Inspection system for the conservation of flexible pavements through the Cascade Trainer algorithm and the use of the DJI Mini 4 Pro drone

ISBN: 978-628-96613-1-6. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2025.1.1.1208

(Sistema de inspección para la conservación de pavimentos flexibles mediante el algoritmo Cascade Trainer y el uso del dron DJI Mini 4 Pro)

***Abstract*— The pavement inspection process is of utmost importance to understand its condition and thus make decisions aimed at its preservation and maintenance. This research proposes a methodology to optimize the pavement inspection process based on the ASTM D6433 standard through the use of drones and the Cascade Trainer algorithm. Images of pavement pathologies were used to train the algorithm and perform pavement inspections in videos captured by the DJI mini 4 pro drone. The algorithm demonstrated high performance with an average accuracy of 96%, a 77% cost reduction compared to the "American Society for Testing and Materials" (ASTM D6433) method, and a performance capable of measuring 600 additional meters per working day. Finally, the results of this research may be useful to promote a proposal to improve flexible pavement inspection for preservation through automated and highly accurate methods.**

Keywords*— *Drone, cascade trainer, pavement, cracks, ASTM D6433, PCI

I. Introduction

According to statistics from the Economic Studies and Statistics Management [1], Lima is the capital with the highest average travel time in Peru. In Lima, vehicular traffic has increased significantly over the years without an effective solution being found. A study by the National Institute of Statistics and Informatics revealed that the National Vehicle Flow Index, which measures the circulation of both heavy and light vehicles, experienced an increase of 2.9% compared to the value obtained in 2021 [2]. This problem causes a considerable loss of time for Lima residents when traveling around the city.

In addition to this, Ashhad, Cabrera, and Roa point out that vehicular congestion negatively impacts a country's road network, with one of its causes being the lack of maintenance in road paving [3]. Asphalt or flexible pavement deteriorates with traffic and over time, affecting the functionality of the road and the safety of drivers and passengers traveling on it. Transportation agencies, through a conservation plan, must regularly evaluate and maintain the pavement. Inspection technologies have improved from manual measurements to automated ones, using computer vision algorithms and deep learning for more precise and efficient detection of pathologies such as cracks, alligator skin, or patching.

There is literature regarding the use of technology for the inspection and detection of faults in flexible pavements. We mention some scientific articles that support decision-making for this issue..

Automatic Pavement Crack Detection Fusing Attention Mechanism. This study presents an automatic method for detecting pavement cracks using the YOLOV5 model and cameras installed on vehicles. The results showed an accuracy of 95.27% in crack detection [4].

Fakhri, Satari, Zakeri, Safdarinezhad. They use UAVs and a convolutional neural network (CNN) to detect pavement cracks. The method achieved an overall accuracy of 98% under challenging conditions [5].

Wesolowski, Blacha, Iwanowski. They introduce the Airfield Pavement Condition Index (APCI), which includes repair inventory and diagnostic tests to evaluate pavements, automating the process and reducing costs [6].

Junqing Z., Jingtao Z., Tao M. They highlight the importance of UAVs for detecting pavement deterioration, using object detection algorithms such as Faster R-CNN, YOLOv3, and YOLOv4 [7].

Ortega Diana et al. They improve the PCI and VIZIR methods using drones for road assessment, demonstrating that drone photogrammetry data are comparable or superior to traditional measurements [8].

A. Proposal

A proposal is made to improve the flexible pavement inspection system of ASTM D6433, taking into consideration the data collection phase in search of improvements regarding cost reduction, time savings, and performance enhancement by using drones and the Cascade Trainer GUI algorithm.

II. Programs and tools

Algoritmo Cascade Trainer GUI

It is a tool or program that can be used to train, test, and improve classifier models. It uses a graphical interface to set parameters and facilitate the use of OpenCV tools for training and testing classifiers [9].

ASTM D6433 Standard

Es una guía para determinar el estado de los pavimentos de carreteras y estacionamientos mediante un método de inspección visual [10].

VLC Media Player

Este programa reproductor multimedia se utiliza para la visualización de los archivos en formato “.tif” obtenidos por parte del algoritmo Cascade Trainer.

