License Plate Reader, Data Acquisition and Analysis

For Border Control in North America

Pramud Rawat, Member, IEEE
CEO, Data Analysis and Simulation Services, LLC
Columbia, MD 21044, USA
prawat@aol.com

***Abstract*—Because of the design diversity, elaborate color schemes, and artwork of the North American license plates, the license plate reader (LPR) systems used to monitor the inbound traffic at international borders become a subject of special interest. Unique problems arise in extracting the plate from a car's photographic image and then locating and reading the number of the plate and the name of its issuing jurisdiction for screening purposes. License plates used in other parts of the world do not pose as many problems in plate recognition as the North American plates do because of their simpler design and minimal design variations. The recent developments in cameras, microprocessors, image processing and pattern recognition capabilities, and secure high-data-rate data communication systems make it worthwhile to explore opportunities for improving the speed and accuracy of the American LPR systems. This paper is devoted to such an exploration.**

Keywords—License plate reader (LPR), optical character recognition (OCR), image processing , machine learning, pattern recognition, law enforcement.

I. Introduction

The examples of plates shown in Fig. 1 provide an idea of the design diversity among plates that are issued in Canada, Mexico, and US. The image of an EEC plate in Fig. 1 illustrates how much more complicated the North American plates are for an automated license plate reader. The problems that these designs pose for the LPR system users in the law-enforcement agencies, and for the highway authorities responsible for toll collection, are described in [1] and [2]. These references include pleas by the International Association of Chiefs of Police (IACP) and others for design simplification and for standardization across jurisdictions in a manner similar to the practice followed by the EEC countries. But, as the report [1] prepared by the American Association of Motor Vehicle Administrators (AAMVA) [1] shows, the momentum has gone in the opposite direction: plates of hundreds of new designs appear on cars each year, making the plate recognition problem harder. As the results of tests conducted by the Institute for Transportation Research and Education at the North Carolina State University [3] show, even changes in the background color and font color can affect the reading accuracy adversely.

It is unlikely but theoretically possible that the state agencies that are responsible for setting license plate design standards would elect to respond to the aforementioned pleas for design simplification and standardization. A universal adoption of RFID tags would be better because it would eliminate the need to read plates. Unfortunately, because of the large number of jurisdictions (in three countries) that would have to get together and act, and the large number of cars that would be affected by such a change, and neither solution can be implemented quickly. It is thus useful in the near term to investigate what the modern technology can do to improve the border traffic monitoring.

Fig. 1 Examples of North American and EEC Plates

II. LPR's Functions

A. LPR System

A typical LPR system includes a mechanism for detecting the arrival of vehicles, cameras with internal image sensors and microprocessors, data communication link to transmit the preprocessed data from camera's internal processor to the external processor, and an external processor connected with the backend processing system.

978-1-4799-1737-2/15/$31.00 ©2015 IEEE

B. Functions

This system can perform the following functions:

- Determine and deliver the license plate's number and the name of the state, province, or the federal district that issued the plate.
- Acquire and organize the scene data and deliver it for retention in the historical files for investigative purposes.
- Acquire and analyze the LPR system's diagnostic data. Take corrective actions that can be taken locally; trigger alarms when appropriate. Maintain historical records of these events.
- Maintain performance records and conduct LPR's performance analyses (example: records of instances when plate number had to be manually entered, to be used in machine learning and upgrade planning).

C. Lookout Lists

In case of vehicles that are on a lookout list, a partial match is adequate for triggering an alert. Since imperfect intelligence can be as much a cause for partial match as any system malfunction, the treatment of vehicles in this category requires separate treatment.

III. Parallel Operations

After an LPR system becomes operational, the machine learning part has to continue to (a) accommodate new plate designs, and (b) refine the feature recognition and plate classification capabilities of the LPR system. Thus while the LPR system is deployed at the border crossing sites, a scientific organizational element has to remain active in maintaining and refining the system.

