Development of Automatic License Plate Recognition Device

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In Japan, automatic license plate recognition systems have been used for more than ten years for measuring the vehicle travel time and other applications that require detailed plate information. To better respond to the requirements in these applications, we have developed an automatic license plate recognition device that features a high recognition rate, low error rate, compact design, high reliability, and low running and installation costs by incorporating innovations in both software and hardware such as new image-processing algorithms, an advanced camera unit, and an image-processing board. Drawing on this technology, we are currently working on the development of recognition systems for foreign license plates.

Keywords: automatic license plate recognition, automatic vehicle identification, image-processing, plate detection, plate extraction, character recognition

1. Introduction

In Japan, automatic license plate recognition systems have been put into practical use for over ten years, with the objective of utilizing them for applications, such as the monitoring of vehicle travel time, that require detailed license plate information. The effectiveness of such systems has resulted in their proliferation nationwide.

We have implemented a variety of software and hardware-related innovations in order to meet the various requirements of these applications, and developed automatic license plate recognition devices that offer such features as high recognition rates, low error rates, high rates of car color determination, compact and lightweight designs, low running and installation costs, and high reliability, through the use of new image-processing algorithms together with cutting-edge imaging units and image-processing boards.

We are also carrying out research and development on recognition devices that incorporate image-processing algorithms separate from those developed in this instance, with the goal of providing license plate recognition for foreign license plates.

In this paper, we report on our efforts related to this research.

2. Overview of Automatic License Plate Recognition Systems

An automatic license plate recognition system consists of automatic license plate recognition devices, a central unit, and network circuitry to connect the various devices, as shown in **Fig. 1**. The automatic license plate recognition devices are normally placed on the side of the road, and each device consists of an imaging unit that photographs the road and a control unit that performs recognition on license plate characters and determines vehicle type (pri-

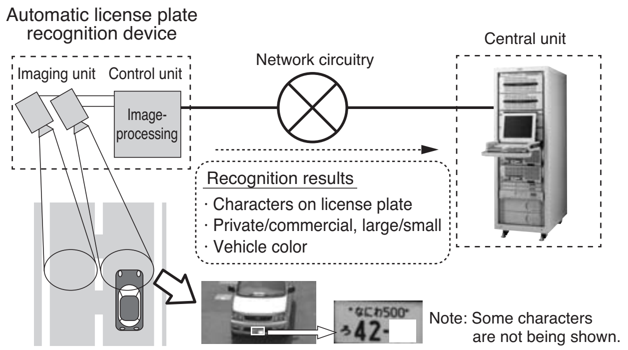

Fig. 1. Automatic License Plate Recognition System Setup

vate/commercial, large/small) and vehicle color.

The information recognized by the automatic license plate recognition device is sent to the central unit via the network, where it is put to use for a variety of applications such as travel time monitoring.

3. Image-Processing Algorithms

3-1 Image-processing sequence

In order to recognize license plate information and determine car color with a high degree of accuracy, the key is having image-processing algorithms that can correctly recognize the characters on license plates and determine colors in a similar manner that an human being perceives them, together with imaging technology that is high enough in resolution to distinguish all the various characters that appear on license plates.

The sequence in which image-processing for the recognition of license plate information and determination of vehicle color occurs is shown in **Fig. 2**. First, the po-

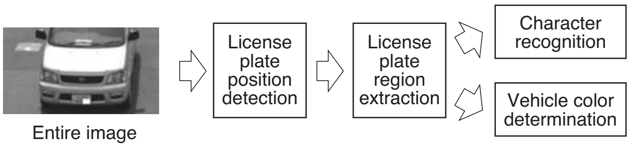

Fig. 2. The Image-Processing Sequence

sition on the vehicle where the license plate is mounted is detected from the photographed image (license plate position detection). Next, the license plate region is extracted from the detected license plate position (license plate region extraction). After that, character recognition and vehicle color determination are performed. The former involves recognition of the extracted license plate characters, and the latter involves inferring the vehicle's hood region in the image from the position of the extracted license plate, and determining its color.