Davinci Resolve

It is video editing software used to limit video sections and focus only on the area necessary for inspection.

III. Materials

TABLE I. MATERIALES UTILIZADOS PARA LOS PROCESOS DE INSPECCIÓN

NAME:	Description:
WINCHA	It is a flexible measuring tape. Generally, it comes rolled up inside a plastic or metal case. It is also graduated in centimeters and inches.
ODOMETER	A device, consisting of a wheel attached to a stick, used to measure distances traveled by various types of vehicles. The instrument provides great precision for measuring long distances.
TRAFFIC CONES	An instrument used to divert pedestrians and/or vehicles, generally used in construction sites or car accidents.
WHITE CHALK	A fine natural mineral used for various tasks; however, for this work, it was used to mark the pavement, which will later be easily cleaned.
DRONE	An unmanned aerial vehicle (UAV), generally of small or medium size. The main advantages of using a drone are accessibility, aerial view, precision, efficiency, and cost reduction."

IV. Methodology

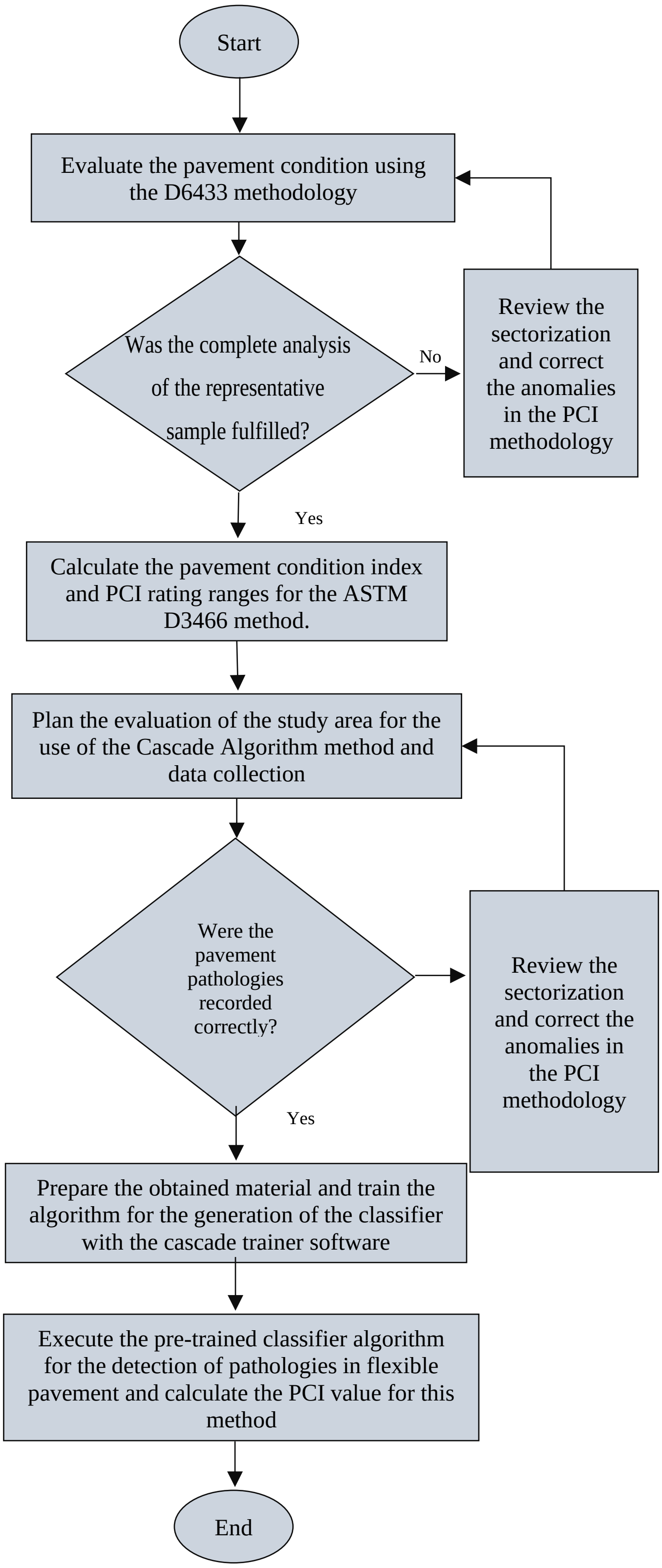


Fig. 1. Flowchart of the procedure

A. Type and Level of Research

Our study, by focusing on the practical application of new knowledge to improve the lives of the population, can be considered technological applied research. Additionally, it can also be classified as operational research, as we seek to solve a problem and make informed decisions based on the results. It is important to mention that this research is at an exploratory level.