Some of the issues that enter in system maintenance and refinement are addressed in the following paragraphs.

A. Design Diversity

There are 96 jurisdictions (states, provinces, and federal districts) that exercise independent authority on the number of different designs that each jurisdiction issues, and the details (background color and graphics, extraneous foreground elements such as slogans, location of foreground elements (the jurisdiction name may be above or below the plate number, and it may be aligned to the left, right, or the center of the plate; the location of the extraneous material can also vary; stickers may be at any corner).

While a large number of designs use plain backgrounds and fonts that an optical character recognition system can easily decipher and a bulk of the plates follow these simple designs, there are a larger number of designs that require special treatment. Reference [1] provides a fairly comprehensive description of design types in 2012. The number of designs runs into thousands, and several hundred new designs surface each year.

The tradition to issue plates of special designs to promote causes such as environmental conservation, or declare membership in a school alumni club, or membership in a sports team's fan club began well before there were any LPRs. Their designs have continued to be artistically inspired.

B. Problem Areas

1) Background: When the plate has a plain background it is easy to separate the background from the foreground. The color of the background can be of use in narrowing the search space for determining the issuing jurisdition's name. It may also help in narrowing the number of design types and thus knowing where the plate's number and jurisdiction name may be located. A multi-colored background that may also be cluttered with graphics elements makes plate classification harder and selection of signatures (possibly histogram-based signatures) to classify the plate becomes a more elaborate undertaking.

2) Contrast: The background color scheme in instances like the New Mexico plate in Fig. 1 reduces contrast quite drastically. This makes it difficult to isolate the foreground elements such as the plate number from the background.

3) Nonstandard Foreground Element Locations: Each plate in Fig. 1 has a different location for the jurisdiction name and extraneous text. The plate number is vertically in the middle but it can be pushed to a side as the Mississippi plate and others in Fig. 1 illustrate.

In some designs a state's name can appear in the extraneous text (example: ***University of North Carolina*** in a South Carolina plate).

The LPR has to be provided with algorithms to locate the alphanumeric text of interest.

4) Fonts: Exotic fonts, even a mixture of fonts, exist as the state name in the Mississippi plate in Fig. 1 illustrates. It is also impossible to say what collection of fonts would appear in future designs. When cursive fonts are used, the character segmentation problem requires special attention.

5) Stacked Letters: Stacked letters can be two deep or three or four deep. They can be vertically aligned or staggered.

6) Text Alignment: The jurisiction name on the Louisiana license plate in Fig. 1 illustrates a cse of curved baseline.

7) Background Graphics Overlapping Text of Interest: The New Mexico, Nunavut, and Sinaloa plates in Fig. 1 illustrate this problem. They blur the contrast with the edges of text that is of interest. And, since there are no restrictions on background graphics design, it is impossible to predict situations that may arise in the future.

Fig. 2 Occlusion by Frame

C. Occlusions

1) Plate Frames: Most car dealers put license plates in frames when they deliver the car. Car owners often buy frames that carry messages of their choice. These frames are thus ubiquitous. They are however a major problem because there is no restriction on their obscuring a part (some times the whole) of the jurisdiction name as showen in Fig. 2.

When the state name is obscured and the LPR system is not equipped to handle partially obscured text, it becomes necessary to identify the jurisdiction visually. This is not only undesirable from a throughput point of view but it becomes harder to recognize the plate's origin by sight as the number of designs grows.

D. Effect of Ageing

Old plates fade and discolor, their retroreflectivity declines, and the plate's texture changes. Since every plate ages differently depending on its particular exposure to elements, plates of same design become different for a camera. This variability calls for machine learning. But, in practice, when plates of a new design are released, one does not have samples of aged plates to use in training. This necessitates use of simulation initially and refining the classification model as experience grows.

