# Embedded Technology and Algorithm for Video-based Vehicle Queue Length Detection 

Yanjie Yao, Kunfeng Wang, Yegan Qian,Gang Xiong (Corresponding Author), Lei Zha


#### Abstract

The vehicle queue length detection, specially based on video, is an important research field of Intelligent Transport System (ITS). It has promising application prospect in such areas as urban traffic control, highway toll system etc. In this paper, by analyzing the video sequence obtained from the fixed-camera, the vehicle movements of each road lane, such as left turn, go straight, turn right, are detected by using telescopic virtual coil, and then the vehicle motion detection and vehicle presence detection are used to calculate the vehicle queue length. On this basis, the vehicle queue detection algorithms are improved, and their threshold values are modified in the paper correspondently. And, the DM642 platform is designed to implement the real-time detection of vehicle queue length on the crossroads. Application experiments prove that the solution can detect the vehicle queue length with high precision, and the detection results meet the accuracy and stability requirements of practical application.


Key Words: DM642; vehicle motion detection; vehicle presence detection; vehicle queue length

## I. Introduction

IN recent years, more and more countries have invested a lot on R\&D of Intelligent Transportation Systems (ITS), and its application practice. In ITS, automatic detection of vehicle queue length and other parameters can provide a lot of important traffic information, and can be used for traffic accidents prosecution and traffic signal control. By using those cameras mounted around the traffic road, a wealth of parameters can be measured, such as vehicle type, traffic volume, traffic density, vehicle speed, etc. Those parameters information can be used for traffic adaptive management and vehicle dynamic guidance.

Some scholars and practioners in the world have done the research and practice on vehicle queue length detection, by using the embedded video technologies, such as hardware technology, programming design, the algorithms of length detection, image processing, pattern recognition, network

[^0]technology and many other fields. Its R\&D areas are mainly about hardware design, software design and algorithm analysis. Significant achievements have been obtained in video pattern processing and recognition areas with the contributions of many scholars all over the world. For example, the researchers from UMN (University of Minnesota) have developed the first video-based vehicle detection system by using of the most advanced microprocessor at that time [1]. The tested results showed good in different environments, so the system can be put into practical use. Compared with USA, Europe and Japan, China's research on ITS starts later than their American counterparts, and the video detection of vehicle queues started even more lately. However, China has carried out a series of research and implementation projects about intelligent traffic management, especially since the 1990s. China has accelerated the research and application steps on ITS significantly, and achieved lots of research results in urban traffic management, highway monitoring system, toll system, security system [2]-[4]. Due to the broad technology fields, and the many existing difficulties can't be overcome, it is still hard to achieve full automation of ITS.

At present, the limitations when the video-based queue length detection technology put into practice include: 1), the threshold setting is difficult; 2), rate of false alarm is high; 3), the precision of acquired data is low and influenced by external environmental interference; 4), large amount of data causes many transmission and processing problems; 5), commonality of data and algorithms is not high, and it is not easy for portability and adaptability.

Many scholars have dedicated to research on these issues, such as Hoose N [5], Rouke A and Bell M G H [6], Fathy M and Siyal M Y [7] [8], Li and Zhang [9] and so on[10]-[13], and these studies promote the development and progress of embedded vehicle queue length detection.

Previous studies have shown that, to obtain vehicle queue length, the vehicle motion detection and presence detection should be done for the incoming video images. In this paper, we analyze the video sequence got from the fixed camera, and utilize the vehicle presence detection and vehicle motion detection to calculate the queue length of vehicles.

This paper is organized as follows: In Section II, we introduce the hardware structure for signal transduction of the vehicle queue detection system. Section III provides the designed algorithm for video-based vehicle queue length detection. Section IV analyzes data flow of the system. Section V presents the experimental results and our analysis


Fig.1. The whole embedded video traffic information collection system


Fig.2. The video board
of the system. Finally, this paper is drawn to a conclusion in Section VI.

## II. Embedded Hardware

The embedded video traffic information collection system of CASIA (Institute of Automation, Chinese Academy of Sciences) is shown in Fig.1, including cameras, video board, routers, laptops and parameters configuration software. The cameras are installed on the eighth floor of the automation building, 100 meters from the stop line, and the vertical distance to Zhongguancun East Road is about 30 meters. The control software can adjust the angle and focal length of the cameras, and parameters configuration software can be easily installed in notebooks, with visualized measurement in real time. The video board processes the incoming signal, uses algorithms to get the vehicle queue length, and finally outputs the results to the parameters configuration software. The video board is the main part of the whole system, and we introduce it as follows.

As is shown in Fig.2, the video board has four parts: video processing chip DM642, video capture module, video display module, and the network module, including two input ports and one output port.