B. Procedureo

Phase 1: Information gathering in the study area through PCI

In the first phase, the work team focuses on studying the work area. That is, in this phase, it is limited to data collection and/or information gathering on the roads using the traditional PCI method. Additionally, within the fieldwork, points that may be beneficial or detrimental to the research, such as time, accessibility, and cost, must be evaluated. Visits are coordinated according to the availability of the assistants and the advisor, if they wish to attend. Furthermore, data collection is mainly between the hours of 7:00 a.m. – 6:00 p.m. on days with low vehicular traffic.

Phase 2: Information Processing and PCI Calculation

After the pavement inspection in the first phase, the information is organized and processed. Formats are created for the PCI calculation for each analyzed section, taking as reference the format developed by engineer Luis Vásquez. Therefore, the research team works in the days following the inspection to create reports that summarize and classify the acquired information. Finally, as a product of the inspection, the pavement condition index is obtained, a value that will determine the current state of the pavement..

Phase 3: Pavement Inspection through Drone-Captured Photographs

Once the pavement inspection using the PCI method has been carried out, the current state of the pavement determined, and each pathology of the fieldwork recorded, a new inspection of the flexible pavement begins; however, this time using a drone. For this, the corresponding arrangements must have been made in advance, according to the company or entity that offers the drone rental or flight service for our study area. Next, Figure 2 will show the drone used for information gathering.

Fig. 2. Drone DJI Mini 4 Pro

Note: The drone records in high resolution (4K), has a range of 18 kilometers and 39 minutes of flight time. However, the route we evaluated took us approximately 10 minutes. Later, high-quality images were collected, as we can see in Figure 3.

Fig. 3. Frames of the DJI Mini 4 Pro drone

Note: Frame extracted from the video taken with the DJI Mini 4 Pro drone, which serves to exemplify the image quality and the visibility of the defects in the photos.

Phase 4: Processing Photographs through Cascada Trainer GUI Software

In the fourth phase, the work team focuses on implementing the neural network "Cascada Trainer GUI" to find improvements in the processes within conventional methods like PCI. Additionally, after collecting the pertinent information, a comparison between the results of the new methodology and the PCI method will be made. Based on the obtained results and after the comparison, the processes that improve the indicators are determined. Finally, it is diagnosed whether the consequences of applying photogrammetry at the intersection are appropriate or not.

Phase 5: Comparison between Methods Used

In the final phase, an analysis of the study results is carried out based on the parameters and benefits of each method. The aim is to highlight data directly related to the cost and execution time of each method. Finally, a conclusion is reached regarding the profitability of the proposed method.

V. CONTRIBUTION

A. Evaluate the pavement condition using the ASTM-D6433 methodology.

In this work, the pavement condition was first evaluated using the traditional method based on the ASTM-D6433 standard. Therefore, the research team planned two days of work to collect the types of failures on the avenue, as well as their characteristics and severity. Additionally, the route has an approximate length of 512 meters, divided into 16 sections, each 32 meters long. The team members also collected all the information about the pathologies found, such as alligator cracking, cracks, and patching, in an established format and standardized spreadsheets.

B. Calculate the pavement condition index and PCI rating ranges for the ASTM D6433 method.

To determine the pavement condition, the PCI rating ranges were used to classify the condition of the road surface. Using the data collected during the inspection process by the research team, calculations were performed in Excel to obtain the pavement condition index (PCI), a value that will determine the condition of the road. Here, one hundred is the maximum value, and zero is the worst rating a section could have.

C. Plan the evaluation of the study area for the use of the Cascade algorithm method and data collection.

To evaluate the avenue using the drone (DJI Mini 4 Pro), the work team planned the aerial route considering the various restrictions that could arise during the flight. For example, the flight zone, flight altitude, schedule, and video image quality were taken into account. Finally, the study area was filmed with the drone, considering the expected image quality.

