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Vehicle Velocity Detection System Based on Real-Time Motion Tracking

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Abstract: *Intelligent transportation systems (ITS) use novel technology relying on computer vision to provide traffic parameters such as average speed in the road, lane changes, vehicles' accelerations/decelerations, vehicles classification, etc. In this paper a mixture algorithm is proposed for velocity detection. The algorithm is based on object tracking, and relies on a perspective transformation. A novel heuristic is proposed to detect cars and trace them. The algorithm is fast enough to run real-time on a normal laptop which makes it efficient in practice (e.g. to be used by police force). There are still some open issues such as shadow detection and cancellation, and occlusion handling that will be considered in future works.*

Keywords: *Object Tracking, Motion Detection, Velocity Detection, Object Positioning.*

1 Introduction

Video sensors become particularly important in traffic applications mainly due to their fast response, easy installation, operation and maintenance, and their ability to monitor wide areas. Research in several fields of traffic applications has resulted in a wealth of video processing and analysis methods [1].

The proposed approach is designed to detect vehicle speeds via tracking the vehicle in a sequence of images.

The project's aim is to determine velocity of vehicles in inter-city roads. The result of this project could help Police Rah. The system is intended to be flexible, easy to use and vision-based that would be enabling to track cars and report speed of vehicles which are visible in the scene.

Till now, several studies have focused on vision-based approaches for traffic surveillance. Also a variety of methods exists for People or Object detection. Mixture models have been used for specific applications. In this paper related works on both problems are reviewed briefly in Section 2. The proposed approach is described in details in Section 3. Experimental results based on some tests carried out on real road movies are presented in Section 4.

2 Previous Studies

Beymer and McLauchlen worked on congested traffic and detecting traffic parameters [2]. Moving edges are used as the main feature for tracking. Based on these features they announced a novel approach for determining traffic parameters.

On the other hand, motion tracking based on background subtraction, as the basis for traffic scene analysis was subject of several studies. Background-model creation, choosing threshold and object positioning are still challenges in single-camera surveillance.

Fig. 1 illustrates the main parts of generic vehicle velocity detection system. Recent studies briefly described in this section.

2.1 Background Model

Many studies on object tracking focused on background model for improving performance of tracking. In all studies, a set of sample images are processed to produce a unique image [2], a formula [3-4] or an infra structure [5] as the background model.

Varying lighting conditions is a major obstacle for tracking algorithms. Some studies use background update strategies [3, 4, and 9] and some other use background normalization to overcome illumination change problems [6].

Elgammal and Harwood model each pixel of background by a Gaussian distribution and introduce a robust, non-parametric approach [3]. In this method a Normal Distribution Function is induced for each pixel representing the probability of that pixel to be in background. In this way they classify pixels based on their probabilities avoiding any extra parameter such as thresholds. KaewTraKulPong improved results of [3] by background update strategies and enhancing probability distribution parameters [4].

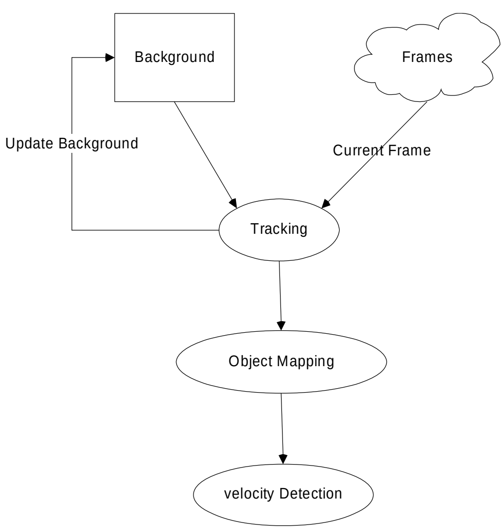

Figure 1 Generic velocity Detection system structure

Some other studies use median of pixel intensities of samples for background model creation. This reduces complexity, while they can exclude non-stationary objects from background modelling process. This feature is very useful in real applications, e.g. assume a normal road with several vehicles travelling. In such road it's impossible to have a clean image that only contains stationary objects of background. Haritaoglu and Harwood introduced a good model that neither suffers from non-stationary objects, nor has any preconfigured parameters and can be used in any environment without any further configurations [5].

