Vehicle License Plate Recognition System with High Performance[1)]

LIU Ji-Lin SONG Jia-Tao DING Li-Ya MA Hong-Qing LI Pei-Hong
(*Institute of Information & Communication Engineering, Zhejiang University, Hangzhou 310027, P. R. China*)
(E-mail: Liujl@zju. edu. cn)

Abstract We present our License Plate Recognition (LPR) System. Using vehicle position sensors and image acquisition card, it captures images of the vehicles automatically and sends the images to computer, then recognizes characters of the vehicle plate. Combined with the web technique, information of certain plates and the images of the vehicles can be browsed conveniently from remote sites. The system frame and workflow of our LPR System are introduced. Some problems and two of our proposed character recognition methods, i. e. method based on PCA-LSM for limited Chinese character recognition and method based on structural feature analysis for alphabetic and digital character recognition, are addressed in full details. The field applications under practical conditions show that the whole recognition rate of our system is over 97% in daytime and 95% at night.

Key words Vehicle license plate, character recognition, PCA-LSM, structural features

1 Introduction

The license plate number has unique information of a vehicle, so image-based license plate recognition (LPR) technology came out to be an important means of automatic vehicle identification. With the rapid development of intelligent transportation systems (ITS), investigation of LPR kept pace with other ITS techniques. Many efforts have been made to develop practical LPR products and some of them also have been put into market[1,2]. Primarily, LPR captures, processes, interprets and records the image of a license plate with the advanced technology of image manipulation, pattern recognition and artificial intelligence. Combined with Web technique and distributed multimedia database technique, the system enables customers to get all of the related information or service immediately from remote sites. The system is also easy to be extended, as management requires.

Now the LPR systems are widely and successfully used in highway surveillance, electronic toll collection, red-light violation enforcement, secure-access control at parking lots and identifying vehicles stolen, or those registered to fugitives, criminals and smugglers.

2 System overview

In our system, two sets of vehicle location sensors are used as an external trigger to detect the vehicle's presence reliably and send a startup signal to the image acquisition & control part. Some hardware-based image preprocessing is integrated in the image acquisition card. The plate location and character isolation & recognition routes are done in the software module. A vehicle information such as the plate number, plate color, lane number, pass time and its plate image and whole vehicle images are recorded as a record to add to the database.

Our system consists of three major modules: a video image-acquisition subsystem, a plate isolation & recognition unit and a data communication & management subsystem. The main system frame is pictured in Fig. 1.

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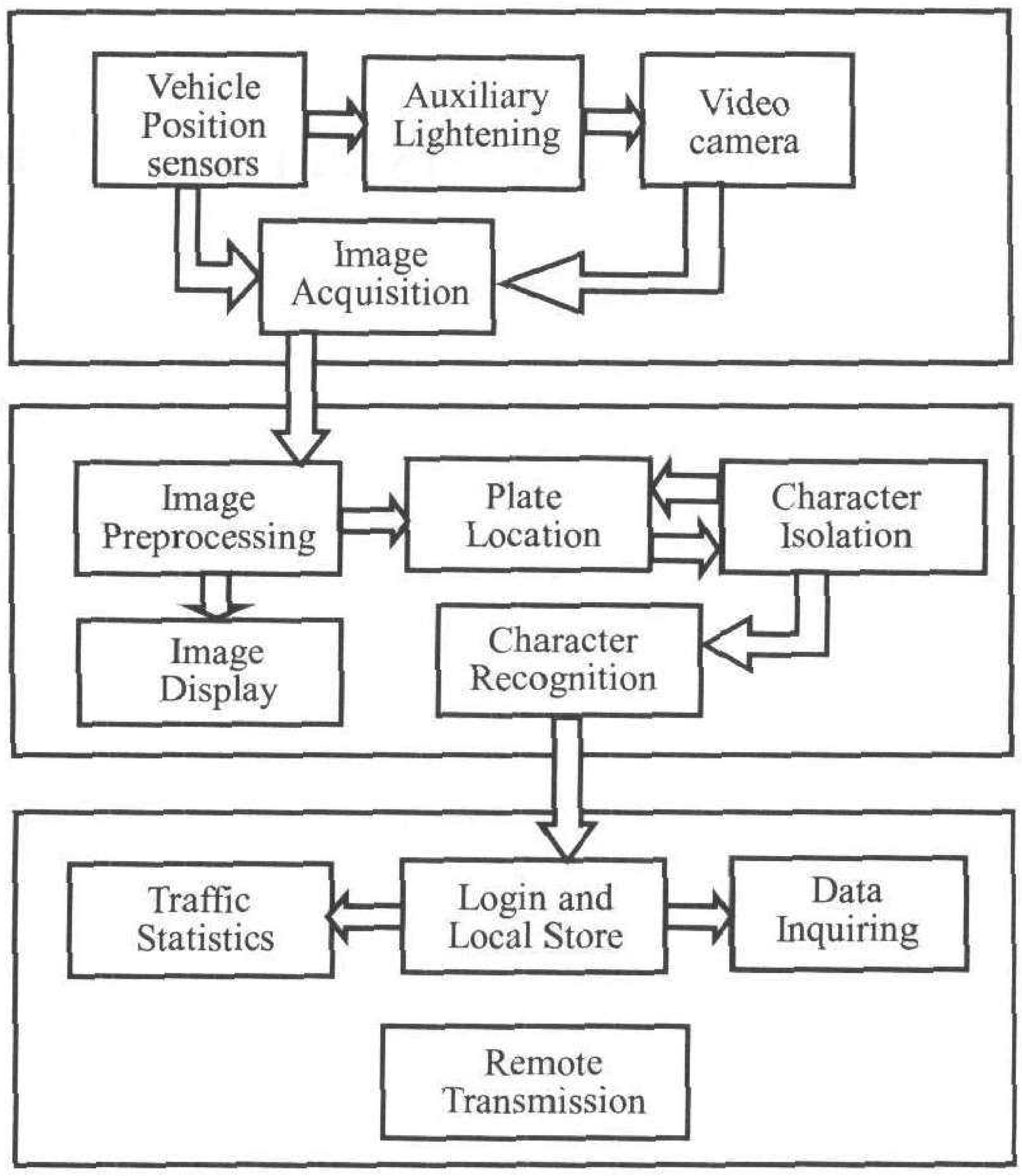


