DIGITAL IMAGE PROCESSING GUIDE IN JUPYTER NOTEBOOK AS A SUPPORT MATERIAL FOR A PROJECT-BASED LEARNING METHOD: CASE STUDY IN LICENSE PLATE DETECTION

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Abstract: *With the advances in Convolutional Neural Networks and the expansion of image and video data, Computer Vision becomes an important area on Artificial Intelligence. Teaching of Digital Image Processing (DIP) as a basic knowledge for Computer Vision expands the horizon of applications and it is an important investment for engineering and computing schools. This work objective is to create a support guide for DIP classes, and for Project-Based Learning (PBL) methods in this area. Using modern technologies such as Python programming language, Jupyter Notebook environment, and OpenCV library, this guide explores a branch of DIP techniques, trying to solve the problem of automatic license plate detection. The guide is composed of eleven notebooks that progressively create the final solution for the plate detection problem based on literature and on DIP reference books. As preliminary results, the projected guide forms a representative material of a DIP discipline, of basic algorithms for the proposed problem presented on literature, and of a real-world license plate detection solution, becoming ideal to be used as a PBL project.*

Keywords: *Digital Image Processing. Guide. Project-Based Learning.*

1 INTRODUCTION

In the last decade, advances in deep learning, especially those brought by Convolutional Neural Networks (CNN), and the increased number of image and video data made Computer Vision one of the most studied areas in Machine Learning and Artificial Intelligent. In this context, teaching Computer Vision for undergraduate students has become a great issue for computing and engineering courses.

The use of deep learning solutions for Computer Vision in a resource-constrained environment, like an embedded system, is a challenge. On that scenario, Digital Image Processing (DIP) systems can be a solution. Also, the knowledge in DIP can be useful for many other tasks as feature engineering, small data problems, real-time computer vision, and data augmentation. Also, deep learning systems eventually have better results when using DIP as a preprocessing approach.

For better learning in applied areas such as Computing and Engineering, it is necessary to take practical lessons, which is a good opportunity to apply active learning methodologies such as case study, more specifically the Project-Based Learning (PBL). In this methodology, the goal is to make students solve complex, and real problems in a collaborative way, and under the guidance of a faculty (ALLEN and DONHAM, 2011).

In general, computational projects involve lots of programming tasks that are hard to explain in traditional reports. Thus, tools such as Jupyter Notebook were developed to join theory, code, equations, figures, and tables in a single document. This modern scientific development environment allows faster reporting and facilitates the visualization of the applied theory on code.

In the context of building applications for Computer Vision and Machine Learning techniques, the Python programming language is one of the most used. Due to its high abstraction in comparison with C or C++ languages, this language facilitates the programming of complex computational issues, such as dealing with matrices. As a result, in the past decade, the computing community developed lots of Python libraries for many applications. On Computer Vision, one of the most used packages is OpenCV, a collection of libraries that implements many DIP techniques.

Thinking about it, this paper proposes an introduction guide for Computer Vision systems, focusing on applying traditional DIP techniques in a case study method using the PBL approach. Moreover, to encourage students to learn the theory behind used techniques, this proposed guide joins theory and application in a single document using the Jupyter Notebook tool. Also, it uses the Python programming language and OpenCV to help students in the task of implementing Computer Vision algorithms and to teach them some commonly used tools in the market.

For the case study, the problem to solve is the license plate detection problem, and it was chosen due to the existence of many approaches in the literature, and also because of the great necessity of license plate recognition systems in the real world. Particularly, the recognition of license plates in open and non-controlled environments is a modern issue to be solved. So to introduce a real modern challenge in the guide, an open unconstrained vehicles database was chosen, the SSIG-ALPR Database (GONÇALVES *et al*, 2018). In this way, the main task of this guide is to build an effective computer vision system using the introduced DIP techniques to solve the license plate detection problem.

The main contributions of this work are:

- introduction guide for Digital Image Processing using Python and OpenCV;
- support material for DIP courses and PBL approaches;
- interactive theoretical and practical guide using Jupyter Notebook;
- simple solutions for license plate detection in an open and non-controlled environment.

2 RELATED WORKS

In order to develop this guide, a number of studies were done within the Project-Based Learning method, and Digital Image Processing techniques used on automatic license plate detection approaches.

2.1 Project-Based Learning method

Historically, PBL was formalized by medical educators. In BARROWS and TAMBLYN (1980), it was reasoned in two postulates:

- learning through problem-solving is much more effective for creating a body of knowledge usable in the future;
- physician skills most important for patients are problem-solving skills, rather than memory skills.