We have developed new image-processing algorithms for performing license plate position detection, license plate region extraction, character recognition, and vehicle color determination.

3-2 License plate position detection

The image taken by the imaging unit might contain, in addition to the vehicle itself, shadows and reflections from the vehicle and buildings near the road as well as pedestrians. All license plates mounted on vehicles must be detected taking such situations into account. Thus, we have paid attention to the great variation in the intensity of the license plate area and have developed a highly accurate method for detecting license plate position. The XY-coordinates of the license plate in an image are detected as follows. (See **Fig. 3**.)

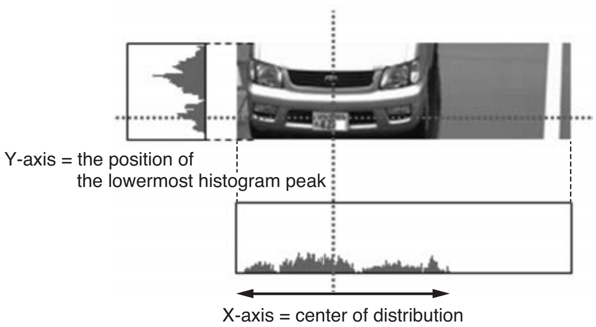

Fig. 3. The License Plate's (X,Y) Coordinates

(1) Pixels in motion are detected according to differences between frames.
(2) Variation in intensity is calculated for pixels in motion in comparison to adjacent pixels.
(3) Histograms are generated as projections of horizontal and vertical intensity variation.
(4) The vertically projected histogram's center of distribution is detected as the X-coordinate of the license plate.
(5) Of the several peaks of the horizontally projected histogram, the one with the lowermost position is detected as the Y-coordinate of the license plate.
(6) Histogram distribution and texture information using each coordinate as standard is applied to the detected XY-coordinates, and a determination regarding unwanted shadows is made.

In experiments, this method has been able to obtain the correct position of the license plate with 98% accuracy.

3-3 License plate region extraction

Next, the license plate region is extracted on the basis of the license plate's position. The size and color of license plates are fixed in Japan, but the shape of the license plate in the image will vary somewhat according to the relative positions of the camera and the license plate. There are also instances in which license plates may have obscured characters or be mounted at an angle. The region of the license plate must be extracted taking these conditions into account. Accordingly, we have developed a method for accurately extracting the region of a license plate that is not affected by the shape of the license plate in the image. (See **Fig. 4**.)

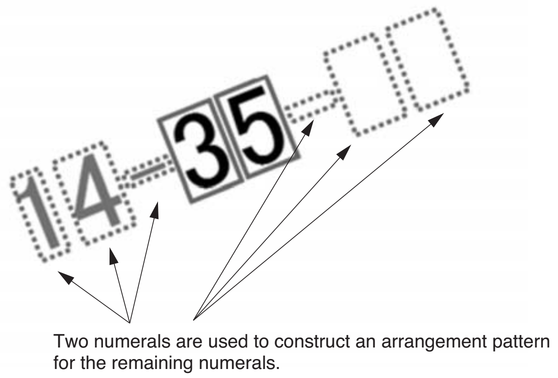

Fig. 4. Specifying the Numeral Arrangement

(1) Candidates for numerals are detected.
(2) Two adjacent candidates for numerals are selected (the area with the solid outline in **Fig. 4**), and using this as a basis, an assumption is made regarding the arrangement pattern of the remaining numerals (the area with the dotted line in **Fig. 4**).
(3) A determination is made as to whether candidate numerals exist within the assumed arrangement pattern, and the corresponding region is extracted as the license plate region.

By applying this method, the license plate region can be correctly extracted even when license plates are mounted at an angle or have obscured numbers.

In experiments, this method has been able to extract license plate regions with 99% accuracy in the cases where the position of the license plate is correctly calculated.

3-4 Character recognition

Recognition of each character on the license plate is carried out by making comparisons with a template of all characters prepared in advance, as described below.

(1) Each character has its position estimated and is then extracted.
(2) The size and intensity (of each character) is normalized.
(3) Feature values (for each character) are calculated.
(4) Similarity levels are calculated by comparing the feature values calculated for each character with those from the template.
(5) The result with the highest degree of similarity is selected.