Fig. 3 shows the input and output module of video board. The whole system uses CCD cameras, and the decoder SAA7115 connects the cameras and the input ports of DM642. The analog signal from camera is converted into digital signal which is in BT. 656 by SAA7115, and is transported into the system by the port VP0 and VP1of DM64


Fig.3. Input and output module


Fig.4. The whole detection of system
2. In DM642, the video data is compressed into JPEG, and then the video stream data is transmitted to the Ethernet through RJ-45. At the same time, the PC on the network can receive the data using parameters configuration software for queue length detection. So we can use the network to realize surveillance and communications. Also the video data from port VP2 is converted into analog signal by SAA7115, and can display on the monitor. By EMIF interface, two 48LC4M32B2 chips are used as the SDRAM memory to extend the available memory-space, and FLASH is used to store the initialization code and configuration information of this system.

## III. Algorithms of Video-based Vehicle Queue Length Detection

The proposed algorithm of video-based vehicle queue length detection includes two major operations: the detection of vehicle queue and the calculation of queue length. Detection of vehicle queue needs vehicle motion detection and presence detection [14]-[16]. As we can see from Fig.4, after setting the detection area and completing all the initiali_

zation, the system starts to do the queue length detection. First, motion detection can eliminate the normal moving vehicles which keep a certain distance from the queue. Then, presence detection is used to filter the road background so we can get the vehicle queue. By the algorithm, a lot of running time has been saved. Next, we just need to make sure the numbers of the mini_region to fulfill calculation of queue length because of the length of each mini_region is settled.

## A. Vehicle Motion Detection

The vehicle motion detection is based on applying the differencing technique on the profiles of the images along the road. At present, the common technique for motion detection is interframe difference and background difference. The interframe difference is sensible, but it can't acquire a full object. While the GSS background subtraction can get the entire information of an object, and it also needs some time to adapt the situation when a moving thing becomes a part of background. So we propose a combination approach of the interframe difference and background subtraction so as to confirm accuracy as well as promote the measurement effect. GSS applied in this paper is used for background setting and updating, consisting three Gaussian distributions, and the rate of background learning is 5000 .

For the reason of saving computational time and reducing the huge processing data, the motion detection and presence detection for queue do not conduct along the entire road at the same time. As in Fig.5, Motion detection is applied both for the head and tail of the queue, while presence detection is applied only for the tail of the queue during the detection. Keep scanning the queue head (stopped line), the length of queue clears to zero once the head moves. When the head is detected no movement, and the tail is stationary at the same time, the queue length can be obtained.

Fig.6. shows the progress of the algorithm. First, the interframe difference is for motion detection. When there is no obvious difference between current frame and former frame, the current frame is trained as a part of background. Otherwise, the complete information of an object can be got using background subtraction. By the cooperation of the two methods, if a substance stops and becomes a part of the background, the background model will be updated for motion information can be detected by interframe difference immediately. Also, when it starts to move, the system can figure it due to its sensitivity to movement.


Fig.6. The combined algorithm flowchart of motion detection

## B. Vehicle Presence Detection

The vehicle presence detection is an important step for queue detection which extracts vehicles from the surface of roads. Here, the approach is based on applying edge detection [17]-[19] on these profiles.

Edges are less sensitive to the variation of ambient lighting and have been used for detecting objects in full frame applications. The method used here is based on applying morphological edge detector (MED) operators to a profile of the image. Basic operations consists erosion, dilation, opening operation and closing operation. Define that: $F=f(x, y),(x, y) \in R^{2}$ is an image, and $(x, y)$ is the pixel coordinate of each point. $f(x, y)$ denotes the gray level of point ( $\mathrm{x}, \mathrm{y}$ ); b(i, j) denots a set of structural elements. In this paper, structural elements we selected is in a model of $3 \times 3$. Common basic MED operators are as follows:

$$
\begin{gather*}
D_{r}=(f \oplus b)-f  \tag{1}\\
E_{r}=f-(f \odot b)  \tag{2}\\
E_{d e}=D_{r}-E_{r}=(f \oplus b)-(f \odot b) \tag{3}
\end{gather*}
$$

M. Fathy and M. Y. Siyal presented several methods for MED. MED is based on summation of erosion-residue ( $\mathrm{E}_{\mathrm{r}}$ ) and dilation-residue ( $D_{r}$ ) operators ( $E_{\text {de }}$ ), which can detect edges at different angles, while the other morphological operators (except Open-Close) use $\mathrm{E}_{\mathrm{r}}, \mathrm{D}_{\mathrm{r}}$ or the minimum of these which are unable to detect some kind of edges. As the above equation (1) and (2), $\mathrm{D}_{\mathrm{r}}$ is the D -value of erosion dilation and $E_{r}$ is the D-value of erosion. $E_{d e}$ is shown in equation (3). What's more, before the MED, the separable median filtering is done for removing noises and reducing disturbs from variable environment.
A combined MED and histogram-based technique is used for vehicle presence detection in this paper. An appropriate dynamic threshold is produced automatically to detect vehicles, and the MED is used for edge detection to ensure the accuracy and precision.