D. Prepare the obtained material and train the algorithm for classifier generation with Cascade Trainer.

The DaVinci Resolve program is used to crop the video area to avoid the visualization of unnecessary objects that could hinder the scope of the research. Then, for the algorithm training, we need to follow a certain nomenclature as shown in Figure 4.

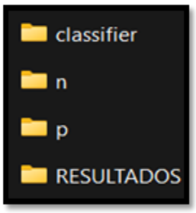


Fig. 4. Typical nomenclature of documents required for the classifier.

Before starting the training, we need to feed the algorithm with information, which includes positive images 'p' and negative images 'n'. In the folder of positive images, we will place those samples that we want the algorithm to detect, such as cracks, patching, alligator cracking and others.

On the other hand, in the negative images, we will place all those that we want to avoid, such as cars, people, trees, etc. Once this is done, we start the training in Cascade Trainer using a configuration of: 300 negative images and 20% positive images (70 samples). This is shown below in Figure 5:

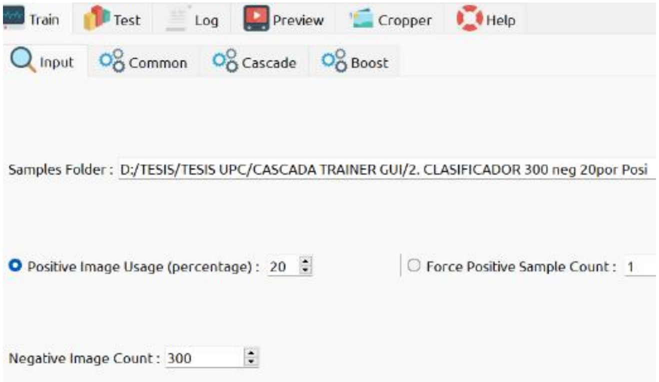


Fig. 5. Interface in the 'Train' section of Cascada Trainer GUI.

After completing this process and starting the training, a folder named 'classifier' will be generated. Inside it, we will find a file in '.xmlfile' format named 'cascade', which will be our classifier algorithm.

E. Execute the pre-trained classifier algorithm for the detection of pathologies in flexible pavement and calculate the PCI value for this method.

Once the pre-trained classifier is obtained during the training run, we use this file to evaluate a video under the characteristics of the generated convolutional neural network. In the 'Test' section, we place the necessary documentation, such as the scale factor, the minimum number of neighbors, and the prepared video for the run according to the section to be analyzed. Details of the configuration used are shown in Figure 6.

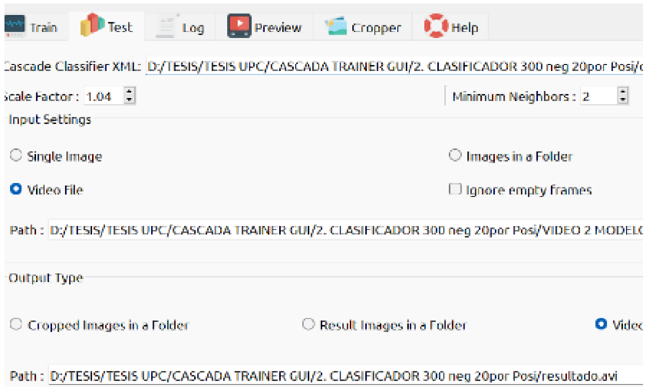


Fig. 6. Interface in the 'Test' section of Cascada Trainer GUI.

After completing this process, a video in '.avi' format will be obtained, which can be handled using the VLC media player tool. Below, we present some of the results in Figure 7 and Figure 8.