E. Bent Plates

I. The operation of vehicles with bent plates is not illegal but they do make pattern matching difficult. Environmental Factors

A. Specification

Sensors that operate in the visual range cannot work in blinding snow, dense fog, etc. Border crossing facilities that remain open in these conditions have to establish special operating procedures. It would be useful to determine an operational envelope that matches the modern technology, and invoke the specification in system procurement.

B. Atmospheric Noise

Rain, snow, mist, and dust particles in the air, affect image quality and plate readability. Since the algorithms that are used for image analysis have to account for these factors, statistical parameters are needed to model atmospheric noise. Additionally, algorithms are needed to connect these parameters with the image preprocessing applications.

C. Mud and Slush Stains

Unlike the atmospheric noise or dust, mud stains can be large and difficult to filter out. The stains that cover an area of interest (like the plate's number) have to be individually located and erased. The image restoration by dilation may have to be supplemented with other AI tools.

D. A Composite Image

Figure 3 shows the sketch of an unclean plate as seen by a camera. The image has salt-and-pepper noise and mud stains. The salt and pepper stains can be removed by filtering, but the larger stains require individual treatment. The frame poses a serious problem in jurisdiction name recognition. The background graphics can be a more serious impediment in character isolation than shown in this figure.

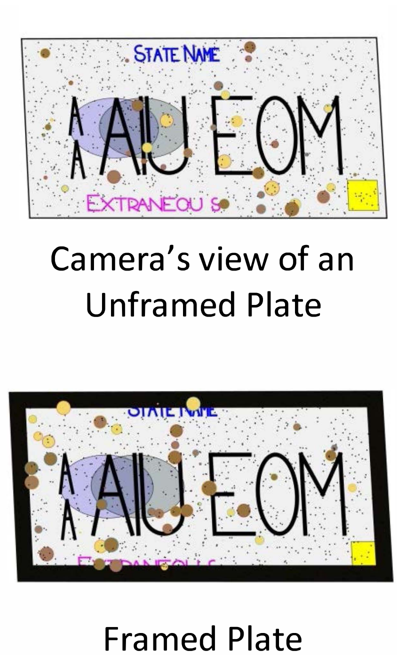

Fig. 3 Camera's View of an Unclean Plate

II. Site Characteristics

An LPR system deployed at an incoming border crossing point operates in conditions that are unique. They affect system design.

A. Space and Power

Space and power are not at a premium at a border crossing facility (as they are for LPRs in a patrol car). Thus extraordinary effort to miniaturize the system is not required and the external processor does not have to be a microprocessor.

B. Illumination

The artificial illumination at a border crossing facility can be designed to serve the LPR fully. An infrared camera can be used to work in fog but it is not needed to keep the operation covert. Everyone who crosses the border expects to be monitored. Lastly, since cars approaching the crossing point approach the inspection station at a crawling speed, it is unnecessary to use strobes to freeze action. An LPR system intended for use in patrol cars operates in a different environment.

Restrictions on use of high beam can be enforced to eliminate glare.

C. Security

Surveillance cameras at train stations have to be designed to be safe from vandalism. Border crossing facilities, in contrast, offer a more secure environment.

III. Hardware Considerations

A. Camera Setup

There are some jurisdictions that require front and rear license plates, others require only the rear plate [1]. Cameras are set up to take both images. This arrangement creates the following situations:

- If one of the plates is readable while the other is not because of its condition (see Fig. 3), the LPR system can report the number from the plate that it can read. When images are noisy, the degree of their *readability* becomes a matter of judgment. The fuzzy logic-based algorithms used in making this judgment require adjustment as experience grows. As already remarked above, the modeling of noise and its effects is a candidate for careful study.
- When both plates are *readable* in the sense noted above, they do allow comparison. In those unlikely instances when the two numbers differ, the cases become subjects for further investigation. When both plates are marginally readable, integration of data from both images can improve the confidence in the read number. It would be desirable to exploit this possibility during image analysis.

