehicle in current frame and distance of vehicle is  $D_1$ .  $[x_2, y_2, w_2, h_2]$  represents the bounding box of vehicle after tracking in next frame and distance of vehicle is  $D_2$ . From figure 2, table 2 and equation (1), the same vehicle with two adjacent frames approximates to equation (1), i.e.

$$w_1 * D_1 \approx w_2 * D_2 \quad (2)$$

According to the invariance of center, we can update tracking result of next frame with equation (3).  $[x_3, y_3, w_3, h_3]$  represents the bounding box of vehicle in next frame after updating.

$$\begin{aligned} x_3 &= x_2 - w_2 / 2 + w_3 / 2 \\ y_3 &= y_2 - h_2 / 2 + h_3 / 2 \\ w_3 &= \frac{w_1 * D_1}{D_2} \\ h_3 &= \frac{h_1 * D_1}{D_2} \end{aligned} \quad (3)$$

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**Algorithm: Short-term and Fast Tracking Algorithm of Vehicle with Distance Information**


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**Input:** Images, bounding box of current frame  $[x_1, y_1, w_1, h_1]$ , radar datas

**Output:** bounding box of next frame  $[x_3, y_3, w_3, h_3]$

1. Match bounding box of vehicle with radar data in current frame to ensure distance D1 ;
  2. Use tracker to track vehicle, get the bounding box in next frame  $[x_2, y_2, w_2, h_2]$ , matching  $[x_2, y_2, w_2, h_2]$  with radar data in next frame to get distance D2;
  3. Update bounding box of vehicle in next frame by equation (3) and get new position  $[x_3, y_3, w_3, h_3]$ .
- 

### 3. Experiment

In order to validate the algorithm, the camera and the millimeter-wave radar are used for data acquisition. The millimeter-wave radar is installed in front of the vehicle. The ESR radar of 76-77 GHz has the ability of long-range and medium-range scanning. The images are collected by the OV10650 camera mounted on the windshield horizontally. The size of the image is 1824\*940\*3. In this paper, the accurate distance of vehicles can be computed by the matching method of bounding box and radar data in [14]. Our approaches are implemented in Matlab 2017b. All experiments are performed on laptop, with single CPU core (2.2GHz) of an Intel Core i7-8750H.

#### 3.1 Evaluation Criterion

When evaluating the performance of the algorithm, we use intersection of union (IoU) to evaluate the performance of each algorithm. We calculate the overlap rate between the bounding box generated by the algorithm and the actual bounding box of the target, as shown in figure 3.

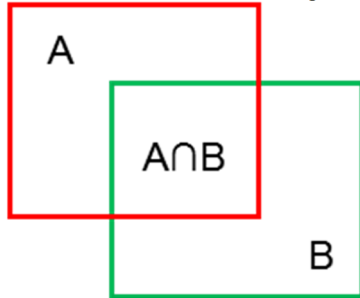


Figure 3. IoU.

The calculation of IoU as follow:

$$IoU = \frac{A \cap B}{A \cup B} \quad (4)$$

IoU is calculated from the tracking result and Ground Truth of the vehicle in each frame. If IoU is larger than the threshold of IoU, it can be considered to finish track successfully. We set different IoU threshold to draw curve and take it to evaluate the performance of the algorithm. As shown in figure 4, the area under the curve is the value of AUC. The larger the AUC, the better the performance.

