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IMAGE PROCESSING OF ANDROID-BASED PATROL ROBOT FEATURING AUTOMATIC LICENSE PLATE RECOGNITION

S.Madhan, M.Pradeep
Bannari Amman Institute of Technology & Ebet Group Of Institutions
Contact No: 9942748297
E-mail: bitmadhan@gmail.com
Contact No: 9952646974
E-mail: pradeepm5664@live.com

***Abstract*— This work develops an Android-based robot featuring automatic license plate recognition and automatic license plate patrolling. The automatic license plate recognition feature combines 4 self-developed novel methods, Wiener deconvolution vertical edge enhancement, AdaBoost plus vertical-edge license plate detection, vertical edge projection histogram segmentation stain removal, and customized optical character recognition. Besides, the automatic license plate patrolling feature also integrates 3 novel methods, HL2-band rough license plate detection, orientated license plate approaching, and Ad-Hoc-based remote motion control. Implementation results show the license plate detection rate and recognition rate of the Android-based robot are over 99% and over 98%, respectively, under various scene conditions. Especially, the execution time of license plate recognition, including license plate detection, is only about 0.7 second per frame on the Android-based robot.**

Key Words: Android, License Plate Patrolling, License Plate Recognition, Robot.

I. INTRODUCTION

With the ever-increasing demand of anti-terrorism and public security worldwide, the global law enforcement has severely been fighting against stolen vehicles or vehicles hung with stolen license plates so far. Because these vehicles, both automobiles and motorcycles, are most likely used for terrorist activities or criminal vehicles. In addition, these vehicles are always parking in or running from unimaginable corners. It is necessary for the global law enforcement to carry out the license plate investigation anywhere, anytime, even under exhausted manpower condition. Therefore, the automatic patrol robot equipped with automatic License Plate Recognition (LPR) functionality can satisfy the growing demand and gain the expanding attention.

Figure 1. Mechanism of Android-based robot featuring LPP and LPR.

On the other hand, global digital video surveillance manufacturers are unexceptionally interested in the mobile robotic LPR technology so as to evolve the existing fixed LPR systems to portable embedded ones or mobile robotic ones. Thus this work develops the Android-based robot offering accurate LPR and reliable License Plate Patrolling (LPP) motion control for this emerging demand. It is composed of an Android-based smart phone platform and an Ad-Hoc-based mobile robot as shown in Figure 1, and the Android-based smart phone platform is mounted onto the Ad-Hoc-based mobile robot. Specifically, this work chooses boot loader unlocked Google Nexus One smart phone as the Android-based smart phone platform, and omnidirectional-wheel WowWee Rovio robot as the Ad-Hoc-based mobile robot. In this work, the motion control of the Ad-Hoc-based mobile robot is actually steered by the Android-based smart phone platform through peer-to-peer Ad Hoc networking, while the automatic LPP feature is routinely began by the

Ad- Hoc-based mobile robot. As soon as the Android-based smart phone platform detects and finds the license plate, the Ad- Hoc-based mobile robot will be remotely controlled to approach the license plate. As for the automatic LPR feature, it is still performed by the Android-based smart phone platform, especially by the built-in auto-focus camera and low-power embedded processor, for long-endurance and cost-effective requirements. Besides, it is also a key consideration that plenty of open-source computer vision libraries, like OpenCV, Tesseract OCR, etc., are increasingly ported and supported on Android operating system[1].

This work can meet both specifications of portable embedded and mobile robotic LPR systems, and it can be further transformed into any ubiquitous and diverse devices. This work not only can be applied to stolen license plate tracking and roadside inspection, but also can be extensively applied to parking lot patrolling, container logistic investigation, or automotive manufacturing management.

Figure 2 illustrates the overall algorithm flowchart of the developed Android-based robot featuring automatic LPP and automatic LPR. The flowchart in Figure 2 is made up of three main sub procedures. 1) License Plate Patrolling (LPP), 2) License Plate Detection (LPD), and 3) Optical Character Recognition (OCR). Referring to Figure 2, the organization of this paper is as follows. Sections II and III describe automatic LPP feature and automatic LPR feature, respectively, in detail. Here, Section II is divided into 3 subsections: HL2-band rough license plate detection, orientated license plate approaching, and Ad-Hoc-based remote motion control. Section III is divided into 4 subsections: Wiener-deconvolution vertical edge enhancement, AdaBoost plus vertical-edge license plate detection, vertical edge projection histogram segmentation stain removal, and customized character recognition. Implementation results about LPD rate and LPR rate improved by the 4 proposed methods in Section III are also exhibited. The implementation methodology of the Android-based robot featuring automatic LPP and automatic LPR in this work is illustrated explicitly in Section IV. Finally, Section V draws conclusions and future work.