The details of each readability decision are worth recording and analyzing for their final use in machine learning.

B. Scene Cameras

The information on a car's make, type, and color is a useful addition to the information on its number and issuing jurisdiction's id. Adequate photographic and image processing capabilities (in the external processor) are well within reach and the image processing tools to extract the car's make, type, and color from its image are now worth exploration.

C. Smart Cameras

In Reference [4] smart cameras are defined as "vision systems that not only take images but also understand them." Both, the image taking capability and image understanding capability, are beneficiaries on the Moore's Law. This is reflected in the multi-megapixel image sensors and the FPGA (field programmable gate array) microprocessors. These two components in a modern camera allow an object of interest to be tracked and focused on and they set the f-stop, shutter speed, and gain (ISO setting) using an impressive level of intelligence at remarkable speed. They also take care of image preprocessing (removal of noise, enhancement of contrast, removing effects of camera vibration and object's motion …). The image data is compressed as required by the data communication link and the external processor.

1) Customizability: A systems integrator can purchase COTS image sensors and microprocessors to meet the specifications established by a system procuring agency. If the interface and performance requirements are defined, and maintenance requirements are documented, component-level replacements can be made by any qualified O&M agent for maintenance and upgrades.

2) Remotely Uploadable Code: Modern cameras provide capablility to upload the code. This is extremely useful for a system that works on code created by machine learning. A number of commercial firms provide high-level programming tools for a rapid development and testing of the image processing software and creating error-free HDL code to run on a microprocessor [5].

D. External Processor

Since space and power are not limiting factors, the external processor can be a regular workstation with multiple cores for parallel processing. It can be connected with a bank of hard disks to provide storage capacity that is unlimited for all practical purposes. Furthermore, the use of workstations, in place of microprocessors, eliminates the need for fixed word length code written in a fixed programing language.

In addition to extracting the plate number and jurisdiction name, the external processor can also be used for:

- Delivering image data to the officer's screen, allowing the officer to zoom in on a part that needs to be examined closely
- Storing records of corrections and manual entries made by the officer
- Keeping track of the system's state of health to run diagnostics and trigger alarms
- Switching to redundant systems when appropriate to keep the system operational
- Acquiring and analyzing performance data for use in the machine learning
- Assembling data for streamlining the site operation.

E. Local Area Networks

In older surveillance systems the network capacity was a limiting factor. The image data had to be compressed by the camera's microprocessor before its delivery to the external processor.

The modern multi-megapixel color cameras generate data in volume that is several orders of magnitude greater than did the cameras in the not too distant past. Judging by the problems that the designs of North American license plates create in plate recognition, it becomes necessary to make a full use of the high resolution data by preserving the information that it contains.

Fortunately the modern secure, high speed, fiber optics based data networks eliminate the bandwidth limitation problem in linking the camera with its external processor [6]. The applications residing in the external processor can make full use of the high resolution data for feature extraction.

IV. IMAGE PROCESSING

A. Design Samples

It goes without saying that machine learning cannot proceed without plate samples to train on. This makes it necessary for the machine training site to acquire samples for training as soon as they become available. During the initial training information on effects of ageing will be lacking, but the effects of noise can be simulated.

After the deployment of the application, the information on plates can be accumulated at the border sites and delivered to the machine training site.

B. Nature of the Image Processing Problem

The image processing problem in plate recognition is highly domain dependent and does not become subsumed into the problem of optical character recognition for the following reasons:

