Comparative evaluation of UAV photogrammetry and mobile laser scanner for flexible pavement failure detection in developing countries

Abstract. Flexible pavements constitute a critical infrastructure that, throughout its life cycle, faces degradation caused by climatic variables and traffic loads. This deterioration affects their mechanical properties, leading to cracks and failures that reduce their functionality and longevity. It is therefore imperative that advanced analytical methodologies are applied to identify the appropriate level of intervention to ensure their optimal serviceability. Recently, technological innovations have emerged that allow the detailed assessment of flexible pavements in an efficient manner, covering large areas in a short time. This research focuses on whether drone photogrammetry (UAV) or mobile laser scanning (MLS) is more appropriate for the diagnosis of surface imperfections in flexible pavements in the context of developing countries, as well as the impacts that its adoption could have on road assessment. The qualitative study is based on a literature review and uses the Choosing by Advantages (CBA) method to evaluate and compare the decisive qualities in the selection of technologies. The results indicate that the mobile laser scanner provides accurate topographic and geometric characterisation at the millimetre level. However, drone photogrammetry, standing out for its high flexibility, low cost and ease of operation, presents itself as the most viable solution for continuous road condition monitoring.

1. Introduction

Road infrastructure plays a key role in global integration by facilitating economic exchange and fostering socio-economic progress [1]. However, its deterioration entails significant risks that adversely affect both road safety and economic efficiency, leading to accidents and excessive costs. In the case of the region, Latin America, CEPAL conducted an evaluation to measure the quality of roads in the 19 countries observed (see image 1). The score achieved in the latest survey of 2017/2018 was 3.6, which represents a slight improvement compared to the score of 2007/2008 (3.2) and 2015/2016 (3.5). While this indicator is a regional average, the score declined for Chile, which remains the leader in the region [2].

Fig. 1. Road quality indicator for Latin America (19 countries) and other countries and regions of the world, taken from (Boletín FAL 367 de la CEPAL, 2018).

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ties and seventh out of nine countries in South developing country contexts, such as Peru, where the optimisation of resources and the efficiency of the pavement condition index resulted in the development of a series of algorithms capable of processing the information obtained from vehicle-based laser scanning. These technologies enable detailed analysis of the road surface, automatically identifying deteriorated areas and quantifying anomalies using specialised algorithms. This information is vital for road condition monitoring.

2. Theoretical framework

2.1. UAV photogrammetry

Photogrammetry is defined as the technique whose objective is to accurately study the shape, size and position in three dimensions of objects or phenomena using a series of images observed from different viewpoints. It is a method that, using images captured with an unmanned aerial vehicle, allows for the creation of three-dimensional (3D) road models. Supported by Pix4Dmapper photogrammetry software and some algorithms, they succeeded in extracting pavement surface model information, including length, width and depth of deterioration.

2.2. Mobile laser scanner

The mobile laser scanner represents an emerging technology that has consolidated its presence in developing countries. To this end, it will seek to determine the attributes, characteristics and quantifying anomalies using specialised algorithms. This information is vital for road condition monitoring.

3. Methods

In 2018, a surface assessment of urban roads was conducted using an unmanned aerial vehicle on Avenida Separadora Industrial, blocks 8 to 10, in the district of Ate, Lima. Its main objective was to calculate the pavement condition index. This device, equipped with 4 propellers and a 20 MP camera, was used to record all the pathologies found on 520 images for the move thanks to the integration of cameras with 360° vision and position and navigation receivers. It can be configured with various sensors to enable the collection of road condition data, covering parameters such as International Roughness Index (IRI), Run Number (RN), Rut Depth, Mean Profile Depth (MPD), Sensor Measured Texture Depth (SMTD) and others.

Roughness Index (IRI) is a parameter that takes into account the profile of the road and the condition of the asphalt surface on streets and roads, exceeding detection limits in the last 20 years. The key words used were: "Evaluation", "failure", "flexible pavements" and their combinations. The following table shows the total number of articles obtained using the selected technologies, following the guidelines of the Choosing by Advantages Analysis (CBA) methodology. This study proposes a comprehensive evaluation of these innovative diagnostic techniques, with emphasis on their applicability in developing countries. To this end, it will seek to determine the attributes, characteristics and quantifying anomalies using specialised algorithms.