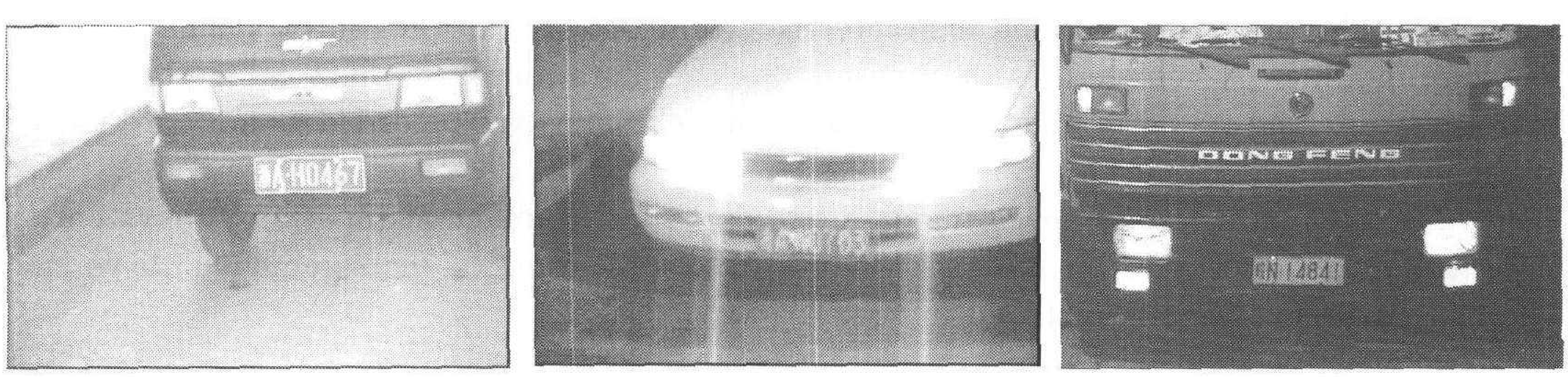
Fig. 1 System block diagram

3 System workflow

3.1 Image acquisition

Consisting of two couples of vehicle location sensors and certain logic, the Vehicle Position Sensor detects the arrival of vehicle and triggers the capture of Vehicle Image with license plate through CCD camera. A special-purpose Image Acquisition Card is developed which decodes and digitizes two independent video sources simultaneously. The RGB digital image signals are saved into buffer frames on board and read into EMS memory through PCI.