II. LICENSE PLATE PATROLLING FEATURE

Initially, in the sub procedure of LPP, autonomous patrol is inherently launched by the Ad-Hoc-based mobile robot according to the predefined patrolling point and path planning. Next, the Android-based smart phone platform keeps working on the rough license plate detection to search the license plate candidates. Once one or more license plate candidates are found, the Android-based smart phone platform will evaluate the relative distance and the visual angle of the nearest license plate candidate, and drive the mobile robot through Ad Hoc networking to approach the nearest one until the plate is close enough, that is, the character on the plate is clear enough.

Because reliable LPP is the fundamental step for the developed Android-based robot, especially when license plate patrolling, searching, and approaching are proceeding under various conditions of illumination, scene, perspective, etc. This work proposes two simple but practical methods for rough license plate detection and license plate approaching, respectively, and implements peer-to-peer Ad Hoc networking mode for remote motion control [2]. The proposed ideas are summarized as follows.

A. *HL2-Band Rough License Plate Detection*

This work proposes HL2-band rough LPD for LPP. In this method, the scene image captured from the built-in camera of the Android-based smart phone platform is converted and decomposed by 2D Haar Discrete Wavelet Transform (DWT) twice to extract the HL2 subband feature. Because

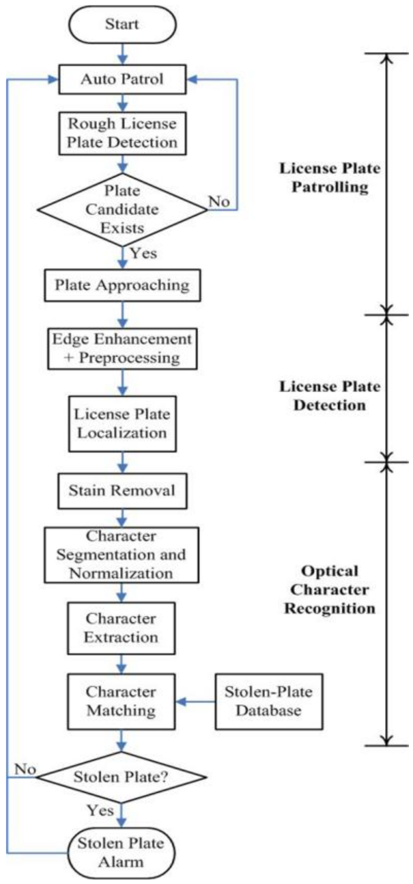

Figure 2. Algorithm flowchart of Android-based robot featuring LPP and LPR.

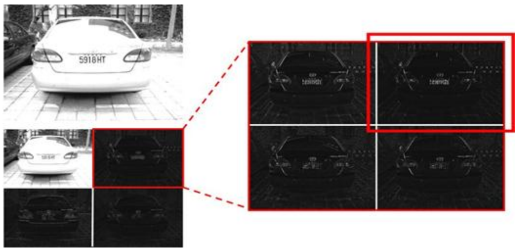

Figure 3. Illustration of HL2-band rough LPD.

LL, LH, HL, and HH subband elements decomposed by 1-level 2D Haar DWT primarily contain the original scene image's average details, horizontal edge details, vertical edge details, and diagonal edge details, respectively. HL2 subband features extracted from HL subband element through 1-level 2D Haar DWT again contains much richer vertical edge details of the scene image for better license plate detection accuracy and reliability, which is shown in Figure 3.

B.Orientated License Plate Approaching

In order to make the Android-based robot approach the nearest license plate candidate, the Android-based smart phone platform initially evaluates the horizontal declination angle of the license plate candidate as shown in Figure 4(a) to orientate the map coordinate system. The map coordinate is originated at the location of the license plate and its Y-axis is orthogonal to the surface of the license plate. Against the orientated map coordinate system, the developed Android-based robot turns its head to parallelize the

Y-axis direction of the orientated map coordinate system. Next, the Android-based smart phone platform measures the distance between the robot and the center of the license plate candidate to determine the X-axis moving distance as shown in Figure 4(b). Finally, the Android-based robot will move ahead to the license plate candidate until the plate region is clear enough as shown in Figure 4(c).