## C. Threshold Selection

When the queue detection system is installed on roads, it is necessary a training phase to determine proper threshold values of histogram [20]-[22]. Here, we take examples from Otsu, a scholar of Japan, who presented the Otsu method in 1979 [23]. Let $u$ is the average gray value of the whole image, and $\mathrm{w}_{0}$ represents the proportion of points in foreground while $\mathrm{w}_{1}$ is the proportion of points in background, and $\mathrm{u}_{0}$ and $u_{1}$ are the average gray value of foreground and background respectively.

$$
\begin{equation*}
\mathrm{u}=\mathrm{w}_{0} \times \mathrm{u}_{0}+\mathrm{w}_{1} \times \mathrm{u}_{1} \tag{4}
\end{equation*}
$$

Go through all the gray value from the minimum to the maximum until find a certain gray value $t$ maximizing the following equation (5):

$$
\begin{equation*}
\mathrm{g}=\mathrm{w}_{0} \times\left(\mathrm{u}_{0}-\mathrm{u}\right)^{2}+\mathrm{w}_{1} \times\left(\mathrm{u}_{1}-\mathrm{u}\right)^{2} \tag{5}
\end{equation*}
$$

So the value of $t$ is the proper threshold value $T$. If the gray value $f$ of a point is greater than $T(f \geq T$ ), we think it belongs to vehicle edges. Otherwise, if the gray value f is lower than T ( $\mathrm{f}<T$ ), it belongs to background.

To reduce the computational time, the equivalent formula (6) can instead of (5) to find the greatest $g$.

$$
\begin{equation*}
\mathrm{g}=\mathrm{w}_{0} \times \mathrm{w}_{1} \times\left(\mathrm{u}_{0}-\mathrm{u}_{1}\right)^{2} \tag{6}
\end{equation*}
$$

In this way, the threshold selected can be updated dynamically.

## D. Algorithm Summarization

In this paper, the entire strategy for queue detection based on all the aforementioned vehicle motion detection and presence detection is as Fig.7. The proper T is definite by OTSU to differentiate the roads and vehicles. To motion detection, the combined approach of the interframe difference and background subtraction not only improves the sensitivity but also promotes the effect of detection results. And the edges got by morphological gradient $\mathrm{E}_{\mathrm{de}}$ are clear and accurate enough for the presence detection.

Before the practical detection for queue, separable median filtering is done for noise removal. The background is created in GSS with three Gaussian distributions which can update dynamically, and the rate of background learning is 5000.The combined motion detection algorithm gets rid of the normal moving vehicles to get the stopped cars. If a car does not run for a while and becomes a part of the background, its no-moving information can be easily detected by interframe difference. Then background model is re-established and the stopped object is saved in tracking modules. Thus even the object runs again, it will be found immediately. For the selection of threshold, the histogram is scanned from 0 to 255 by gray level. Till the largest $g$ is gained by equation (6), edges of vehicles will also get. Finally, MED is used to measure the tail of the queue excluding the background.

For the reason of saving computational time, motion detection is applied both for the head and tail of the queue, while presence detection is applied only for the tail of the queue during the detection. Keep scanning the queue head (stopped line), the length of queue clears to zero once the head moves. When the head is detected no movement, and the


Fig.7. Algorithm diagram for vehicle queue length detection
tail is stationary at the same time, then the distance between them is the queue length. Next the toll moves forward one profile, the mini_region_number will plus one. Only when the value of vehicle edges is greater than the threshold $T$, the queue length increases (adding mini_region_number). On the contrary, the mini_region_number will minus one.

In this paper, the length of each mini_region for calculation of queue length is some 5 meters (about the average length of a car). Using the formula that $\mathrm{L}=5 \times$ mini_region_number, we can get the vehicle queue length in the end.

## IV. Program Process of DM642

The software system encodes the input images transmitted by cameras, and produces JPEG images which PC can debug. The encoding library and decoding library are integrated together in RF-5 (Reference framework 5) [24], and the Fig. 6. shows the program flow chart of DM642.

First, initialize modules.