During the night, the luminance is low but the headlights of the vehicles are dazzling, which makes the plate in the image lack of ample contrast, even disturbs the plate image in some case. So we improve the system in two ways. The system is equipped with an ordinary camera but capable of Back Light Compensation, Halation Elimination and Automatic Gain Control, and we have investigated the best camera's working condition of our system. We added flash lamp as the auxiliary lightening, which is also triggered by the Vehicle Position Sensor. Flash lamp enhances luminance of the whole image. Through these means and the image preprocessing of the Image Acquisition Card, the plates in the images during the night become definite; the whole image looks like the images during the day, which greatly improves the recognition rate during the night. Example images are shown in Fig. 2.



(a) The vehicle image in the daytime

(b) The vehicle image during the night (before improvement)

(c) The vehicle image during the night (after improvement)

Fig. 2 Image examples

3.2 Plate location

In plate location algorithm, we mainly utilize the characteristic of the plate in vehicle images: there are plentiful characters in the plate region, therefore, this region is particularly rich in difference in gray level compared to its surrounding region. So the base of the location of vehicle plate is achieved primarily through differentiating the whole vehicle image region and then binarizing the difference image.

We project the binary difference image horizontally and vertically, properly smoothen these two projection curves, and search their peaks to find the accurate rectangle that includes the plate. The prior knowledge about the size, the proportion between length and width of plate is used to eliminate the locating mistakes. The flow of plate locating is pictured as Fig. 3.

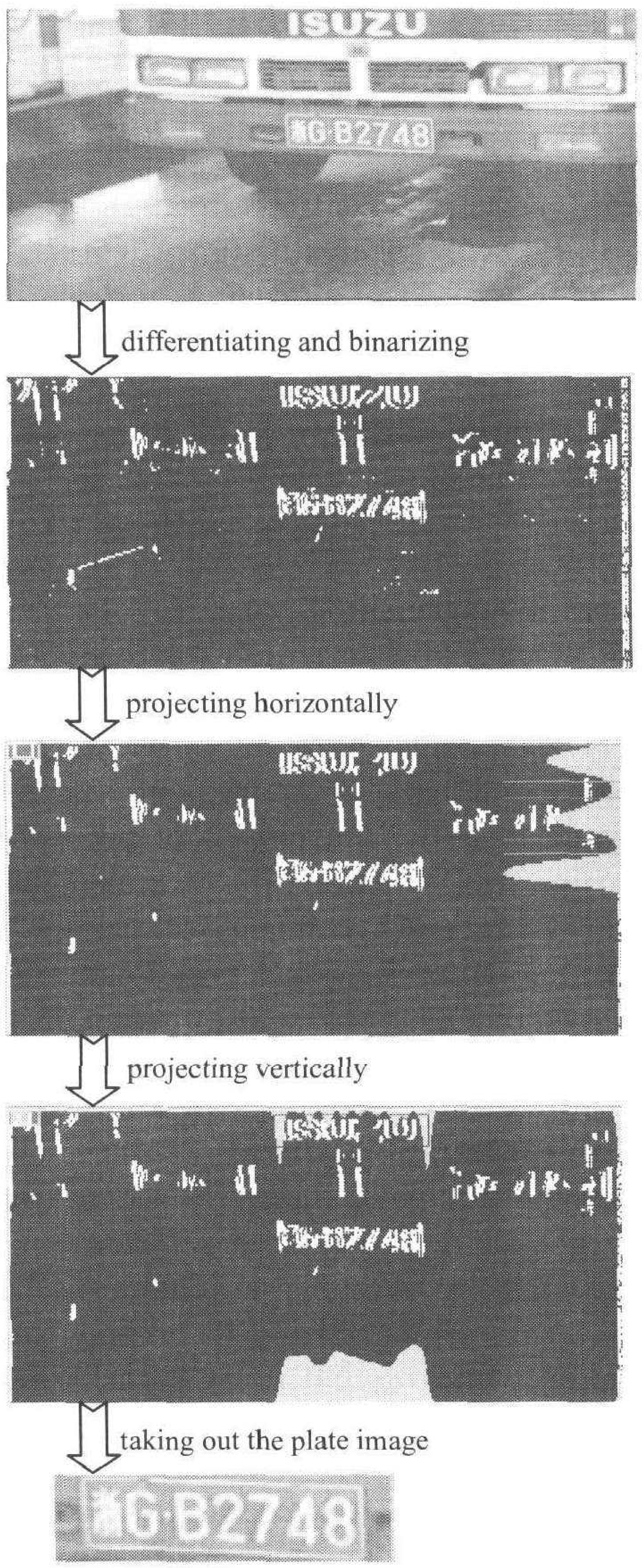


Fig. 3 Flow of plate locating

3.3 Character segmentation

From the plate image, each character should be segmented accurately in vertical and horizontal directions. Because the license plate of vehicles are normalized, the characters and their structure are also well-regulated. Based on a prior knowledge about the structure of the plate, we use certain image processing technologies, for example, plate obliquity detection and rectification, region labeling, etc to isolate each character. The frame of the plate would bring trouble to the segmentation, so the problem is specifically investigated.