SCHMIDT and YEW (2011) studied how learning is driven in PBL, concluding that this method used in collaborative small groups can encourage the activation of prior knowledge, providing the environment to structure it. Also, the PBL facilitates the understanding of new information related to the problem and increases the long-term memorability associated with it.

In the last two decades, the application of PBL in engineering and computing courses has increased. RIBEIRO (2008) showed that this method can be used in engineering grades or disciplines and concluded that even in partial implantations, the gains obtained by the PBL justify its adoption. PEREIRA *et al* (2017) described a full experience, showing the lessons learned, and the remaining challenges of the application of PBL methodology over four years in the Industrial Engineering program. This experience was widely recognized by the students as one of the Industrial Engineering program’s differentiating features and by the whole school community.

ANGELO and BERTONI (2011) evaluated the application of PBL in many disciplines of Computer Engineering course. It combined a series of students experiences and declarations and, it tried to measure the efficiency of the method. They concluded that it can develop students abilities and attitudes that are not explored in traditional learning methods. Similarly, BITTENCOURT *et al* (2013) studied the use of PBL in some computing disciplines and pointed out the acquisition of high-level social and cognitive skills by students, and the approximation to the professional environments.

We noticed that lots of papers are being published studying the effects of active learning and PBL and how they affect the learning process and trying to find new approaches for their application. Finally, the PBL researchers present some real applications of PBL and their obtained results.

2.2 Digital Image Processing and the Automatic License Plate Detection Problem

Around the world, license plate detection systems are being used mostly for security systems as traffic monitoring, infraction detection, cities access control and speed radar systems. Many solutions were proposed for this problem, but still, there is space for research, especially those focused on building solutions for diverse scenarios and situations. Most solutions are not robust enough for unconstrained scenarios, like external places with cars in movement, where there are lots of noise fonts, as for example, shadows, water pools reflectance, light variance during the day, plates reflectance, blurs caused by vehicle speed, and others.

Many DIP approaches were developed for plate detection, the majority for controlled scenarios such as parking lots. However, using outdoor scenarios to teach digital image processing seems to be reasonable, since many DIP techniques can also be applied.

In ATIWADKAR *et al* (2015), the authors classified four classes of algorithms: binary image processing, gray-level processing, color processing and using computational intelligence. On binary image, they described two techniques. One is the edge detection, such as Sobel gradient, that tries to identify brightness transition zones, and, as a consequence, the borders of objects in the image. The other is a morphological approach which uses morphological operators to detect license plate by comparing the contrast between the background, plate, and characters. For gray-level, two approaches were highlighted: region-based segmentation, and sliding concentric window. For color, they mentioned the space color transformation as a technique to capture the difference between background, plate, and chars colors. Also, histogram-based approaches are cited in this category. Finally, artificial neural networks and Adaboost classifier were the machine learning algorithms cited.

BHATTI *et al* (2014) created a diagram summarizing the main techniques used for license plate detection. In this diagram, they presented the following approaches: Edges, Morphological, Neural Networks, Image Transform, Histogram-based, Color-based, Smearing, Feature-based, and Texture-based. In that work, the authors made a comparison chart including all considered techniques with accuracy results for plate detection.

Similarly, in VIDHYA and SUNDARI (2015), the authors described edge-based, morphological-based and sliding concentric window as the main techniques on literature survey. They also mentioned connected components analysis, space color conversion, texture approaches, and Hough Transform associated with contours detection.

Furthermore, works as GILLY and RAIMOND (2013) also use edge detection and morphological operators as a basic pre-processing for plate detection. Associated to these techniques, they used a region-based segmentation with connected components and cited others approaches such as Hough transform with count algorithm, fuzzy logistic, and features filters (Aspect Ratio, orientation, and Euler number).