2.2 Tracking

Object tracking is one of the main functionalities of machine vision which has been the center of focus of many researches so far. In [7] Keisarian focused on this issue and introduced a new approach on tracking vehicles. He uses frame-background subtraction information and inter-frame difference as two independent features to track motion.

Besides traffic surveillance systems, people tracker systems have novel methods too. W4 as a people tracker system, only uses frame subtraction information as the basis of people detection and tracking [5].

Many other researches are focused on stereo vision to eliminate the effects of occlusion and distortion. Bertozzi who is famous for his stereo discussions introduces GOLD system [8]. He uses lane information for determining object positions and image histograms for removing occlusions.

Besides, edges and corners are also very useful for tracking. Beymer introduced a velocity detection system base on tracking edges [2].

2.3 Object Mapping

When the tracking phase is done the next step is to determine the object position in real-world coordinates. Fig. 2 depicts such mapping. The most popular approach to support such mapping is Inverse Perspective Mapping or the so-called Homography method [2, 7, 8, and 9].

Mallot and Bulthoff created the Homography method. They introduce a transformation matrix which converts image coordinates to real-world coordinates and is called Homography matrix [10].

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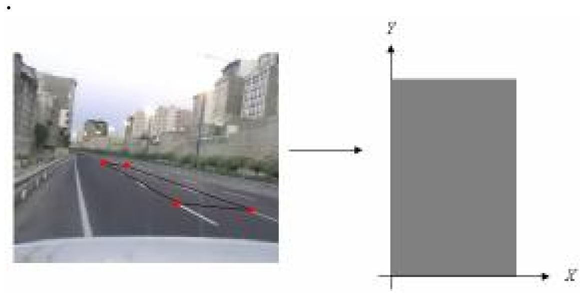

Figure 1 Perspective transform

2.3 Object Mapping

The vehicle velocity could be easily determined if the former described modules of the system work correctly. Under constant speed assumption during the monitoring period, the speed of the vehicle on the road is [9]:

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$$v = \frac{dy(t)}{dt} \tag{1}$$

In the reviewed works no other speed detection strategies were found. And in most researches velocity detection phase has not been discussed in details.

3 Proposed method

The main objective of this work is to find the velocity of vehicles traveling in inter-city roads. The introduced software works based on object tracking approach to detect vehicles in roads. Then, a positioning module estimates position of objects in real world. And the final step would be calculating the speed of object based on produced information.

Firstly, background model generation process will be described and then algorithms used in different system sections are introduced. In some studies this kind of categorization is called offline and online process [9]. In our case offline process includes background generation and Homography transform induction, and online process contains tracking, vehicle determination and velocity detection.

3.1 Offline Process

As mentioned before, offline process contains background model generation and Homography matrix computation. The former includes the creation of a model for background to rely on. And the later is the process of computing appropriate transformation matrix for Homographic mapping [10].

Based on recent studies and after implementing some of them we used W4 background model [5]. Assume we have sample images to create background model. First step is to categorize pixels as stationary or non-stationary in each frame. This is done by checking the intensity difference of each pixel with its corresponding pixels in temporal neighbourhood images. Condition is defined as follows.

$$T \equiv (\left|I_{(x,t)} - I_{(x,t+1)}\right| > 2s) \wedge (\left|I_{(x,t-1)} - I_{(x,t)}\right| > 2s) \tag{2}$$

Where $I_{(x,t)}$ is the intensity value of pixel x in time t and s is the standard deviation of pixel x over samples. If T is *false* the point is considered as a stationary pixel and could be involved in background model calculation. In other case, the pixel is either an outlier[1] or belongs to a moving object, so should be excluded in further processes.

Background model will then be created via some intra-frame and inter-frame processes. At first images are scanned one by one to find Maximum value, $n(x)$ and Minimum value, $m(x)$. Then all samples are checked to determine medium of the largest inter-frame absolute difference images over the entire image d_m [5].