Segmentation is performed for the classification. At the same time, segmentation should be done in co-operation with the classification, so that some segmentation mistakes could be corrected, and success of segmentation is reinforced. In Fig. 4 an example of segmentation is shown.

Fig. 4 Character segmentation

3.4 Character recognition

In character recognition, several classification methods based on such character features as projection feature (CPF), perimeter distance feature (PDF) and direction contribution density (DCD) are adopted. After normalization of the character image, features are extracted and through the multi-level templates-matching classifier, the character is classified [3].

To further improve the recognition, we have proposed two algorithms, which are used for the recognition of limited Chinese characters on license plate and that of alphabetic and digital characters, respectively. In Section 4, these two algorithms are described in full detail.

3.5 Data communication and management

In order to facilitate the access of data from remote sites and data management, Web-based technique and distributed multimedia database technique are used in our system, as Fig. 5. The system works in Web Browser/Web Server (B/S) mode. It enables data to be rapidly collected, continuously updated, structured and displayed. Web technology is used in the proposed approach to address the limitations of present process modeling practices. Our system presents the design and functionality of a Web-based system. It is developed on the Windows NT platform (Internet Information Server (IIS)) or Win98 platform (Personal Web Server (PWS)) using Active Server Pages (ASP). The system utilizes a multitiered design structure matrix (DSM) configuration to present collected data. This matrix-based technique has proven to be an effective tool for planning and managing product development programs through information flow analysis.

As shown in Fig. 6, a user interface is provided and the clients need no setup or installation procedures and the system can work stably for a long time without any maintenance. Customers can immediately get all of the related information or service through the web site and it makes the systems easy to extend their functions[3].

Logged in our system, users are permitted to browse the information of any vehicles passing the surveillance region . Information fuzzy search, data statistics, alarm etc. can be achieved through the public telephone net. Users are also allowed to set forth the time interval they are interested in. For example, all the vehicles displayed in the following Fig. 6 passed the tollgate between 10:03:00 03/02/2000 and 10:05:00 03/02/2000.

Using our LPR system with web technique, users can get the recognized results, the colors of the plates, the type of the vehicles, the lane number, the recording time and the recorded images of plates and vehicles from the web site. Remote diagnosis and maintain are also supplied.