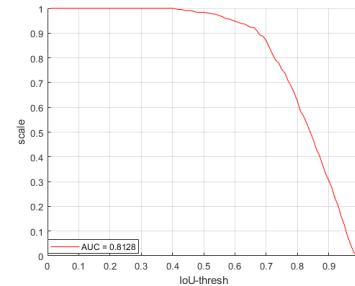


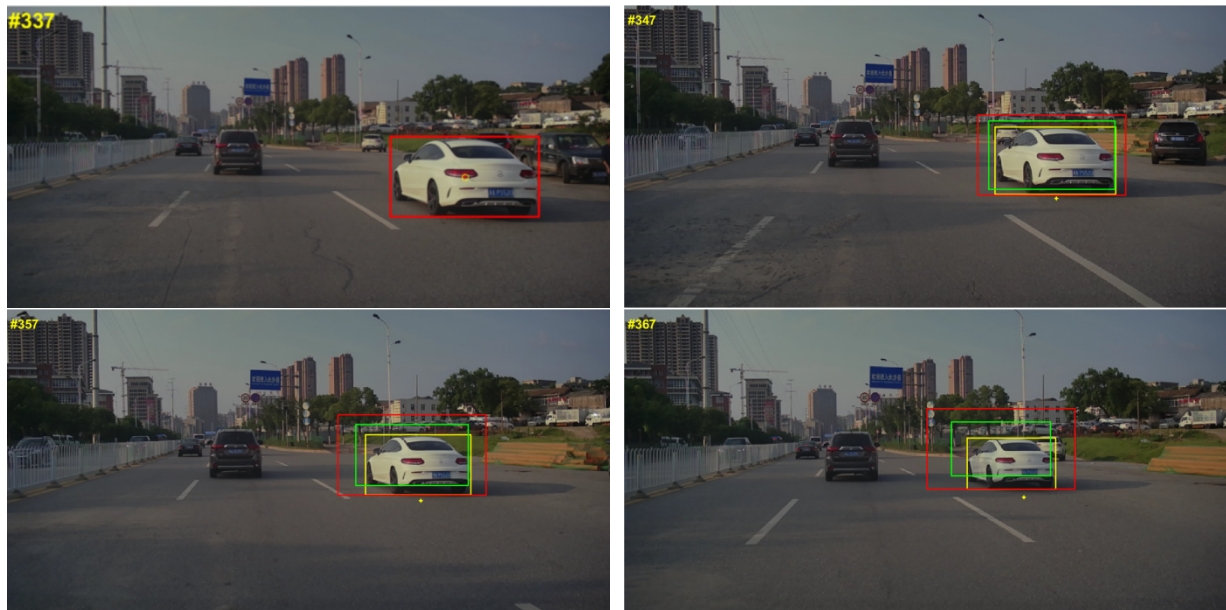
Figure 4. Curve of different threshold.

#### 3.2 Results

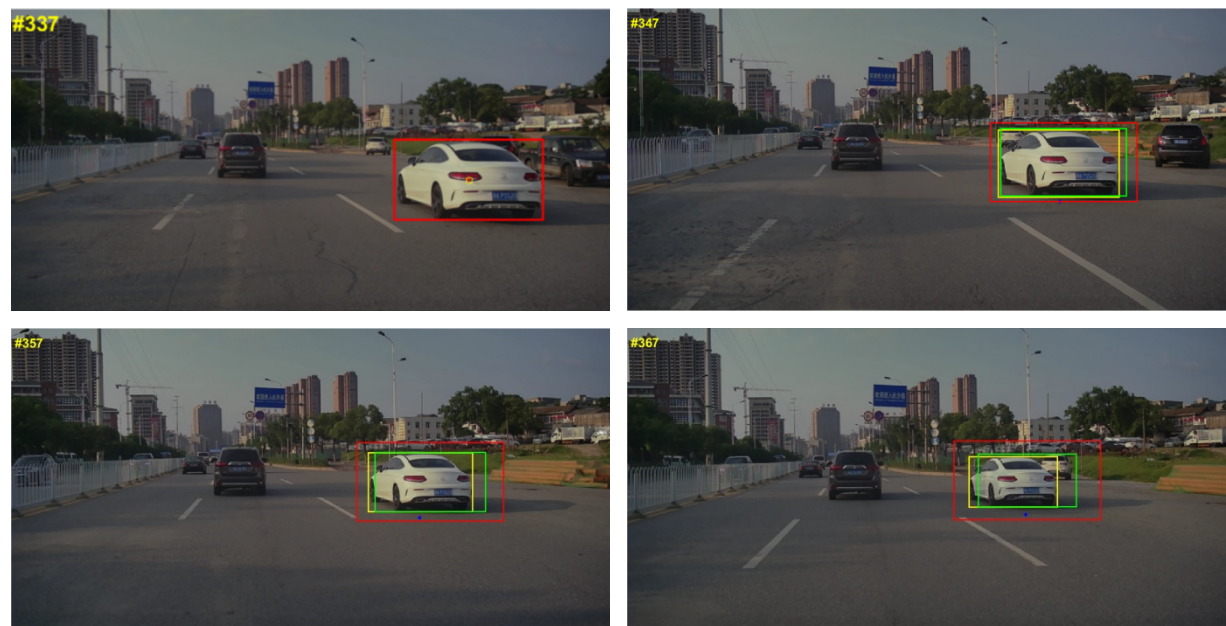
In order to test the performance of the algorithm, we select two groups data to test algorithm, each of which includes image sequences and millimeter wave radar data corresponding to image sequences.