The purpose of this study is to identify the most relevant technologies for surface failure analysis of flexible pavements. The total flight time was 6 minutes and 50 seconds, during which 145 georeferenced photos were obtained. Photogrammetry using unmanned aerial vehicles (UAVs), unlike traditional manned aircraft photometry, offers remarkable advantages such as high flexibility, low cost and easy manoeuvrability, emerging as an exciting option for road management. Given this reality, early identification and correction of pavement failures is essential. Technological progress has led to non-destructive assessment methods such as photogrammetry using unmanned aerial vehicles (UAVs) and mobile laser scanning. These technologies enable detailed analysis of the road surface, automatically identifying deteriorated areas and quantifying anomalies using specialised algorithms. This information is vital for road condition monitoring.

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3.1. Choosing by Advantages (CBA)

Created by Jim Suhr in 1999, the decision-making system is based on the advantages of alternatives by making comparisons between a range of options [14]. The flowchart for implementing the CBA method is illustrated in figure 2 below.

To understand and effectively apply the CBA methodology, it is essential to have a clear understanding of the key definitions involved in the process [15].

- **Alternative:** These represent the existing options that are used to compare and eventually select in a subsequent process.
- **Factor:** Factors encompass the information associated with the various alternatives.
- **Criteria:** As defined by the CBA methodology, criteria are weighting characteristics that are assigned to evaluate and give weight to each identified factor. For example, considering cost as a constraint may be a criterion.
- **Attribute:** These are the values or metrics that represent the factors, considering the weighting of the criteria. These values can be qualitative and/or quantitative.
- **Advantage:** Advantages or beneficial differences are attributes assigned to each factor during the selection process. These advantages are consolidated by identifying the best alternative based on the total importance of these attributes.

3.2. Process of applying the CBA method

To understand the process of applying the methodology, we will build on previous research [16, 17]. The order of the steps is explained below:

1. **Identification of alternatives:** The process is initiated by identifying the alternatives that can provide advantages over the others. In this context, two different technologies are explored for the surface evaluation of flexible pavements.
2. **Defining differentiating factors:** It is crucial to define factors that reveal significant differences between the alternatives. For example, between the (UVA) technology and the mobile laser scanner (MLS), one factor could be the accuracy of the expected topographical and geometric information.
3. **Determination of evaluation criteria:** Criteria necessary to evaluate the attributes of the alternatives are established. These criteria can define preferences, such as the highest accuracy as a favourable criterion.
4. **Description of attributes:** the attributes of each alternative are detailed using information from previous research. These attributes represent distinguishing characteristics of each option, for example, the resolution achieved in the evaluation below 10 mm.
5. **Determination of Advantages:** alternatives are compared by identifying the advantages relative to the least preferred attributes according to the defined criteria. An advantage could be, for example, that option one has an operating cost $80 lower than option 2.
Assigning Importance to advantages:

A value is assigned to each factor per alternative, reflecting the importance of the advantages.

Benefits Importance Quantification:
The importance of the benefits is quantified by assigning values to each fact or per alternative. The sum of the values for all alternatives represents the total importance of the benefits.

Consideration of the cost factor:
the cost factor is integrated, this approach incorporates economic aspects into the decision-making process, including investments, operating and maintenance costs. Finally, decision makers choose the best available alternative within budgetary constraints, a fundamental principle of the CBA method.

4. Results

Both mobile laser scanning and drone photogrammetry share similar purposes, both aiming to collect data for analysis, documentation and construction of three-dimensional (3D) models. Their applications are wide-ranging and represent fundamental alternatives to traditional methods of assessing, measuring and developing 3D models. The question many practitioners ask is: which of these two technologies is more effective for obtaining reliable and accurate measurements?

In this analysis, we examine the advantages and disadvantages of both technologies. Then, using certain criteria, we will apply a scoring system based on the CBA methodology in order to facilitate decision-making according to the specific needs of each project.

4.1. Advantages

The great advantage of using drones lies in their low cost of acquisition, maintenance and operation compared to traditional alternatives. According to Amorim and Munaretto [18, 19], the diversity of these aerial vehicles is remarkable, covering different ranges and photometric capabilities. Rotary-wing drones (helicopters or multirotors), fixed-wing drones like conventional aircraft, and even hybrids, capable of being remotely controlled or executing pre-programmed flight missions, are available. A distinctive feature of drones is their significant miniaturisation, achieved through small propulsion, power and navigation systems. Technological innovations in sensor technology, particularly in terms of miniaturisation, have made it possible to equip drones with a wide variety of sensors and tools. These include high-resolution digital cameras, infrared thermal cameras, and multispectral cameras [20]. Due to their operational characteristics and small size, drones can fly at low altitude, capturing aerial photographs and videos with high spatial resolution and exceptional clarity of the local state in all seasons. This is especially beneficial in areas that are difficult to access. For these reasons, the dissemination and application of this technology in various sectors looks highly appropriate and promising.