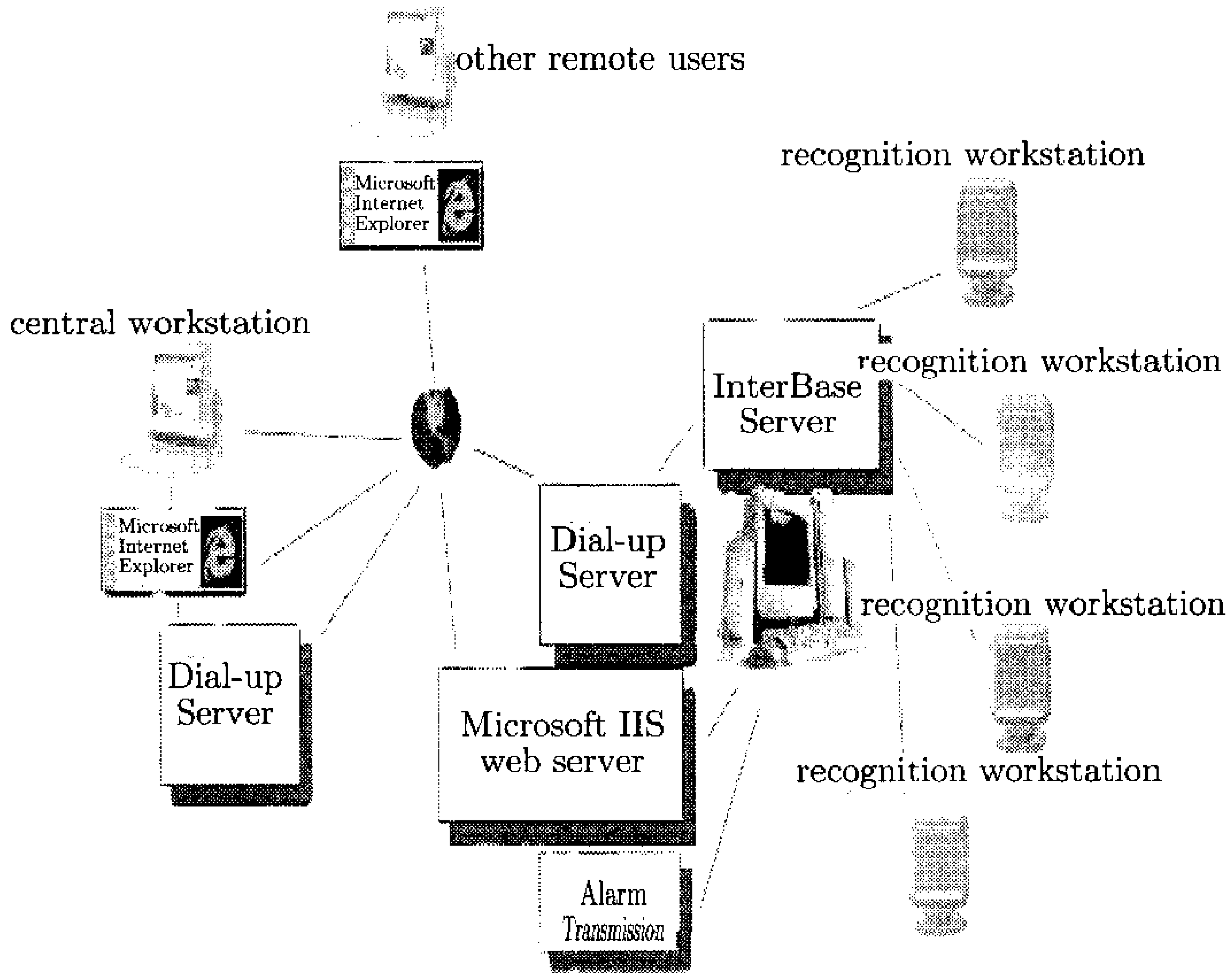


Fig. 5 Data communication model of our system

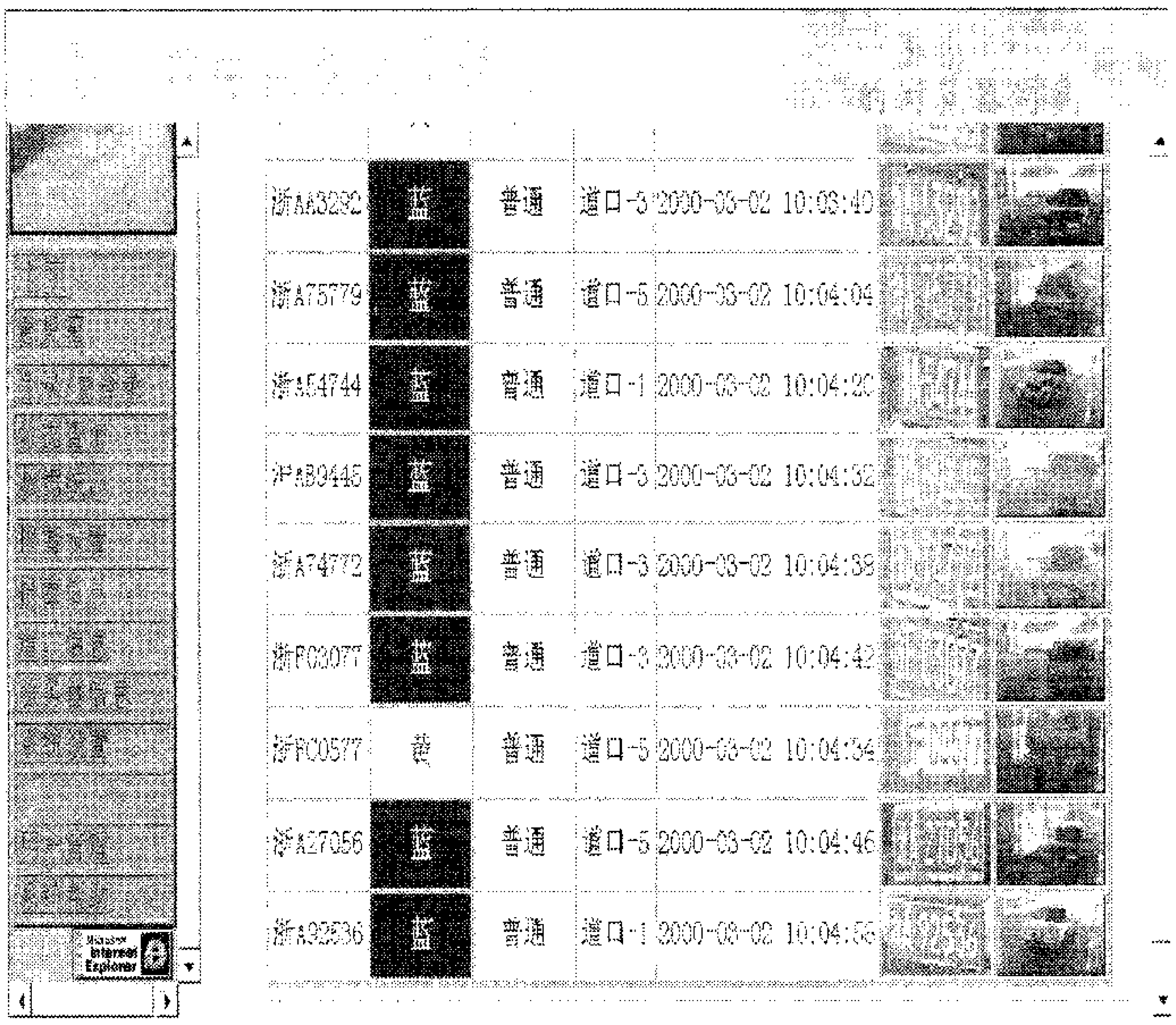


Fig. 6 User interface

4 Technique of character recognition

Character classification and recognition is a crucial task for our system realization. The main methods to do this work are template-matching method[4] and neural network method[1]. The former mostly employs the statistical features, which are always based on the projection technique or grid technique, and has the disadvantage of low discrimination power to similar characters and slow recognition speed due to the too huge feature data, while the latter faces the problem of selection of input data and optimization of network parameters. So in our system, two algorithms, which are used for the recognition of limited Chinese characters on license plate and that of alphabetic and digital characters respectively, are proposed. Experiments show that these methods work very well for the improvement of our system performance.

4.1 Recognition of Chinese characters based on PCA learning subspace method (LSM)[5]

Principal Component Analysis (PCA) method is a very useful pattern recognition method and is widely used in human face recognition[6]. It extracts character features directly from the original gray image, rather than from binarized image, so it can keep as much intrinsic information of each character as possible. Our proposed