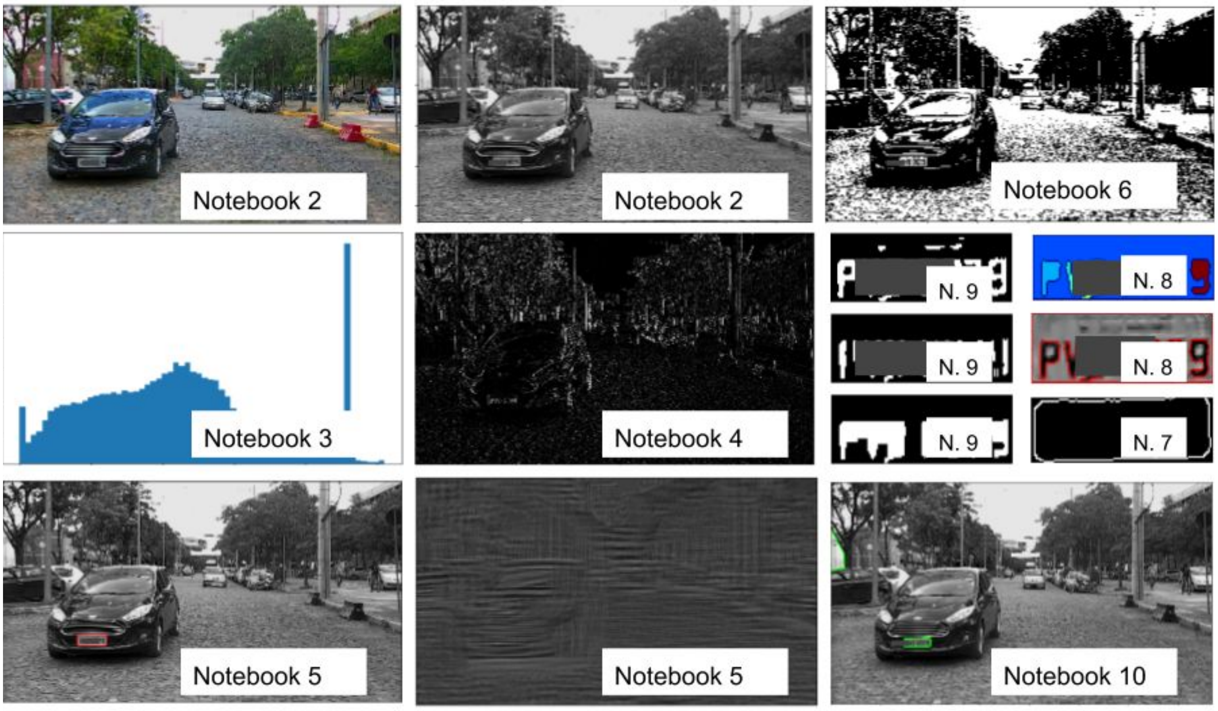
As seen, lots of DIP techniques have been proposed and tested for that purpose. In this work, we focused on edge detector and morphological operations to solve this problem. Nonetheless, other techniques were explored and some will be implemented on future tasks.

3 THE DIGITAL IMAGE PROCESSING GUIDE

The proposed guide consists of a series of Jupyter Notebooks that follow a project-based methodology. So when exploring the guide, students will learn technique by technique and, in the last notebook, they will combine them to form solutions for the case study. As a challenge, the chosen database includes difficulties caused by variance on illuminance, the presence of shadows zones, the different distance between the license plates and the camera, the variability of plates and vehicles, the presence of more than one plate in a single image and the non-fixed position for the plate.

Most of the notebooks introduce the student into the Python programming language and to some techniques of Digital Image Processing. This group was based on the main references: GONZALEZ and WOODS (2006), and PEDRINI and SCHWARTZ (2008). The Figure 1 illustrates some results obtained in the notebooks.

Figure 1 - Some results obtained by the guide notebooks



The first notebook is a brief introduction to Numpy and it focuses on handling arrays. The creation and manipulation of multidimensional arrays, matrices operations, and random numbers generation are some of the explored Numpy functions. The second starts the use of the OpenCV package with image reading function and converting space of colors function. The space of color conversion was used to turn the image from a three-channel RGB image to a one channel grayscale image.

In the third and fourth notebooks, the spatial filters were explored. In the third one, it is approached smoothing filters, and it is explained their usage for removing noise and smoothing images. The showed filters are Mean, Median, Gaussian and Bilateral filters. Also, it is presented the image histogram and its equalization as a method to correct the contrast and the brightness of an image. In the fourth notebook, the focus is on edge-based filters. So, the Laplacian, Prewitt, Sobel, and Canny edge detection filters are studied, including also the Unsharp Mask edge enhancement filter.

The fifth notebook continues exploring the use of spatial convolution masks, introducing the Template Matching technique. In this example, the cropped plate from the image was used as the template to locate the plate on the original image using different similarity or dissimilarity metrics.

In the sixth to the eighth notebooks, it is studied the segmentation process. This topic is divided into three sections, one for each notebook: thresholding-based segmentation, discontinuity-based segmentation, and region-based segmentation. On the first section, global thresholding, adaptive thresholding, and thresholding by Otsu are explored. The discontinuity segmentation is taught using the Hough Transform for lines as an example. Finally, for region segmentation, the Watershed algorithm is chosen.