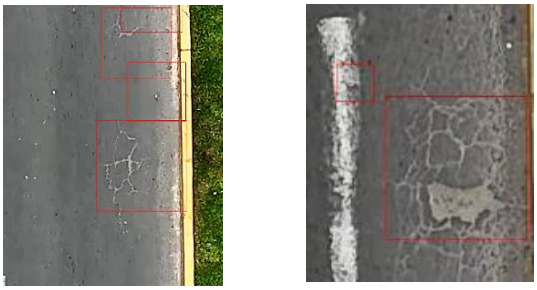
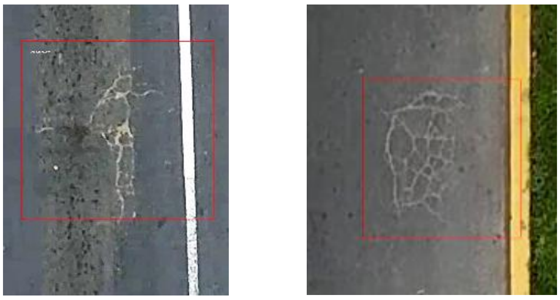


Fig. 7. Result of the run with the algorithm in Section 16



(a) Detected cracks (b) Crocodile skin cracks

Fig. 8. Result of the run with the algorithm in Section 10

Then, to evaluate the pavement condition using this visual content, the AutoCAD program was used to calculate the dimensions of the defects by scale. Additionally, based on the characteristics of the pathologies identified in the pavement, the pavement condition index (PCI) was calculated and the 16 analyzed sections were reclassified.

VI. VALIDATION

A. Results

Below, in Table II, we can see the summary and comparison of the PCI value for the 16 analyzed sections using the classifier algorithm generated by the Cascada Trainer GUI software vs the inspection using the ASTM D6433 method.

TABLE II. COMPARISON BETWEEN PCI VALUES DETERMINED BY THE METHODS USED

Section	Initial Abscissa	Final Abscissa	PCI Value		Precision
			ASTM D6433	Cascade Algorithm	
1	0+000	0+032	69	76	91%
2	0+032	0+064	72	76	61%
3	0+064	0+096	54	54	100%
4	0+096	0+128	84	84	100%
5	0+128	0+160	80	80	100%
6	0+160	0+192	90	88	98%
7	0+192	0+224	68	68	100%
8	0+224	0+256	88	88	100%
9	0+256	0+288	64	64	100%
10	0+288	0+320	58	58	100%
11	0+320	0+352	58	58	100%
12	0+352	0+384	58	58	100%
13	0+384	0+416	85	85	100%
14	0+416	0+448	68	68	100%
15	0+448	0+480	64	64	100%
16	0+480	0+512	82	72	88%
				Average value =	**96%**

B. Analysis of Results

Once the results of the methods using ASTM D6433 and Cascade Algorithm for the inspection of flexible pavement in a 512-meter sample have been obtained, the cost, time, performance, and error percentage values for each of them have been determined. We can analyze the results based on our indicators. Below, in Table III, we present the comparison between cost, time, and performance of the method:

TABLE III. COST-TIME-PERFORMANCE COMPARISON OF THE METHODS USED OR BETWEEN PCI VALUES DETERMINED BY THE METHODS USED

METHOD	COST	TIME	PERFORMANCE
ASTM D6433	$ 937.63	2 days 2 hours	0.448 (km/DAY)
Cascade Algorithm	$ 215.31	1 day	1.115 (km/DAY)

Note: The costs used for each method may vary according to the salary expectations of each professional.

In Table III, noticeable differences can be observed regarding the cost and time quantities for the execution of a pavement inspection by each method.

VII. CONCLUSIONS

- The ASTM D6433 inspection method has a cost of $937.63 per kilometer, including the PCI calculation. In contrast, the Cascade Algorithm method has a significantly lower cost of $215.31, representing a 77% reduction compared to the ASTM D6433 method.
- The Cascade Algorithm method demonstrates higher performance, completing the inspection of one kilometer of road in 8 hours of work, while the ASTM D6433 method requires 18 hours of work. Both methods include the PCI value calculation.
- The use of drones and algorithms not only optimized the inspection process but also provided a high average accuracy of 96% in the PCI values obtained per section, facilitating informed decision-making for pavement maintenance and repair.
- Field data collection for 512 meters of road using the Cascade Algorithm method took only 20 minutes, while the ASTM D6433 inspection method required 8 hours of work.

Recognitions

This project received partial support from the group of professors of the Thesis Project I course at the Universidad Peruana de Ciencias Aplicadas, for which we are very grateful.

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