PCA learning subspace algorithm first sets up the subspace for each class using PCA method, then makes some adjustments to the PCA subspaces according to the classification result of training samples. This leads to a remarkable improvement on the character classification rate.

Let $\boldsymbol{x}$ be the n-dimension vector which represents an original gray image, K be the number of classes, $C_s(s=1,2,\cdots,K)$ be the s_{th} class, L^i be the i_{th} class subspace. Without regard to the rejection recognition, then an input pattern $\boldsymbol{x}$ can be classified as the i_{th} class according to the following rule:

$$\text{if } i = \arg\min(g_s(\boldsymbol{x},L^i)),\ \text{then } C(\boldsymbol{x}) = C_i$$

where g_s is the classification judgment function which can be defined by its projection residue error in subspace L^i, i. e. :

$$g_s(\boldsymbol{x},L^i) = \|\boldsymbol{x}-\boldsymbol{M}_i\|^2 - \|P_i(\boldsymbol{x}-\boldsymbol{M}_i)\|^2 \quad (i=1,2,\cdots,K) \tag{1}$$

$$L_i = L(u_1^{(i)},u_2^{(i)},\cdots,u_m^{(i)}) \tag{2}$$

$$U^{(i)} = (u_1^{(i)},u_2^{(i)},\cdots,u_m^{(i)}) \tag{3}$$

where $\|\boldsymbol{x}\|$ is the 2-norm of vector $\boldsymbol{x}$, $\boldsymbol{M}_i$ is the mean vector of L^i. P_i is the projection matrix of L^i. When $U^{(i)}$ is an orthogonal basis, P_i can be written as:

$$P_i = U^{(i)}U^{(i)\mathrm{T}} \tag{4}$$

The PCA subspace algorithm can be described as follows.