C. Ad-Hoc-Based Remote Motion Control

Because this work adopts the boot loader-unlocked Android-based smart phone platform, the Wi-Fi driver of the Android-based smart phone platform can be elaborately switched from Access Point mode to Ad Hoc mode through root certificate authority. At first, an Ad Hoc networking gateway on the Android-based smart phone platform is set up and started through the open-source utility, android-wifi-tether. Then, this work also changes the Wi-Fi mode of the mobile robot to Ad Hoc mode, and makes the mobile robot connect to the Ad Hoc network whose Service Set IDentifier (SSID) is broadcasted by the Android-based smart phone platform. Finally, after the Ad-Hoc-based mobile robot registers an IP address to the Ad Hoc networking gateway on the Android-based

(a)

(b)

(c)

Figure 4. (a) Map coordinate system orientation. (b) X-axis moving distance evaluation. (c) Y-axis moving distance evaluation.

Smart phone platform can request any motion control commands to steer the Ad-Hoc-based mobile robot remotely.

III. LICENSE PLATE RECOGNITION FEATURE

As mentioned earlier, LPR feature can further be segmented into two sub procedures, LPD and OCR. In these two sub procedures, this work proposes 4 novel methods, Wiener-deconvolution vertical edge enhancement, AdaBoost plus vertical-edge license plate detection, vertical edge projection histogram segmentation stain removal, and

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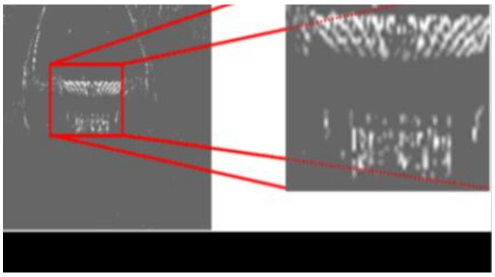
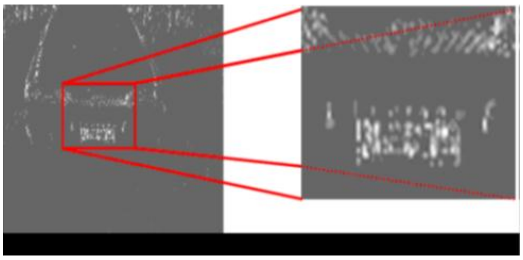
customized character recognition, for better LPD rate and OCR rate. 4 novel methods are clarified in order as below.



(a)



(b)

Figure 5. (a) Original vertical-edge scene image, and (b) that enhanced by Wiener deconvolution filter.

A. Wiener-Deconvolution Vertical Edge Enhancement

In general, most LPD systems make use of the vertical edge density feature to discriminate the license plate candidate region from the background of the scene image, because most characters on the license plate have higher vertical edge density than the background. If some vertical edge enhancement preprocessing method is put on the original scene image in advance, LPD will work better. Because Wiener convolution is originally used for image blurring, this work proposes to deconvolute the scene image with a horizontal-direction Wiener filter for vertical edge enhancement. The experimental result in Figure 5 shows the vertical edge density and intensity of the license plate are strengthened by a horizontal-direction Wiener deconvolution method, and those of the background, like radiator grilles, are simultaneously weakened.

Figure 6 compares the LPD rate between the proposed Wiener-deconvolution vertical edge enhancement and lots of conventional vertical edge enhancement preprocessing methods. Here, LPD can use any vertical-edge-based method. For consistency, this paper adopts self-developed AdaBoost plus vertical-edge license plate detection that is described later. "Inverse" means Direct Inverse Filter [4], "CLS" means Constrained Least Squares Filter [5], and "Wiener" means proposed Wiener deconvolution filter. Above are linear filters. On the other hand, "L-R" means Lucy-Richardson Filter [6] and "Blind" means Blind Deconvolution Filter [7]. They are iterative nonlinear filters. The scenes in the experimental database are filled with various complex backgrounds, like parking lot markings, plate-like