In addition to background model, Homography matrix calculation is the other part of the system that should be done offline. In this phase four particular points with known real-world coordinates would be specified for the system. The Homography matrix is determined using Inverse Perspective Transform [10]. Base formula for Homography transformation showed in (3).

$$\begin{pmatrix} mP'_{HA} \\ mP'_{HB} \\ -mh \end{pmatrix} = \begin{pmatrix} x'_1 & y'_1 & z'_1 \\ x'_2 & y'_2 & z'_2 \\ x'_3 & y'_3 & z'_3 \end{pmatrix} \cdot \begin{pmatrix} lP'_{IA} \\ lP'_{IB} \\ -lf \end{pmatrix} \tag{3}$$

Where $x'_1, \ldots, z'_3$ denote the components of the axes of the camera frame I expressed in real world coordinates, P' is the particular pixel which should be mapped. l and m are coefficients used to normalized third element of matrixes.

3.2 Online Process

After offline processing, the system is ready for real-time tracking and velocity detection. The system structure and architecture used in online

[1] Distinct pixels that could be assumed as noise

processing are discussed here. A mixture model base on mentioned studies is proposed.

The tracking module is illustrated in Fig. 3. Initially each frame is subtracted from current background model. Based on subtraction result moving blobs are extracted. Regions that do not contain moving blobs are used to update the background model [3]. Meanwhile the same information along with history of objects observed in previous frames is used as input to a processing module which determines current status of objects observed in the scene (Scene analysis and tracking). This module plays the main role in tracking phase. Naturally, current object information is used to update object history for later use.

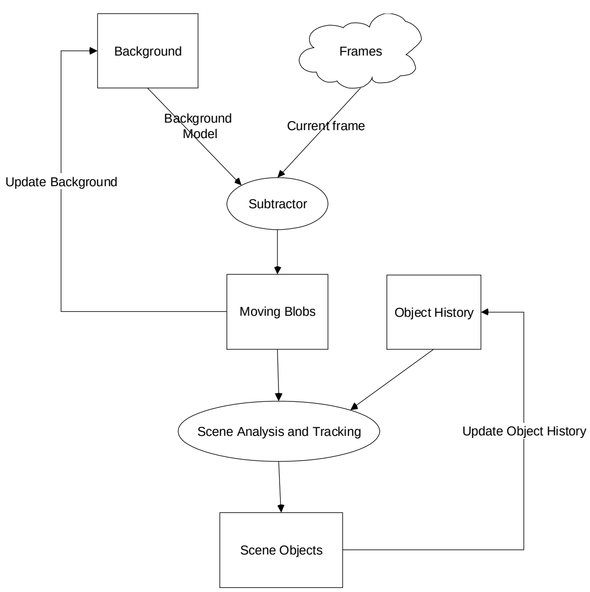

Figure 2 Tracking module's architecture

To have a better understanding of the process, subtraction and scene analysis modules are discussed in more details.

In most studies it is common to use a simple subtraction to obtain silhouette[2] [2, 7, 8 and 9]. However, there are other approaches that use special comparing methods for silhouette detection. In such approaches each background pixel is described via some statistical features, e.g. maximum intensity [5], minimum intensity [5], intensity probability distribution [3, 4]. And each pixel is determined to be included in silhouette image by a specific criterion.

In this work, every pixel is classified as moving object if the condition the result of (4) is *true*, otherwise the pixel is considered as stationary.

$$(I^t(x) - m(x)) < kd_m \vee (I^t(x) - n(x)) < kd_m \quad (4)$$

Where $m(x)$, $n(x)$ and d_m are calculated in offline process. And k is constant which is equal to 2 is this case.

Fig. 4 illustrates the result of subtraction module. As it can be seen in the figure, subtraction process generates raw silhouette. Since silhouette might contain noise, some morphological operations are utilized for reducing noises. Erosion makes noises to disappear while several passes of dilates connects separated contours.