Morphological operations are presented on the ninth notebook. The studied operations are erosion, dilation, open, close, tophat, blackhat, low pass filter, and gradient. In the tenth, the student will study forms of representation and description of objects. The representation algorithms presented are the border following and the polygonal approximation. On the other hand, the shown descriptions are the perimeter of a contour, the area of a region delimited by a contour, and the minimal area bounding box.

The last notebook is the final project for the case study of license plate detection. This project was divided into two steps, the first step is a detector of possible plates, named candidates. In this step, two approaches were suggested: one based on edge detection named board, and another based on morphological operations named morphological.

The board's approach starts by applying a blur in the image to reduce the noise and then equalizes its histogram to uniform the dataset brightness. After this, the algorithm applies a Sobel filter over the horizon axis to highlight the vertical lines in the image. Then, it makes an Otsu thresholding to filter only the most import vertical lines and applies a dilatation in horizon axis to create a region where there was a high concentration of vertical lines, such as the plate due to the characters. After this, it uses a boundary tracing algorithm to get contours of these formed regions, bounding and filter them by area and aspect ratio, obtaining the plates candidates regions.

The morphological approach starts doing a histogram equalization, trying to uniform brightness of the database. After, it applies a grayscale tophat operation to highlight the whiteness of plate, caused by reflectance, above the darkness of the car paint. Then, it does an Otsu thresholding followed by a morphological filter. This filter is compounded by an open and a close operation. The choice of the kernels for these morphological operations was made thinking of conserving the plate region using rectangular kernels. So the algorithm produces a binary image with the rectangular whiteness regions highlighted. This image passes by a boundary tracing algorithm to bound the contours and filter them by aspect ratio and area.

The second step is a filter for candidates to select the best candidate for the plate. In this case, some initial tests were made and the algorithm which presented the best results was chosen. We named this algorithm as Uniform Inners Contours (UIC), because, for each candidate, it detects the inside contours in the thresholded image, selects them by aspect ratio and size, counts the selected contours and calculates the standard deviation of the centers of the regions delimited by these contours. For a good plate image, the inside contours will be the plate characters whose centers are aligned, so the standard deviation will be small. Applying a minimum limit for the number of selected contours and getting the candidate with minimal standard deviation, the algorithm defines the best candidate.

4 RESULTS

These results focus on demonstrating how representative the final project and the algorithms used on the guide are. It is relevant to know if the final project really solves the case study suggested and how the showed techniques belong to the literature of DIP.

As reference, this works used two books: GONZALEZ and WOODS (2006), and PEDRINI and SCHWARTZ (2008). Both books define basic concepts and methodologies for DIP, and help to develop a foundation that can be used as a basis for further studies and researches. In Table 1, the chapters of each book are shown and those which are presented on the guide are indicated.

Table 1 - The guide representativeness by the reference books

GONZALEZ; WOODS, 2006	LPD Guide	PEDRINI; SCHWARTZ, 2008	LPD Guide
Introduction	NO	*Introdução*	NO
Digital Image Fundamentals	YES	*Fundamentos de Imagens Digitais*	YES
Intensity Transformations and Spatial Filtering	YES	*Transformadas de Imagens*	NO
Filtering in the Frequency Domain	NO	*Realce de Imagens*	YES
Image Restoration and Reconstruction	NO	*Segmentação de Imagens*	YES
Color Image Processing	NO	*Compressão de Imagens*	NO
Wavelets and Multiresolution Processing	NO	*Representação e Descrição*	YES
Image Compression	NO	*Análise de Texturas*	NO
Morphological Image Processing	YES	*Morfologia Matemática*	YES
Image Segmentation	YES	*Registro de Imagens*	NO
Representation and Description	YES	*Classificação de Padrões*	NO
Object Recognition	NO		

As seen on related works, many approaches for automatic plate detection have been proposed among the years. It is noticeable that the presented surveys and works mainly cited the use of morphological operations and edge detection. In this context, the final project was designed to incorporate these approaches. Also, this guide explores others techniques cited by plate detection literature such as Hough Transform and region-based segmentation. So, for foundation purposes, the guide works as a starting point for searching for better solutions to the chosen problem.

In order to compute the real effectiveness of the proposed solution for the plate detection algorithm, we executed our best approach, which was the Board approach with UIC, calculating the Jaccard coefficient, a common metric for detection problems. Therefore, for a threshold of 0.5, this approach detected 73.35 % of the plates. Considering that some of the plates are from motorcycles, and our algorithm is not prepared to detect it, this value will probably be better if those plates were removed. Also, some images have more than one plate which can cause a wrong answer if the algorithm detects the plate that is not the ground truth.