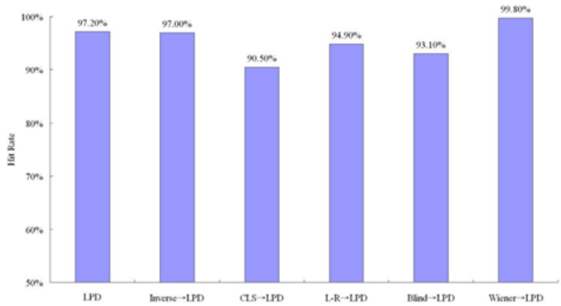


Figure 6. LPD rate comparison between various vertical edge enhancement methods based on AdaBoost plus vertical-edge LPD.

pavements, trench grates, road markings, roadside plants, radiator guards, mirror images on windshields, or street lampposts. The total amount of sample images in the database is 1038. From Figure 6, it is obviously shown that the accuracy and reliability of LPD is improved significantly.

B. AdaBoost plus Vertical-Edge License Plate Detection

Although AdaBoost cascaded classifier with proper and adequate training of license plate patterns is almost feasible for exact LPD, this work proposes two auxiliary methods to make plate-based AdaBoost LPD more accurate and reliable under various scene conditions. One method is character-based AdaBoost license plate verification to filter out the false positive outcomes of plate-based AdaBoost LPD by polling, and the other method is vertical-edge-based alternative LPD which is activated when no license plate candidate can be found by plate-based AdaBoost LPD and character-based AdaBoost license plate verification. Figure 7 illustrates the flowchart of the proposed AdaBoost plus vertical-edge LPD.

Under complex and diverse environmental conditions, the license plate candidate localized by LPD cannot be perfectly exact. So the localized license plate candidate is usually preset a little larger than the actual localized license plate region in order to avoid impairing any character information on the license plate. The localized license plate candidate is inevitably accompanying with some border stains, so the subsequent OCR procedure tends to misunderstand border stains as characters and is prone to make recognition mistakes. It is easier to remove interior stains on the license plate because interior stains are similar to salt and pepper noise and can be easily eliminated by mathematical morphology, but it is quite harder to remove trapezoid

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border stains residing at the right side and left side and interlinking border stains at the upside and downside.

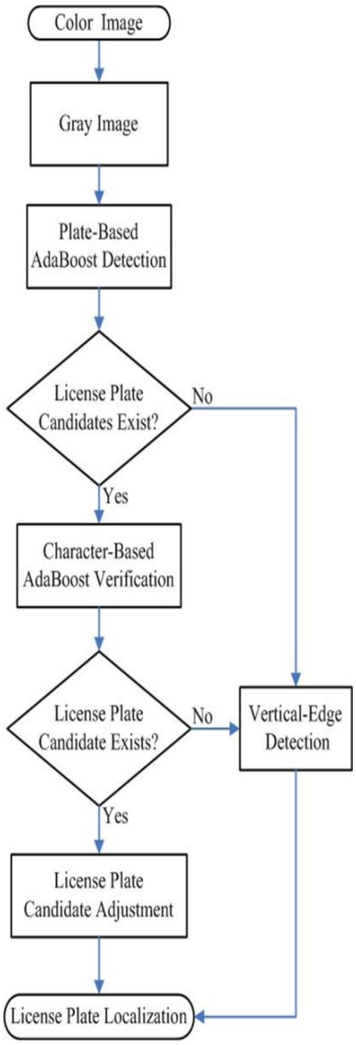

Figure 7. Flowchart of AdaBoost plus vertical-edge LPD.

C. Vertical Edge Projection Histogram Segmentation Stain Removal

In this work, Vertical Edge Projection Histogram Segmentation (VEPHS) method with fill-in and connected component labeling is proposed to handle with border stains. The proposed stain removal method can entirely remove trapezoid border stains at the right side and left side and interlinking border stains at the upside and downside.

Figure 8 demonstrates any 4 cases of actual implementation results. In each implementation result of Figure 8, the upper image represents the original license plate candidate localized by LPD, and the lower image exhibits the clean license plate candidate after its border stains are removed by the proposed VEPHS stain removal method with fill-in and connected component labeling. In Figure 8, "Time" means the execution time of the proposed stain removal method itself on the Android-based smart phone platform, and "Plate Number" displays the OCR outcome of the cleaned license plate candidate. The success rate of the stain removal is 100%, and the OCR rate is over 99%. From Figure 8, the execution time costing from 30 ms to 150 ms can prove the proposed VEPHS stain removal method is simple but practical. The content and amount of the experimental database here is completely the same as that for aforementioned LPD rate comparison.

