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Performance analysis of vehicle number plate recognition algorithms developed by using the discrete wavelet transform and the digital image correlation

Análisis de rendimiento de algoritmos de reconocimiento de placas de números de vehículos desarrollado mediante la transformación de ondas discretas y la correlación de imagen digital

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Abstract

Objective: To develop two algorithms to evaluate through the comparison the performance of the Discrete Wavelet Transform (DWT) and Digital Image Correlation (DIC) techniques for the recognition of patterns, and more specifically the automatic recognition of license plates. **Results y Conclusions:** It can be concluded that one algorithm outperforms the other depending on the test performed; it is imperative to conclude that the most optimal algorithm for the recognition of vehicle registration using the DWT in conjunction with the DIC is that in which the recognition with the HOG detector is performed as an FBM technique; because although the algorithm that uses the normalized cross-correlation has the best performance in terms of time processing.

Palabras claves: Automatic number plate recognition, discrete wavelet transform, digital image correlation, histogram of oriented gradients, normalized cross correlation.

Resumen

Objetivo: Desarrollar dos algoritmos a fin de evaluar el rendimiento de las técnicas de Transformada Wavelet Discreta (DWT) y Correlación Digital de Imágenes (DIC) para el reconocimiento de patrones, y más específicamente el reconocimiento automático de matrículas, a través de la comparación. **Resultados y conclusiones**: Se puede concluir que un algoritmo supera al otro dependiendo de la prueba realizada; de este modo, el algoritmo más óptimo para el reconocimiento de la matrícula del vehículo utilizando, el DWT en conjunto con el DIC, es aquel en el que se realiza el reconocimiento con el detector HOG como técnica de FBM, aunque el algoritmo que utiliza la correlación cruzada normalizada tiene el mejor rendimiento en términos de procesamiento de tiempo.

Keywords: Reconocimiento automático de matrículas, transformada wavelet discreta, correlación de imágenes digitales, histograma de gradientes orientados, correlación cruzada normalizada.

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Introduction

The exponential growth of vehicles in the cities and the desired migration of these towards S*mart Cities* have led to the need for having more control over vehicles in both public and private spaces by incorporating intelligent systems which implement algorithms for automatic monitoring.

Therefore, *digital image processing (DIP)* techniques have started to be implemented in automatic number plate recognition algorithms used in plenty systems such as traffic control, parking access control and surveillance.

In this paper, two algorithms for number plate recognition were developed, in which the plate's characters recognition was made through two different *pattern matching* methods: *Area based matching* (ABM) and *features based matching* (FBM).

The first algorithm implements the *Normalized Cross-Correlation* (NCC) as a technique for ABM; the second one uses *the Histogram of Oriented Gradients* (HOG), as the technique for FBM; this, in order to establish the algorithm that best adapts to the vehicle number plate recognition when using patterns analyzed and synthetized by using the *Discrete Wavelet Transform.*

Fundamentals

Machine Vision is a field of *Artificial Intelligence* which purpose is to automatically extract, analyze and comprehend the information in an image [1, 2]. *Pattern recognition* is also a part of the artificial intelligence, which is responsible for the description and recognition of the objects [3, 4] in an image from both, the *characteristics extraction* and the *pattern matching* respectively.

One technique that can be applied to this field is the DWT, which allows the reconstruction of signals with enough information and a significant reduction in time processing [5] through decomposing the signal in approximations (low frequency components) and details (high frequency components) [6]; obtaining detailed information [7, 8] or hidden characteristics in an image and removing redundant and irrelevant information. Meanwhile, the DIC is directly related to *pattern matching* because it allows measuring the change between two or more images through methods based either on the image's pixels' intensity or the image's own characteristics [9, 10, 11, 12, 13, 14, 15].

Vehicle number plate recognition systems

The proposed design for the development of the algorithms was divided into the stages of: *acquisition*, *processing, analysis and recognition.* These algorithms were developed with Matlab R2015a, using both the Image Processing Toolbox and the Wavelet Toolbox.

Acquisition

For the development of the algorithms, 438 photographs of vehicles were taken. The photographs were acquired during day, under different lightning conditions and with the best possible capture conditions in order to reduce variations in the acquisition process. Frontal pictures of the license plate were taken as well to ease further stages like *plate localization*. A sample of the resulting pictures can be seen in figure 1.

Figure 1. Sample of the input image

Image processing

Initially, techniques for *resizing*, *gray scale conversion*, *noise reduction* and *edges enhancement* were applied to the input image to improve its quality, making easier stages like *segmentation* and *characteristics extraction* for further plate *localization* and final *recognition* of the number plates.

Plate Localization

To find the place within the picture where the license plate is located and extract it from the image, techniques like: *Canny Filter* for *edge detection*, *region growing, connected-components labeling* and *thresholding* were used. The result is the picture of the plate as shown in figure 2.

Figure 2. Vehicle number plate

Character Segmentation

Once the number plate was localized, the next step consists in the *segmentation* of the individual characters in the plate (refer to figure 3) by using again *region growing* and *connected-components labeling.*

Figure 3. Character segmentation

Up until this stage, the algorithm was able to correctly localize and segment 72.6% of the plates in the data base of 438 photographs.

Discrete Wavelet Transform (DWT)

The DWT was applied to both algorithms to reconstruct the images of the characters from its horizontal and vertical details; whereby, five *wavelet families* were selected: h*aar*, *daubechies2 (db2), symlets2 (sym2)*, *biorthogonal1.1 (bior1.1)* and *reverse biorthogonal3.1 (rbio3.1)*.