- The plate number and jurisdiction ID have to be extracted almost in real time. It is therefore very helpful to narrow the search space as rapidly as possible. (Images captured by a toll lane camera can, in contrast, be processed in batch mode.)
- A plate has no more than 20 alphanumeric characters that the LPR has to decipher (unlike the document scanner used by Google to digitize books). These few characters are, however, difficult to extract from their cluttered background and they pose problems because they are often displayed in esoteric fonts that vary among the several thousand plate designs and continue changing as plates of new designs get issued.
- The occlusion caused by the plate frame makes it necessary to treat the jurisdiction ID image as graphics rather than a character set.
- Large mud stains that at times cover parts of the alphanumeric characters leave holes after their removal. This becomes a difficult problem for optical character readers to resolve. Since the character strings have no lexical counterpart (no match in a dictionary), and no syntax (no discernible pattern such as *ABC 123*) for making intelligent guesses. The system has to rely completely on what it can see.
- The distance between the camera and plate depends on the car's position. The two-dimensional plate image that the camera captures becomes nonrectangular and of an unforeseen size.

C. A Possible Strategy, Reliance on Signatures

The primary purpose of signatures is to reduce the size of the search space as rapidly as possible. Identification of the plate type can have a major beneficial effect on the processing speed.

1) Plate Design Type: It is reasonable to assume that when a new plate design surfaces, its color scheme, foreground element set and element locations, and font types do not change between plates that are produced in accordance with it. If an easily computable signature is developed for each design, then plates belonging to it can be quickly classified and the system does not have to hunt to locate its areas of interest.

2) Jurisdiction ID: While the jurisdiction ID can be obscured by plate frame, it is fortuitous that there are less than a hundred jurisdiction names to choose from. (Their exotic fonts do add to the complexity; the complexity is also added depending on whether it is the upper part is obscured for jurisdiction ID near the top edge, or the lower part when it is placed below the plate number)

3) Stains: Mud and slush stains do not depend on plate design. The three-dimensional subset of the RGB space that contains stain color data can be built to isolate regions that contain stains.

D. Image Normalization

The nonrectangular plate images can be normalized by selection of key points for each design during the initial machine training [7, 8]. Plate corners cannot be used for this purpose because of the possibility of frames that cover plate edges.

E. Image Preprocessing

Preprocessing of raw images is carried out to simplify the steps involved in feature extraction and image classification. Procedures are installed in the camera's microprocessor to perform functions such as contrast enhancement, image sharpening, white balance bracketing (for accurate color rendering), high dynamic range accommodation (recovering details when part of the plate is in bright light while part is in dark shadow), corrections for camera vibration, etc. The high powered microprocessors can also be used to apply filters to remove noise – even stains.

It was customary in the past to work with gray scale data in image processing [9 – 12]. In the recent years there has been a significant rise in interest in the processing of color images and algorithms have become available for color image analyses [13-15].

As noted earlier, the microprocessor code can be installed and modified remotely by the machine learning site.

F. External Processing at the Workstation

1) Plate Image Analysis: The application package for license plate recognition can be developed rapidly by using the comercialy available packages such as the one described in [5] that come equipped with a vast collection of routines for image enhancement, filtering, morphological analyses, fuzzy logic utilization, and neural networks.

2) Character Recognition: In a high-resolution image, alphanumeric characters can be regarded as composites made of strokes – straight or curved strips of widths much shorter than lengths [15]. The pixels contained in strokes are darker than the background in most designs. In these cases simple thresholding at a suitable gray scale allows creation of a binary image that can be handled by directly optical character readers.

In isolated cases, when the background color scheme becomes very similar to the font color, the problem becomes complicated and the optical character reading system has to be customized. Special distance measurement algorithms have to be devised to handle the data from the red-green-blue channels for colorimetric differentiation.

The common optical character readers for document scanning use the lexical database to classify characters that image analysis cannot handle. In an LPR operation the lexical aid is possible only in reading jurisdiction names. Plate numbers in contrast do not even follow a standard syntax.

The reading of stacked letters would pose no problem when they exist in a high resolution image, but the manner in which the stacked letters are addressed in databases used for screening needs to be determined.

When icons, such as a miniature map of Texas, are imbedded in the plate number, it becomes necessary to check whether they have to be included in the number delivered for screening. Same is true for blanks that may be imbedded in the text.