D. Customized Character Recognition Because Tesseract OCR open-source library is originally used for OCR of general documents, not for OCR of license plates, this work elaborately retrain the font characteristics of each character on real Taiwanese license plate into the character dictionary of Tesseract OCR [8]. Then, through Java Native Interface (JNI) technique, this work ports LPR-customized Tesseract OCR onto the Android-based smart phone platform as a plug-in module of Android operating system.

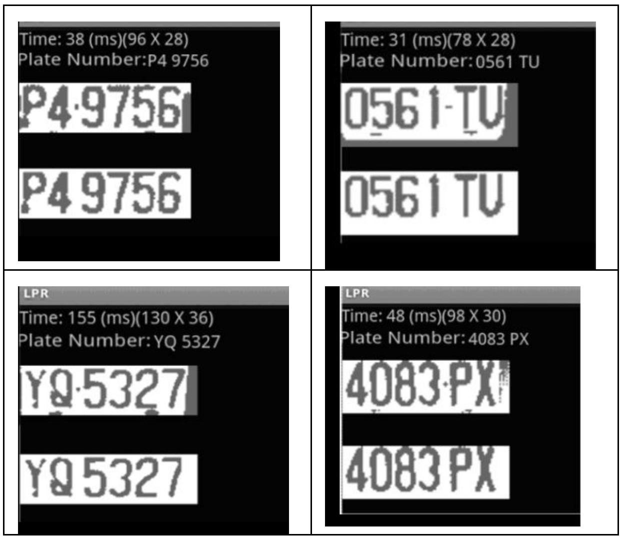

Figure 8. Implementation results of VEPHS stain removal method.

In addition, this work also proposes to adjust hybrid-pitch character segmentation of Tesseract OCR for the font characteristics of Taiwanese license plate.

Figure 9 demonstrates the field trial about OCR results of the developed Android-based robot featuring LPP and LPR. In Figure 9, the upper row demonstrates LPP and LPR results of automobile cases, and the lower row demonstrates those of motorcycle cases. The field trial result with OCR rate of over 99% and overall LPR rate of over 98% verifies that Tesseract OCR can perform well on LPR in Taiwan or elsewhere by customizing its character dictionary elaborately. Besides, Figure 9 manifests the execution time of LPR (LPD and OCR) of the developed Android-based robot takes only about 0.7 second per frame. Here, the clock frequency of the processor on Google Nexus One smart phone platform is simply 1 GHz.

Figure 9. Field trial about OCR results of Android-based robot featuring LPP and LPR.

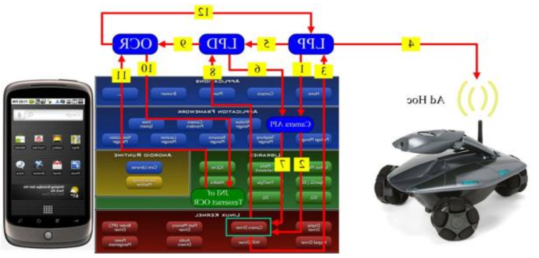

Figure 10. Implementation methodology of Android-based robot featuring LPP and LPR.

IV. IMPLEMENTATION METHODOLOGY

Figure 10 specifies the overall implementation methodology of Android-

based robot featuring LPP and LPR. In Figure 10, the directional lines on the Android-based smart phone platform not only represent the implementation methodology, but also indicate the execution flowchart of implemented modules interactive with Android embedded operating system architecture.

As shown in Figure 10, this work implements 3 applications: 1) LPP application to utilize Android-based camera driver module and Ad-Hoc-Mode Wi-Fi driver module for HL2-band rough license plate detection, orientated license plate approaching, and Ad-Hoc-based remote motion control, 2) LPD application to employ Android-based camera driver module and JNI-wrapped OpenCV library for Wiener-deconvolution vertical edge enhancement and AdaBoost plus vertical-edge license plate detection, and 3) OCR application to apply JNI-wrapped Tesseract OCR library and JNI-wrapped OpenCV library for vertical edge projection histogram segmentation stain removal and customized character recognition.

V. CONCLUSIONS AND FUTURE WORK

In this work, the Android-based robot featuring mobile LPP and real-time LPR already can work well. In the near future, more smart LPP features and efficient LPR features will continuously be developed and integrated into the Android-based robot.

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