Firstly, the target vehicles in the image sequences of the above two groups are labeled. Then, target tracking is carried out by our algorithm. The results are shown in figure 5, where the red bounding box represents the tracking result of the original algorithm, the green bounding box represents the tracking result of our algorithm, and the yellow bounding box represents the Ground Truth of vehicle.

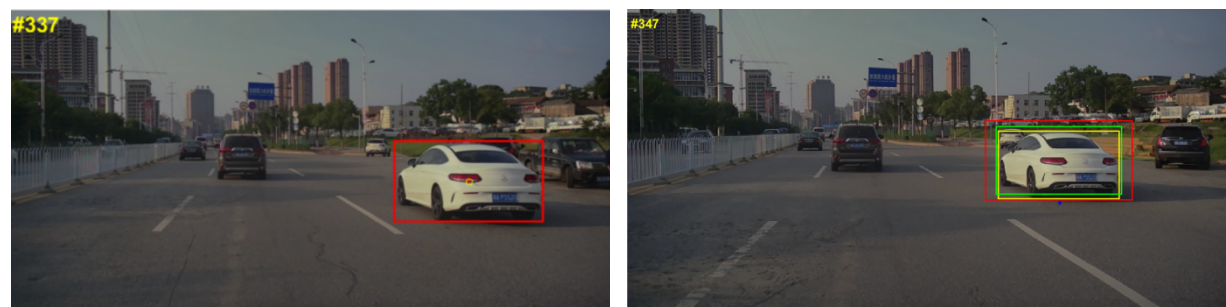




(a) Tracking result based on MOSSE.



(b) Tracking result based on CSK.





(c) Tracking result based on KCF.

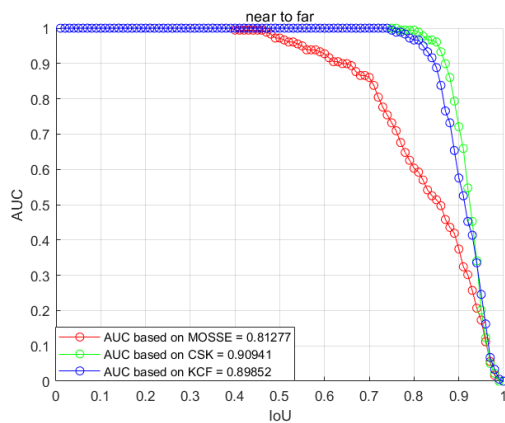
Figure 5. Tracking results based on three algorithms.

As shown in figure 5, the introduction of millimeter wave radar information can better solve the scale problem in the original tracking algorithm. However, it can be seen from the figure 5 that the scale optimization algorithm works better in a short time after the vehicle is initialized. As time goes on, the tracking effect becomes worse and drift is prone to occur. This is due to the change of vehicle shape caused by the change of position between vehicles, resulting in the center of vehicle is no longer the position with the highest response. This is the defect of the original algorithm itself. And our algorithm has a good scale optimization effect in a short period of time, which can not only maintain high speed, but also maintain good tracking results. In order to make the algorithm available for a long time, it needs to be reinitialized by vehicle detection algorithm after tracking for a period of time.

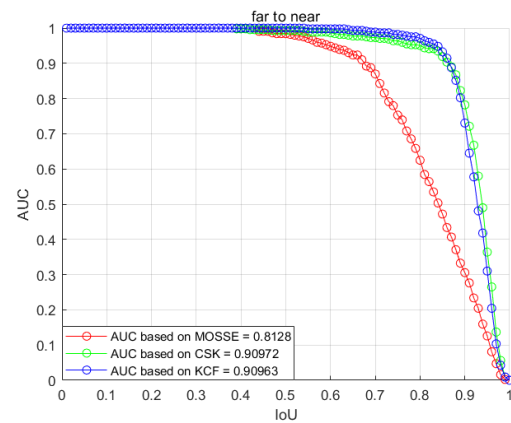
To select which of the three tracking algorithms is the best for tracking, we test two groups image sequences, one is from near to far, the other one is from far to near. The results of vehicle detection run once every 15 frames for tracking initialization. The results are shown in figure 6 and table 3.