This system requires a high degree of recognition accuracy, and since the demands to reduce misrecognition are particularly strict, we have improved accuracy by combining multiple algorithms for calculating similarity.

In experiments, this method has been able to correctly recognize all characters with 99% accuracy in the cases where the license plate region is correctly extracted.

3-5 Vehicle color determination

Lastly, the region of the vehicle hood within the image is estimated from the position of the extracted license plate, and its color is determined by comparisons with color samples that correspond to the intensity of the license plate.

The color data (RGB values) present in the image of an object depends on lighting conditions. Lighting conditions are determined by a combination of numerous environmental conditions, including the location and angle of the sun, the weather, and the presence of structures near the road. However, it is impractical to directly estimate lighting conditions from these environmental conditions.

Accordingly, for our device, our attention has been focused on the fact that the colors of license plates are generally defined by law, so that lighting conditions can be estimated according to the intensity of the license plate in an image, and we have adopted a method for determining vehicle color that utilizes color samples that correspond to the estimated lighting conditions. An overview of this method is described as follows.

First off, color samples with corresponding colors and RGB values are created in advance, corresponding to the numerous lighting conditions under which the intensity of the license plate will vary.

The procedure for utilizing these color samples to determine the actual color of a vehicle is as described below.

(1) Estimating the license plate intensity: The average intensity level of the license plate region acquired through license plate region extraction is calculated as the license plate intensity level.
(2) Selecting a color sample: Color samples are created in advance as shown on the right side of **Fig. 5**, and the color sample that corresponds to the license plate intensity level calculated in step (1) is selected.
(3) Deciding on a color determination region: The location on the hood or trunk of the vehicle which provides an optimal region for color determination is estimated based on the position of the license plate as determined during license plate position detection, and on that basis, a color determination region is decided on.
(4) Color determination for each pixel within that region: The next step is to determine the color of each pixel contained within the color determination region by utilizing the color sample selected in step (2). This method makes use of the CIE L*a*b* color space[1], which approximates human perception, and the color closest to the color sample as determined by calculating Euclidean distances is selected.
(5) Counting each color: Instances of each color found within the color determination region are counted, and the color that occurs with the highest frequency is considered to be the vehicle color. However, many commercial vehicles are painted in multiple colors, so outputting only the color with the highest count will detract from the convenience of the user. Thus, our device is designed to increase user convenience by outputting the two colors that occur with the highest frequency as the vehicle colors.

In experiments, we categorized vehicle colors under nine colors, and created eight color samples that assumed

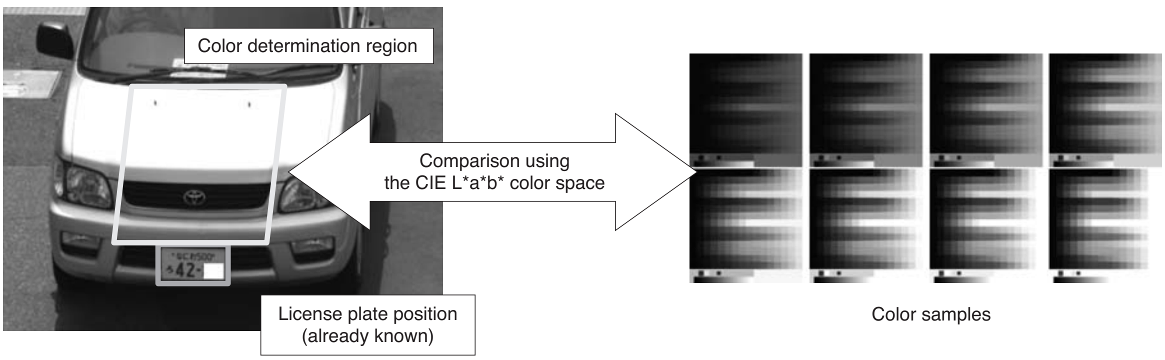

Fig. 5. Color Determination Using Color Samples

eight levels of license plate intensity that would vary according to changes in lighting conditions. Vehicle color was correctly obtained for over 80% of vehicles evaluated.