First calculating covariance matrix $R_i(i=1,2,\cdots,K)$ of subspace L^i using training samples $x_j^i(j=1,2,\cdots,N_i)$; Then calculating eigenvectors $u_j^{(i)}(j=1,2,\cdots,p)$ and eigenvalues $\lambda_j^{(i)}$ of R_i using SVD method; Next sorting eigenvalues $\lambda_j^{(i)}$ in descending order, i. e. $\lambda_1^{(i)}\geqslant\lambda_2^{(i)}\geqslant\cdots\geqslant\lambda_m^{(i)}$, and constructing subspace L^i using basis vector $U^{(i)}$; And then calculating the projection matrix P_i of subspace L^i using Eq. (4). The fifth step is to calculate projection residue error $g_s(\boldsymbol{x},L^i)$ of input vector $\boldsymbol{x}$ in subspace $L^i(i=1,2,\cdots,K)$ using Eq. (1); Finally assigning pattern x into that class which minimizes the projection residue error $g_s(\boldsymbol{x}, L^i)$.

After getting the initial character subspaces with above PCA algorithm, we use learning subspace method (LSM) to optimize them. The main idea of LSM is to rotate two kinds of subspace with training result of training samples, so as to make character vector x become closer to its corresponding subspace and farther away from its first matched but not corresponding subspace. The training stage of PCA-LSM includes:

Step1(Initialization). Set the training times of sample to N and let $k=1$;

Step2. Input training sample $\boldsymbol{x}$ in a uniform probability manner and calculate its projection residue error $g_s(\boldsymbol{x},L^i)$ in subspace $L^i(i=1,2,\cdots,K)$ using Eq. (1);

Step3. Mark the two subspaces, using L^0 to represent $\boldsymbol{x}$-corresponded subspace and L^r to represent $\boldsymbol{x}$-matched subspace, i. e. of all the subspaces L^r is the one which minimizes the projection residue error apart from L^0;

Step4. Update L_k^o and L_k^r using

$$\begin{aligned} L_{k+1}^o &= (I+\mu_0\boldsymbol{x}\boldsymbol{x}^{\mathrm{T}})L_k^0 \\ L_{k+1}^r &= (I-\mu_1\boldsymbol{x}\boldsymbol{x}^{\mathrm{T}})L_k^r \end{aligned} \tag{5}$$

where $\mu_0=\eta_1/(\boldsymbol{x}^{\mathrm{T}}\boldsymbol{x})$, $\mu_1=\eta_2/(\boldsymbol{x}^{\mathrm{T}}\boldsymbol{x})$, η_1 and η_2 are updating factors which are greater than zero;

Step5. Set $k=k+1$, if $k\leqslant N$, then repeat Steps 2～5; otherwise end training.

In our system, the PCA-LSM has been used to distinguish the Chinese character on license plate. Experiments show that as for the 30 most commonly used Chinese characters, when 100 characters for each subject are selected as training samples and 900 characters as testing sampless, the total recognition rate for PCA subspace method is 93.5%, while for PCA-LSM is 95.32%.

4.2 Recognition of alphabetic and digital characters based on structural features

From the early days on, the recognition of printed alphabetic and digital characters has always been the main contents of all kinds of OCR system. Just like in Chinese character recognition, the difficult in this work is to distinguish similar characters. Research[4] shows that the difference between "R" and "B" is only 0.04% when normalized with a maximum output value and that between character pairs "K" and "B" , "A" and "V", and "U" and "D" are less than 1%. So when statistical method or autocorrelation method is employed to differentiate them, it is impossible to get a high recognition accuracy. In our system a novel approach based on the structural features of these characters is suggested.

Our proposed method is well coincide with the principle of human vision system, for people always look at a character as a linelike object, at least adults do so[7]. Such structural features of characters as the direction of a stroke, the turning corner in a stroke or crossover of strokes often contain a lot of information which can be used for the classification of characters.

Compared with that of Chinese characters, the structure of alphabetic and digital character has the characteristic of simplicity, i. e. there are only a few strokes in it. Instead of using chain-code, straight line segments or fitted curves as structure features[4,7], we select closed curve(s) in a character, minutiae such as ending(s) of a thinned stroke, bifurcation(s) and crossover(s) of thinned strokes, and corner point in a stroke as the structure features.

Closed curve is a global feature of a character. It can be used for the course classification of characters. According to the number of closed curve in it, a character can be classified as one of the following three categories:

- class1. 1 closed curve, including { 0, 4, 6, 9, A, D, O, P, Q, R};
- class2. More than 1 closed curve, including {8, B};
- class3. No closed curve, including the other characters.