Table 3. Speed of our algorithm based on three algorithms.

tracker	MOSSE+Radar	CSK+Radar	KCF+Radar
<b>Speed of Group 1</b>	551fps	265fps	165fps
<b>Speed of Group 2</b>	653fps	270fps	200fps



(a) From near to far



(b) From far to near

Figure 6. AUC of two groups image sequences of our algorithm.

From figure 6 and table 3, it can be seen that millimeter wave radar information based on CSK algorithm can achieve the best results in optimizing target scale, and the speed of this method can reach to 260 fps. Therefore, in order to ensure the rapidity and accuracy of tracking, CSK algorithm is selected for target tracking.

#### 4. Conclusion

Aimed at the problem of poor performance of non-scale tracking algorithm and low speed of scale-based tracking algorithm, a short-term and fast vehicle tracking algorithm based on distance information is proposed in this paper. The accurate range information of millimeter wave radar is used to modify the scale of tracking algorithm. Finally, the effectiveness of the algorithm is proved by experiments. This algorithm can be used to replace vehicle detection results with tracking results in short term.

#### Acknowledgement

Thanks unmanned driving team of the University of Defense Science and Technology especially to provide experiment data.

#### Conferences

- [1] Comaniciu D, Meer P. Mean shift: A robust approach toward feature space analysis[J]. IEEE Transactions on pattern analysis and machine intelligence, 2002, 24(5): 603-619.
- [2] Hess R, Fern A. Discriminatively trained particle filters for complex multi-object tracking[C]//Computer Vision and Pattern Recognition, 2009. CVPR 2009. IEEE Conference on. IEEE, 2009: 240-247.
- [3] Weng S K, Kuo C M, Tu S K. Video object tracking using adaptive Kalman filter[J]. Journal of Visual Communication and Image Representation, 2006, 17(6): 1190-1208.
- [4] Kalal Z, Mikolajczyk K, Matas J. Tracking-learning-detection[J]. IEEE transactions on pattern analysis and machine intelligence, 2012, 34(7): 1409-1422.
- [5] Bolme D S, Beveridge J R, Draper B A, et al. Visual object tracking using adaptive correlation filters[C]//Computer Vision and Pattern Recognition (CVPR), 2010 IEEE Conference on. IEEE, 2010: 2544-2550.
- [6] Henriques J F, Rui C, Martins P, et al. Exploiting the Circulant Structure of Tracking-by-Detection with Kernels[M]// Computer Vision – ECCV 2012. Springer Berlin Heidelberg, 2012:702-715.
- [7] Henriques J F, Caseiro R, Martins P, et al. High-Speed Tracking with Kernelized Correlation Filters[J]. IEEE Transactions on Pattern Analysis & Machine Intelligence, 2014, 37(3):583-596.
- [8] Danelljan M, Häger G, Khan F, et al. Accurate scale estimation for robust visual tracking[C]//British Machine Vision Conference, Nottingham, September 1-5, 2014. BMVA Press, 2014.
- [9] Ma C, Yang X, Zhang C, et al. Long-term correlation tracking[C]//Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition. 2015: 5388-5396.
- [10] Danelljan M, Häger G, Khan F S, et al. Discriminative scale space tracking[J]. IEEE transactions on pattern analysis and machine intelligence, 2017, 39(8): 1561-1575.
- [11] Danelljan M, Robinson A, Khan F S, et al. Beyond correlation filters: Learning continuous convolution operators for visual tracking[C]//European Conference on Computer Vision. Springer International Publishing, 2016: 472-488.
- [12] Danelljan M, Bhat G, Khan F S, et al. ECO: Efficient Convolution Operators for Tracking[J]. arXiv preprint arXiv:1611.09224, 2016.
- [13] Dagan E, Mano O, Stein G P, et al. Forward collision warning with a single camera[C]// Intelligent Vehicles Symposium. IEEE, 2004:37-42.
- [14] Liu X, Sun Z, He H. On-road vehicle detection fusing radar and vision[C]// IEEE International Conference on Vehicular Electronics and Safety. IEEE, 2011:150-154.