For an indirect comparison, we executed the OpenALPR (OPENALPR, 2019) over all images from the SSIG Database. OpenALPR is a commercial system for Automatic License Plate Recognition, and it also has configurations for Brazilian license plates. This commercial system outputs "No license plates found" for 37% percent of the database images, meaning that it did detect plates on 63% of the cases. Then, this can demonstrate that our algorithm really represents a solution to the problem, due to the fact that a commercial recognized solution got similar results.

5 CONCLUSION

Since the popularization of Computer Vision due to the advances in Deep Learning techniques, such as CNNs, many computing and engineering graduation courses have given more attention to Computer Vision, and related areas. Focusing on be a support material for disciplines in this area, this guide was developed attending the necessity of a digital image processing guide with popular news tools such as Python programming language, Jupyter notebook tool, and OpenCV library.

Thinking on improving the guide, the next steps will be the implementation of new notebooks to teach non-explored sections like Fourier transform and compression. Also, more advanced techniques, such as Haar Cascade, Histogram Oriented Gradient (HOG), and sliding windows, will be added to guide. Moreover, a brief introduction in using neural networks and CNN models and some others machine learning techniques are of interest.

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REFERÊNCIAS

ALLEN, D. E.; DONHAM, R. S.; BERNHARDT, S. A. Problem-based learning. **New Directions for Teaching and Learning**. Wiley Periodicals, Inc., n. 128, p. 21-29, 2011.

ANGELO, Michele Fúlvia; BERTONI, Fabiana Cristina. Análise da Aplicação do Método PBL no Processo de Ensino e Aprendizagem em um Curso de Engenharia de Computação. **Revista de Ensino de Engenharia**, v. 30, n. 2, p. 35-42, 2012.

ATIWADKAR, Ajinkya *et al*. **Vehicle License Plate Detection: A Survey**. International Research Journal of Engineering and Technology (IRJET), v.2, 2015.

BARROWS, H.; TAMBLYN, R. **Problem-based Learning: An Approach to Medical Education**. New York: Springer, 1980.

BHATTI, Muhammad Shahid *et al*. Survey of Computer Vision Techniques for License Plate Detection. **Journal of Basic and Applied Scientific Research.** TextRoad Publication, 2014.

BITTENCOURT, Roberto Almeida; RODRIGUES, Carlos Alberto; CRUZ, Danila S. Santos. Uma Experiência Integrada de Programação Orientada a Objetos, Estruturas de Dados e Projeto de Sistemas com PBL. In: **XXXIII Congresso da SBC–XXI WEI**. 2013.

DU, S. *et al*. **Automatic license plate recognition (ALPR): A state-of-the-art review.** IEEE Transactions on Circuits and Systems for Video Technology, v. 23, n. 2, p. 311–325, 2013.

GILLY, Divya; RAIMOND, Kumudha. **A Survey on License Plate Recognition Systems**. International Journal of Computer Applications, v. 61, n. 6, 2013.

GONÇALVES, G. R., *et al.* **Real-time Automatic License Plate Recognition Through Deep Multi-Task Networks**. Conference on Graphic, Patterns and Images (SIBGRAPI), pp. 1-8, 2018.

GONZALEZ, Rafael C.; WOODS, Richard E. **Digital Image Processing**. 3rd Ed. New Jersey: Prentice-Hall, Inc., 2006.

OPENALPR: Automatic License Plate Recognition. OpenALPR Software Solutions, LLC. Disponible in: https://www.openalpr.com/. Access at: 2019 may 08.

PEDRINI, Hélio; SCHWARTZ, William Robson. **Análise de imagens digitais: princípios, algoritmos e aplicações.** São Paulo: Thomson Learning, 2008.

PEREIRA, Marco Antonio Carvalho; BARRETO, Maria Auxiliadora Motta; PAZETI, Marina. Application of Project-Based Learning in the first year of an Industrial Engineering Program: lessons learned and challenges. **Prod**. São Paulo, v. 27, 2017.

RIBEIRO, Luis Roberto. Aprendizagem baseada em problemas (PBL) na educação em Engenharia. Revista de Ensino de Engenharia, v. 27, n. 2, p. 23-32, 2008.

SCHMIDT, H. G.; ROTGANS, J. I.; YEW, E. H. The process of problem-based learning: what works and why. **Medical Education**. John Wiley & Sons Ltd and The Association for the Study of Medical Education, v. 45, p. 792-806, 2011.

VIDHYA, S.; SUNDARI, G. **A Survey on Localization and Recognition of License Plate**. International Journal of Advanced Computational Engineering and Networking, v. 3, 2015.