Minutiae, including its type, direction and position, can be used for the fine classification of these characters. To achieve this purpose, all above minutiae information is organized into an array, a template-matching technique and Euclidean distance are used to evaluate the similarity of testing character and standard template characters. If the compared result is greater than the preset threshold, the character is determined and the recognition process is over. Otherwise recognition work should continue.

Corner point is used to distinguish similar character sets like {"S", "5"} and {"4" "A"} when they are not thoroughly differentiated using minutiae features. The corner point is extracted from some special area of the character according to the prior knowledge about the structure of a character.

How to extract these structural features is another key problem in our method. Minutiae and corner point can be extracted in ordinary image processing and feature extraction ways[8], while closed curve is not easy to get. Although the well-known Freeman chain-code tracking method is often used to detect closed curve in image, it is difficult to implement, because there are more bifurcations or crossovers in the thinned character image. So it is essential for us to develop an algorithm that can do this work.

Our algorithm is based on theory of graph. The thinned character image is viewed as a connected graph. Three kinds of minutia, i. e. ending, bifurcation and crossover, are regarded as the vertexes of it. If we use G to represent a connected graph, and let ε be the number of sides in G, v be the number of vertexes in G, it can be concluded[9] that if $\varepsilon = v$, there is a unique closed curve in G, if $\varepsilon > v$, there are more than one closed curves in it, otherwise no closed curve in it.

So in order to detect the closed curve in a thinned image, the only thing we should do is to count the number of minutiae v in it. After doing that, we can easily get the number of sides using the following Euler's formula[10]:

$$\sum_{u \in V(G)} d(u) = 2\varepsilon \tag{6}$$

where $V(G)$ is the set of sides in G, $d(u)$ is the order of vertex u and is equal to 1 for an ending, 3 for a bifurcation and 4 for a crossover.

5 Conclusion

From the data statistics of many field applications of our LPR system, the system capabilities are estimated as follows: total system accuracy (percentage of characters of license plates correctly identified) is over 97% at daytime and over 95% at night; supreme car speed, over 120 km/h at daytime and 80 km/h; the maximum recognition time is 0.8s and the minimum is 0.1s. And the image resolution is 768×256×24 bits; the image storing size is 15000frames/Gbytes. A web-based user interface is provided in our LPR system for the customers to get all of the related information or service which adopts the Web Browser/Web Server(B/S) mode. From the above statiation we can see that our system works practically, steadily and has high efficiency.

Although our LPR system presents high performance, there are still some efforts to be made to reach perfection. For instance, image acquisition part should be further improved for even higher performance. Now, we are still conducting extensive research and developing more widely adaptable algorithm to improve the performance of our LPR system.

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LIU Ji-Lin Professor of Department of Information Science and Electronic Engineering, Zhejiang University, Hangzhou, P. R. China. He graduated from Tsinghua Unversity, Beijing, P. R. China in 1970. His research interests include on image processing, digital video and ITS(Intelligent Transportation systems.

SONG Jia-Tao Received his bachelor degree in 1988 and master degree in 1991. He is an associate professor and now is a Ph. D. student in Zhejiang University, P. R. China. His current research interests include image processing, pattern recognition and computer vision.

DING Li-Ya Master student of Department of Information Science and Electronic Engineering, Zhejiang University, P. R. China. Her research interests include digital image procesing and understanding.

MA Hong-Qing Received his master degree from Zhejiang University, P. R. China in 1997. He is working on image processing, pattern recognition and intelligent transportation systems.

LI Pei-Hong An engineer working at Department of Information Science and Electronic Engineering, Zhejiang University, P. R. China. He got his master degre from Zhejiang University in 1997. He is working on embedded systms and intelligent transportation systems.

高性能的车牌识别系统

刘济林 宋加涛 丁莉雅 马洪庆 李培弘

（浙江大学信息与通讯工程研究所 杭州 310027，中国）

（E-mail：Liujl@zju.edu.cn）

摘 要 描述了一个车辆牌照识别系统. 该系统首先利用车辆位置传感器和图像采集卡来自动获取车辆图像并传输至计算机，然后识别车牌字符. 结合网络技术，特定车牌信息和车辆图像可以很方便地从远端检索到. 文中介绍了该系统的结构及工作流程，以及两种字符的识别方法：基于 PCA-LSM 的有限中文字符识别方法和基于结构特征分析的字母及数字字符识别方法. 在实际应用环境下，该系统的日间整体识别率超过 97%，夜间整体识别率超过 95%.

关键词 车辆牌照，字符识别，PCA-LSM，结构特征

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