4. Hardware and Software

We have implemented a variety of hardware and software innovations from the perspectives of running costs, low installation costs, reliability and security, and safety, in addition to high license plate information recognition rates and vehicle color determination accuracy, all of which we believe are essential for automatic license plate recognition devices.

4-1 High license plate recognition rates

We use the latest in high-resolution cameras and high-resolution lenses to clearly distinguish each character on license plates, achieving high recognition rates through a combination of image-processing algorithms as described earlier.

4-2 Running costs

(1) Electricity charges (energy consumption)

The predominant sources of energy consumption are LED lamps for nighttime illumination and image-processing boards. As far as LED illumination is concerned, light that is shone outside the viewing angle of the camera is wasted and is responsible for increased energy consumption, so the angle of illumination is made to match the camera's visual angle, and what is more, high-efficiency LEDs are utilized. As far as image-processing boards are concerned, we have developed proprietary image-processing boards that make use of low-energy embedded processors[2]. These measures have enabled us to achieve energy consumption (power capacity) of 400 VA or less for a setup consisting of one control unit and four imaging units (a typical setup that covers four vehicle lanes), which is suitable for the inexpensive fixed-lighting contracts offered in Japan.

(2) Maintenance costs

In general, the emission power of LED lighting declines due to age-related degradation, so periodic replacement of LED lights is required for long-term operation, but periodic replacement of the LED light contained within the imaging unit requires the significant costs of a bucket truck and road lane control in addition to the cost of the part itself, making this a major element of the maintenance cost. It follows, then, that longer lifespan for LED lights will lead to lower maintenance costs. One approach is to slow the advance of age-related degradation and lengthen lifespan by increasing the number of LEDs used and reducing the amount of electric current that flows through each LED, but this would result in larger imaging units and be undesirable in terms of its effect on the urban landscape and installation costs as described below. Therefore, we have developed compact, lightweight imaging units with lifespans calculated to be at least seven years by utilizing special low-degradation LEDs, controlling emission cycles and periods, and using a high-heat-dissipation design.

(3) Communication (subscriber line) fees

The automatic license plate recognition device we have developed at this time allows for one control unit to connect to up to four imaging units, but there will be cases when installing the unit on roads with three or more lanes in each direction will require the installation of five or more imaging units at a single location. In such cases, two or more control units are required, and if each control unit sends data to the central unit via subscriber lines, the number of subscriptions will increase, leading to higher communication fees. Therefore, we provide a setup that allows for direct connections between control units using standard LAN cables, so that data from multiple nearby control units can be combined and sent via a single subscriber line, making it possible to reduce subscriber line fees.

4-3 Installation costs

In addition to utilizing high-efficiency LEDs, we have at our disposal technical expertise related to outdoor equipment, such as the use of materials with good heat dissipation and optimal placement of cooling fans, and have succeeded in making the imaging units compact and lightweight (under 6 kg). This will increase the number of cases in which the units can be installed on existing traffic sign poles, and will thus help to lower installation costs.

4-4 Reliability and security

In general, mechanical moving parts are considered to have a higher risk of breakdown or age-related deterioration than semiconductors and other electronic parts. Accordingly, we have eliminated mechanical moving parts as much as possible and improved device reliability through the adoption of CF (CompactFlash) cards instead of hard disks as a data storage medium, and by the adoption of electronic camera shutters instead of lenses with mechanical irises for controlling image brightness. With the same reasons in mind, our image-processing boards are mounted with solid capacitors only, rather than with aluminum electrolytic capacitors.

On matters of security, we encrypt the data sent to the central unit as well as the data stored internally during malfunctions of the network circuitry, using generic encryption methods that are widely used in the computer industry.

4-5 Safety

To prevent the unlikely circumstance of an imaging unit falling due to a loose bolt or some other factor, we use fall-prevention wires, double-nut bolts, and cotter pins.

5. Specifications of the Automatic License Plate Recognition Device

The specifications for the automatic license plate recognition device we have developed are provided in **Table 1**.