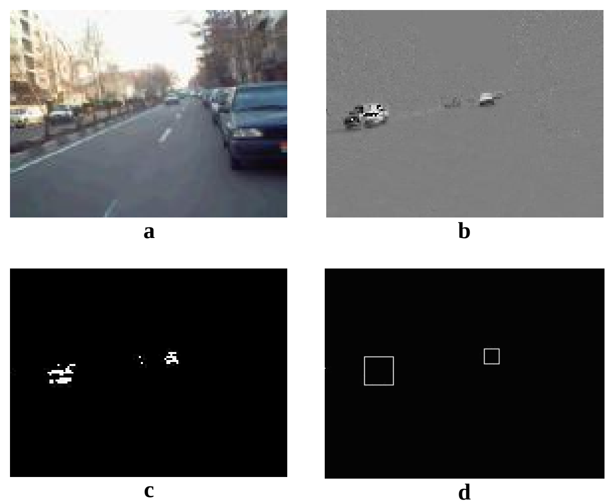

Figure 3 Subtraction results (a) Current frame (b) Silhouette (c) Subtracted frame from background enhanced for better view (d) Bounding Rectangles

In this stage, an approach is used for object labeling. Every blob is checked in object history, if there is any record in history, the record will be updated otherwise a new record would be created.

Camera noise and subtraction noise sometimes create misdetections that could be fixed in this stage, e.g. the running car that is approaching camera, sometimes might be detected as a small blob and be removed by morphological operators. However in this situation, it doesn't exist in subsequent frames, so object history could recover this blob and improve algorithm correctness.

[2] The image indicating pixels of the moving objects

The algorithm prevents elimination of the object for a while (say q frames) and after that object would be permanently deleted. On the other hand, when an object is to be created, object addition would be delayed for q frames, and if the object exists in q subsequent frames it would be approved for addition.

When objects are ready, the next stage is object positioning. Using inverse perspective mapping, real world co-ordinates of objects would be determined using (5).

$$H \times \begin{pmatrix} x \\ y \\ 1 \end{pmatrix} \approx s_i \times \begin{pmatrix} X \\ Y \\ 1 \end{pmatrix} \qquad (5)$$

Where x and y are image coordinates of pixel, X and Y are real world coordinates, H is Homography transformation matrix and s_i is simple coefficient for normalizing third element of matrix.

Then we have objects and their positions. All we need to do is tracing position of an object in time and calculate velocity based on position and time. A time window of one second is considered for computation of vehicle velocity.

4 Experiments

We tested the algorithm on several movies captured from Tehran's roads. Some results are presented in this section.

Fig. 5 shows a car and the detected speed for it. After car identification, its position is determined using Homography matrix. Based on car position and change of this parameter through time, velocity of the car is calculated.

Since the unique identifier of the car is the basis for all calculations, to have robust velocity detection it is crucial to determine the identifier in a robust and reliable manner. Heuristics mentioned in section 3.2 helps the system with this aim.

As viewed in Fig. 6 the car in Fig. 5 approaches camera while its unique ID has not changed. This is because of proper functionality of Object Identification stage.

The speed of the car is almost constant and it can be observed in following figures. Nearly same velocity results have been obtained in both images which is a proof for correctness of object positioning and velocity detection modules.

Figure 4: Detected car coming with determining speed

Figure 5: Detected car after some while

Fig. 7 shows the results of the algorithm in a completely different scene. The results show that the algorithm succeeds to report velocity even if it can only detect parts of car which contain wheels. It should be mentioned that the bottom right point of the car is used for the mapping process and so for positioning of the vehicle.

5 Conclusion and Future works

In this paper, a tracking based traffic surveillance system was developed. The system's building blocks, which are background model generation, Tracking, Mapping and Velocity Detection, were described. A combination of different methods reported in literature was employed to form the proposed system. For background model generation and tracking the W4 approach was used, however some additional heuristics were involved. The mapping algorithm is based on the well-known approach called Homography transformation approach. Car velocity is computed considering the constant velocity assumption during short time periods. An experimental result for the velocity detection system on several real world scenes proves promising.

Figure 6 Result of application in another scene

One area of work which can improve the performance of the system is shadow detection & exclusion. When source of light is from behind, shadow will be in front of vehicles and may deteriorate the performance of object positioning algorithm. Enhancing silhouette generation by adding shadow removal process is our next step.

Some studies have been done on shadow exclusion in traffic surveillance applications [11, 12] that are being investigated by authors.

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