As noted earlier, the edge strips on frames very frequently cover the upper part of the jurisdiction's name if it is located above the plate number and the lower part if it is placed below the plate number. However, since there are less than a hundred jurisdictions, it is quite feasible to put together a morphological pattern recognition system to read the name in spite of the occlusion. Even if most of the text is obscured there is enough information to classify the plate.

Interestingly, this may not be necessary in some cases. The miniature Texas map icon imbedded in the plate number already indicates that the plate was issued in Texas, making it unnecessary to read the name. There are other objects on the plate that serve a similar purpose.

V. ILS Considerations

It is useful to think of LPRs as mission-critical systems must meet a high requirement for availability. This requires a carefully modularized system design that facilitates component-level maintainability and upgradability using readily available skills. The use of commercially available components for the camera, and commercially available workstations and disk drives makes this goal fully realizable.

Furthermore, the installation of LPR system at hundreds of crossing lanes is expensive and time consuming. It cannot be replaced every time the operational requirements or technology changes, or some of the components become obsolete and unavailable. The requirements for scalability and upgradeability have to be built into the initial design.

It is also useful to develop an ILS philosophy to establish policies for parts warehousing of parts and development of skills for system maintenance.

VI. Concluding Remark

The views expressed in this paper are strictly the author's. They are products of his crystal gazing, therefore untested. They are offered with the hope that a homeland security agency in North America contemplating LPR system procurement would find them in some degree useful.

References

[1] "Best Practices Guide for Improving Automated License Plate Reader Effectivenes through Uniform License Plate Design and Manufacture," American Asociation of Motor Vehicle Administrators (AAMVA), October 30, 2012.

[2] David G. Roberts and Meghann Casanova, "Automated License Plate Recognition (ALPR) Systems: Policy and Operational Guidance for Law Enforcement," Washington, D.C.; US Deoartment of Justice, National Institute of Justice, 2012

[3] D. J. Findley, C. Cunningham, J. C. Chang, K. A. Hovey, and M. A. Corwin, "Effects of License Plate Attributes on Automatic License Plate Recognition," Institute for Transport Research and Education, North Carolina State University, 2012

[4] A. L. Belbachir (Editor), "Smart Cameras," Springer, 2010.

[5] R. C. Gonzalez, R. E. Woods, and S. L. Eddins, "Digital Image Processing using MATLAB," 2nd Ed., Gatesmark Publishing, 2009.

[6] B. A. Forouzan, "Data Communications and Networking," 4th Ed., McGraw Hill, 2007

[7] R. Hartley and A. Ziserman, "Multiple View Geometry in Computer Vision," 2nd Ed., Cambridge University Press, 2003.

[8] P. K. Sinha, "Image Acquisition and Preprocesing for Machine Vision Systems," SPIE Press, 2012

[9] W. Burger and M. J. Burge, "Principles of Digital Image Procesing, Fundamental Techniques," Springer-Verlag, 2009

[10] W. Burger and M. J. Burge, "Principles of Digital Image Procesing, Core Algorithms," Springer-Verlag, 2009

[11] W. Burger and M. J. Burge, "Principles of Digital Image Procesing, Advanced Methods," Springer-Verlag, 2009

[12] R. C. Gonzalez and R. E. Woods, "Digital Image Processing," 3rd Ed., Pearson Prentice Hall, 2008

[13] S. J. D. Prince, "Computer Vision: Models, Learning, and Inference," Cambridge University Press, 2012

[14] T. Gevers, A. Gijsenij, J. van de Weijer, and J-M Geusebroek, "Color in Computer Vision, Fundamentals and Applications," Wiley, 2012

[15] A. Coschan and M. Abidi, "Digital Color Image Processing," Wiley-Interscience, 2008.

[16] M. Cheriet, N. Kharma, C-L Liu, C. Y. Suen, "Character Recognition Systems, A Guide for Students and Practitioners," Wiley, 2007