6. Efforts toward Foreign License Plate Recognition

At present, we are pursuing research and development on foreign license plate recognition by combining the algorithms described in this paper with separate algorithms that utilize Bag of Features[3] methods characterized by the use of HOGs (Histograms of Oriented Gradients)*1, and

Table 1. Specifications of the Automatic License Plate Recognition Device

Item	Description
Items recognized	Recognizes all characters on license plates, distinguishes private/commercial, large/small (large/medium plating)
Recognition rate	Rate of correctly identifying all characters on license plates: over 95%
Special license plate recognition	License plates with obscured characters License plates mounted at an angle
Target vehicles	Vehicle detection: four-wheeled vehicles and motorcycles License plate recognition: four-wheeled vehicles and motorcycles* *A method for motorcycle is under development
Maximum recognition field of view	4.0 m
Recognizable vehicle speed	Up to 120 km/h
Recognizable minimum gap between vehicles	0.5 seconds
Vehicle color determination	9 colors (daytime)
Side angle	Up to 30°
Data storage	Stores data to be sent to central unit during network malfunctions (Sends to central unit once network is restored)
Security	Data encryption using generic encryption methods
Number of imaging units per control unit	Up to 4 imaging units
Combined use of subscriber lines	Data from up to 3 control units can be combined
Size / weight	Imaging unit: Max. 200 mm (H) × 300 mm (W) × 450 mm (D) / max. 6 kg Control unit: Max. 850 mm (H) × 450 mm (W) × 350 mm (D) / max 60 kg
Environmental conditions	Ambient temperature: -10°C to 50°C Waterproofing: IPX3 Maximum instantaneous wind speed: 50 m/s
Energy consumption	Under 400 VA with 4 imaging units + 1 control unit / 100 V AC
Lighting lifetime	More than 7 years
Length of cables between imaging unit and control unit	Maximum 100 m
Imaging unit fall prevention	Fall-prevention wires, double-nut bolts, cotter pins
Other	Equipped with anti-fog heated glass

SVM (Support Vector Machine)*2 methods.

Applying this combined algorithm to sample vehicle images taken in Thailand using consumer digital cameras resulted in a license plate detection rate exceeding 90%. **Figure 6** provides an example of Thai license plate extraction.

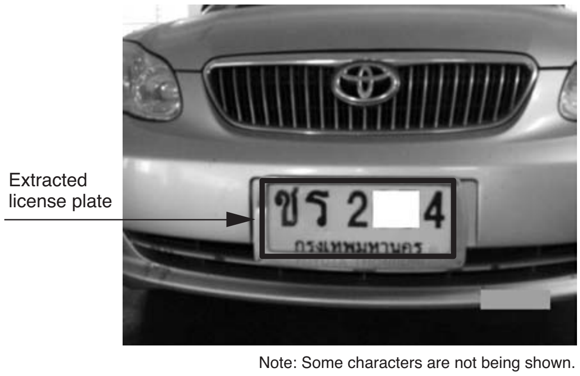

Fig. 6. Example of Thai License Plate Extraction

7. Conclusion

We have implemented a variety of software and hardware-related innovations and developed a new automatic license plate recognition device that offers a variety of benefits, including high recognition rates, low error rates, high vehicle color determination rates, compactness in size, high reliability, low running costs, and low installation costs, accomplished using new image-processing algorithms and cutting-edge imaging components and image-processing boards.

8. Acknowledgements

We would like to express our deepest gratitude to all those who have provided us with guidance and cooperation in the development of this device.

Technical Terms

*1 HOG (Histogram of Oriented Gradients): Histogram of oriented gradients is an image feature value. An image is divided into multiple local regions, and a side-by-side vector of histograms oriented in the direction of the luminosity gradient of each region is calculated as the image's feature value. One characteristic of this method is that it is robust with regard to differences in position and variations in illumination.

*2 SVM (Support Vector Machine): A support vector machine is a method of pattern recognition. In theory, it is the most efficient method for solving two-category classification problems and provides high identification performance when dealing with unlearned data.

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