1) Initialize processor and system board. Initialize BIOS environment and CSL (Chip Support Library); Set 128K cache, so as to map to the CE0 and CE1 space of EMIF, and request the highest priority; make sure the maximum length of DMA priority sequence.
2) Initialize RF-5. Initialize the channel module of RF-5 and the module of $I^{2} C$ and SCOM that works for the inner units' communication and transformation.
3) Establish the input and display channels. Build up an example about the input and display channels.
Then, the system runs the six task modules under the management of DSP/BIOS. These modules comprise two image capture task, one image compress task, one video output task, one network task and one network initialize task. All of the tasks are integrated by RF-5, communicate with each other through SCOM module, and transport information of data and control between the function modules. By cooperation of these tasks, the queue length can be calculated and shown on the software in real time.

We take advantage of TI CCS2.20.18(Code Composer Studio) EDI to develop and debug code. The DSP program does the initialization firstly, then starts DSP/BIOS, controls the six tasks, processes data, and output the detection results in the end.

## V. Experimental Results and Analysis

The results of operations of the algorithms compared with manual observations of images confirm that the queues are detected and its parameters are measured accurately in real time.


Fig.8. The results of queue length


| Date | Weather | Date | Weather |
| :---: | :---: | :---: | :---: |
| 5.3 | sunny | 5.9 | sunny |
| 5.4 | rainy | 5.10 | sunny |
| 5.5 | rainy | 5.11 | sunny |
| 5.6 | cloudy | 5.12 | sunny\&windy |
| 5.7 | clear | 5.13 | sunny\&windy |

Fig.9. The weather conditions during experiment

The experimental station is installed in the eighth fool of automation building, and the camera is mounted to a northern intersection from south to north direction in front of the building. The results of operations of the algorithms are observed in a period of two weeks (about ten workdays) and shown as Fig.8. In our experiment, images from the second camera which is mounted to the stop line of the intersection are processed by the parameters configuration software in real time. Considering the experimental environment, there is one left lane and two straight lanes to be detected without the right lane (see the blue Lane sign in Fig.8). As far as we can see in Fig.8, the queue is marked in red and the results of length can be read directly on the left top of the picture and right area of the software.
Fig. 10 illustrates the complete detection process of a queue length applied to the detection results of the left lane in Fig.8. possible period when a queue appears and reaches to the longest is 8:30-9:30 and 16:30-18:30 every day, satisfying the rush hour for work of a day. At the same time, the average data of left lane is greater than the straight lanes', because there are two straight lanes to relax the congestion while only one left lane. The time required for queue detection is about $0.5-5 \mathrm{~s}$. This is the time when the queue is fully present and

First in Fig. 10 (a), the queue starts to appear when there is no motion at the stop line as the traffic light is red, and the length is 10 m . Then, the length increases to 75 m in Fig. 10 (b). Next, Fig. 10 (c) shows the maximum length ( 85 m ) for this queue process. Finally, Fig. 10 (d) is the end of the queue--the length data falls to zero immediately once the head of the vehicle queue moves.

The evaluation phase was performed on a two weeks period. In order to evaluate the correctness of the algorithm, acquired images and the correspondent values of queue length have been saved every 15 seconds in case of queue response, and every 20 minutes otherwise. The number of acquired images is about 120 frames during 8:30-18:30 every day in various weather conditions as Fig.9.

Fig. 11 describes the statistics of average value for queue detection results in the left and straight lane. The most detected in the scene and the algorithm is executed for the entire scene. It meets the requirements for real-time system.

## VI. Conclusion

In this contribution we have presented a real system for traffic queue detection. It is able to detect queues in each of
the monitored lanes, providing their duration along with a severity index. By means of an extensive testing phase, the system shows to be robust with respect to weather conditions and illumination variations. As an important area of research for ITS, we still have a large amount of work to do deeply. In order to minimize false, future works include an analysis of the proposed improvements, the setting of an appropriate stop line, and the compensation for camera vibration and so on. Furthermore, other vehicle parameters like the vehicle type, vehicle speed and license plate are all important directions and full of interests to study.

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    Yanjie Yao, Kunfeng Wang and Gang Xiong are with State Key Laboratory of Intelligent Control and Management of Complex Systems, Beijing Engineering Research Center of Intelligent Systems and Technology, Institute of Automation, Chinese Academy of Sciences, Beijing, 100190,China(e-mail: yyjsunny@msn.cn; kunfeng.wang@ia.ac.cn; phone: 010-625-54288; fax: 010-625-54288; e-mail: gang.xiong@ia.ac.cn).
    Yegan Qian is with the Anhui Radio TV Station, Anhui Hefei, 230022, China (phone: 0551-341-5524; fax: 0551-342-2353; e-mail: yegan_qian@ya hoo.com.cn).

    Lei Zha is with the Jiangsu China Sciences Intelligent Engineering Co. Ltd., Suzhou Industry Park, WeiTing Town, 215000, Suzhou, China (e-mail: colley@scsic.com).