The first three were selected based on literature [13], whereas *wavelet bior1.1* and *wavelet rbio3.1* were selected based on visual criteria given that these stand out best the details of the images (as shown in figure 4).

Figure 4. Letter F, reconstructed with wavelets (from left to right): haar, db2, bior1.1, rbio3.1

All the individual characters were later stored in a database to be used as *reference images or pattern characters* (figure 6).

Figure 6. Character patterns reconstructed from the horizontal and vertical details with wavelet haar

The same was done to the segmented characters from the input license plate (*input characters*) (figure 7)

Figure 7. Characters from the segmented license plate reconstructed by using the DWT

Analysis and recognition

The main purpose of this stage is to compare the *reference characters* to the characters extracted from the license plate of the car. This is done by matching each character from the plate to each character from the *database* to find the amount of similarity among them. This process would later lead to the final *recognition* of the car's number plate.

For this, two different techniques were used, one for each developed algorithm.

Normalized Cross-Corelation (NCC)

In the first algorithm, the correlation coefficient was used to establish the measure of similarity between the *pattern characters* and the *input characters*, so that a maximum correlation coefficient obtained from comparing the plate's characters with the reference characters implies both images are similar, therefore they are the same character. Since the NCC was computed for this algorithm, a correlation value of 1 means both images are exactly the same, but since this technique uses the information from the intensity level of each pixel in the image, patterns variate according to the illumination at the acquisition environment. For this reason, a match between two characters can be recognized if the correlation value ranges from 0.7 to 1.

Histogram of Oriented Gradients (HOG)

By the other hand, the second algorithm uses the *HOG detector.* This method extracts the characteristics [14] from input characters and stores them in a *HOG characteristics vector.* This vector is then compared with the *HOG characteristics vector* of each *reference character* in the database. The comparison of both vectors is done by computing the *Euclidean Distance*; so that a minimum value obtained (zero or close to zero) means both vectors are similar; thus, both images are similar as well.

Results

Recognition

The recognition percentages obtained for both algorithms using the *wavelet transform* for character reconstruction are shown below (Table 1).

Table 1. Number plate recognition percentage for characters reconstructed with the dwt

PLATE RECOGNITION (%)		
WAVELET	**NCC**	**HOG**
Haar	**53%**	**99%**
Sym2	**30%**	**32%**
Db2	**28%**	**29%**
Bior1.1	**52%**	**99%**
Rbio3.1	**53%**	**98%**

However, one additional test was done by using characters which weren't reconstructed by using the wavelet transform, i.e. characters in *grayscale*. The recognition percentages for this additional test are shown in table 2.

Table 2. Number plate recognition percentage for characters in grayscale

PLATE RECOGNITION (%)		
	NCC	**HOG**
Grayscale	*92%*	*98%*

The best performance in the algorithm using the NCC altogether with the characters reconstructed from the wavelet transform is obtained when using the *wavelet families: haar (53%), bior1.1 (52%)* and *rbio3.1 (53%),* in comparison to using the *wavelet families: sym2 (30%)* and *db2 (28%)*. However, using grayscale *reference characters* result in much better character recognition *(92%).*

Just as mentioned above, the algorithm which uses the *HOG detector* has better recognition percentages when using reconstructed characters with the *wavelet families: haar (99%)*, *bior1.1 (99%)* and *rbio3.1 (98%).*

When the matching is done by using *grayscale characters*, the recognition percentage is 98%; which is 1% less if compared with the recognition percentage obtained from applying the discrete wavelet transform using *wavelet families: haar* and *bior1.1 (99%).* This 1% difference could be significant in traffic control or surveillance systems.

Time processing

Time processing analysis was solely done for *wavelet families: haar*, *bior1.1* and *rbio3.1*, since these are the ones with which the best recognition performance was obtained. This test was done on a DELL computer with a 64 bits OS, 3GHz Intel Core i5 processor and a 4GB RAM.

The results for time processing are shown in table 3.

Table 3. Total processing time using characters reconstructed with the dwt

TIME PROCESSING (s)		
WAVELET	**NCC**	**HOG**
Haar	*1.61*	*1.82*
Bior1.1	*1.57*	*1.77*
Rbio3.1	*1.61*	*1.8*

The time processing for the additional test, in which the characters used are grayscale images, is presented in table 4.

Table 4. Total processing time using characters in grayscale

TIME PROCESSING (s)		
	NCC	**HOG**
Escala de grises	*1.45*	*1.64*

In general, the algorithm with the best time processing performance is the one in which the matching is done by using the NCC; however, both the algorithms have the least processing time when using characters reconstructed with the *wavelet bior1.1*.

Conclusions

From the performance results one can tell that one algorithm surpass the other depending on the test performed; nonetheless, it is imperative to conclude that the most optimal algorithm for vehicle's number plate recognition using the DWT altogether with the DIC is the one in which the recognition is done with the *HOG detector* as a FBM technique; because although, the algorithm which uses the normalized cross-correlation has the best performance in terms of time processing, the percentage of recognition is very low when using the DWT (between 51% and 53%), unlike the one using *HOG,* which recognition percentages varies between *98%* and *99%.*

Besides, since the *HOG detector* doesn't require using the intensity values from each pixel in the image to be computed, it's not sensitive to illumination, shadows or any other related changes in the environment; at the same time, it allows having minor changes in the acquisition angle of the photograph without compromising the recognition; which facilitates to adapt this technique to the vehicular license plate recognition in real environments and conditions.

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