On the other hand, the advantages of laser scanning technology and the application of photogrammetric principles to obtain three-dimensional data are evident in research such as that conducted by Wang and Smadi [21]. The system employed by these researchers involves specialised cameras, area scanning and line scanning cameras, called LRIS (Laser Road Imaging System). This system makes it possible to cover a 4-metre cross-section of the road with a resolution of 1 millimeter, even at speeds exceeding 100 kilometers per hour. LRIS is designed to enhance the contrast and visibility of small cracks in the road, both longitudinal and lateral, and can operate in daylight due to its immunity to variations in external lighting conditions and shadows cast by objects along the tracks, viaducts or even by the vehicle itself. Other significant benefits of this system include its compactness and low power consumption of less than 200 watts [21].

Fig 2. Cracks and depressions in 2D and 3D models obtained by mobile laser scanning, taken from (Wang & Smadi, 2011).

4.2. Disadvantages

In relation to the disadvantages of drone photogrammetry, it is crucial to point out the difficulty in classifying certain elements, such as vegetation, as well as the limitation of access to all angles of an object. In addition, this technique does not allow measurements to be taken with the same precision as other methods. The quality of the camera used has a direct impact on the results obtained, which implies that, in case of relevance in topographic details, investment in high-resolution cameras is necessary.
In addition, there is the need to acquire specialised software, as well as the time investment in training professionals to use powerful equipment for processing positions and the resolution required for the desired level of detail [23]. Obtaining a high-quality equipment and trained personnel is required to conduct the process of producing the point cloud using drone photogrammetry requires a considerable amount of office work.

### Table 2. Comparison of attributes for both alternatives

<table>
<thead>
<tr>
<th>Factor/Criteria</th>
<th>UAV (photogrammetry)</th>
<th>Mobile laser scanner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of intervention in the normal flow of the vehicle traffic on the road.</td>
<td>Restricted.</td>
<td>Restricted.</td>
</tr>
<tr>
<td>Requires additional information, such as timestamp, amplitude, reflectivity, and pulse shape deviation. Making the process of obtaining the frames. Also, the production of the frames.</td>
<td>Only one laser scanner is required.</td>
<td>Only one camera and software is needed.</td>
</tr>
<tr>
<td>Average time in the data collection phase</td>
<td>About an hour and a half</td>
<td>Approximately 3 and a half hours</td>
</tr>
<tr>
<td>Importance:</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Average relative importance:</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>

### Table 3. Rating of the attributes on a range of 0 to 10

<table>
<thead>
<tr>
<th>Attribute:</th>
<th>UAV (photogrammetry)</th>
<th>Mobile laser scanner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy of topographical and geometrical information.</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Requires expensive equipment and trained personnel.</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Color analysis and checking.</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Geospatial accuracy with 1 mm scanning resolution point cloud.</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Laser pulse in numerous directions or interferes with other pulse not detected.</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Requires less analysis area and the laser pulse in numerous directions or interferes with other pulse not detected. Making the processing is successive until reaching the 3D model.</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Natural cost.</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Lithium battery cost of the equipment plus scanner.</td>
<td>$131.25</td>
<td>$125</td>
</tr>
</tbody>
</table>

Average hourly rate for UAV crew: $75.

The hourly rate for UAV crew: $95.

The average hourly cost of mobile laser scanner: $100.

TOTAL: $2652.25

TOTAL: $146.25
5. Conclusions

The advantages of UVA photometry technology introduce new scenarios and application possibilities in road management for flexible pavements. The UVA technology can guarantee a superficial, influential variable, although it can be compensated through specific investment policies and plans. In contrast, non-destructive testing (NDT), do not require direct intervention on the road structure. The selection of UVA technology for road management applications of developing countries is effective and suitable for developing countries, such as Peru, where the study of surface degradation by means of three-dimensional models is dimensionally representative. In this sense, the selection of UVA technology outperforms the mobile laser scanner (MLS) as a new approach for integrating environmental, social, and economic factors to evaluate asphalt pavements.

References

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