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Distress Manifestation in Asphalt Pavements: Comparison between Local and Unmanned Aerial Vehicle (UAV) Measurements

Manifestação de Defeitos em Pavimentos Asfálticos: Comparação entre a Medição Local e por Veículo Aéreo Não Tripulado (VANT)

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Abstract

Surface surveys of asphalt concrete pavement condition the maintenance and rehabilitation solutions employed; however, they are laborious protocols for field operators. The use of Unmanned Aerial Vehicles (UAVs) in the remote assessment of these pavements has become an alternative, but still lacks validation about current Brazilian regulations. This study sought to compare conventional surface assessment methods (DNIT 006/2003 - PRO, DNIT 007/2003 – PRO, and DNIT 433/2021 - PRO) with the survey carried out by UAV, and to compare the DNIT's cracked area assessment methods. The assessment was carried out over two 400-meter stretches. The DNIT 433/2021 - PRO standard was more conservative than the DNIT 007/2003 - PRO protocol in determining the cracked area. In addition, the two segments result in the same Global Gravity Index (GGI) classification between the walking and UAV methods only when rutting is disregarded. It was also found that the device achieved, on average, 82% of the cracked area values obtained by the DNIT 007/2003 - PRO and DNIT 433/2021 - PRO standards. Thus, it was possible to verify that the Brazilian regulations generate different cracked area results, being used for other purposes and that the UAV, in the scope of this work, the UAV was a technically viable alternative for speeding up the evaluations but was unable to identify cracks with smaller openings (FC-1 class) and three-dimensional distresses.

Keywords: Pavement management; Image processing; Remote pavement assessment

Resumo

Os levantamentos de superfície em pavimentos revestidos por concreto asfáltico condicionam as soluções de manutenção e restauração empregadas; todavia, consistem em protocolos laboriosos para os operadores de campo. A utilização de Veículos Aéreos Não Tripulados (VANTs) na avaliação remota desses pavimentos tem se tornado uma alternativa, mas ainda carece de validação com relação às normativas brasileiras atuais. Este estudo buscou comparar os métodos convencionais de avaliação de superfície (DNIT 006/2003 – PRO, DNIT 007/2003 – PRO e DNIT 433/2021 – PRO) com o levantamento realizado por VANT, e comparar os métodos de avaliação de área trincada do DNIT. A avaliação foi realizada em 2 trechos de 400 metros. Verificou-se que a norma DNIT 433/2021 - PRO é mais conservadora quando comparada ao protocolo DNIT 007/2003 – PRO na determinação da área trincada. Além disso, os dois segmentos resultam em mesma classificação pelo Índice de Gravidade Global (IGG) entre os métodos por caminhamento e VANT apenas quando são desconsiderados os afundamentos. Ainda, constatou-se que o dispositivo atingiu, em média, 82% dos valores de área trincada obtidos pelas normas DNIT 007/2003 – PRO e DNIT 433/2021 – PRO. Assim, foi possível verificar que as normativas brasileiras geram resultados de área trincada distintos, sendo utilizadas para finalidades diferentes, e que o VANT, no escopo deste trabalho, foi uma alternativa tecnicamente viável para agilizar as avaliações, mas não foi capaz de identificar trincas de menor abertura (classe FC-1) e defeitos tridimensionais.

Palavras-chave: Gerência de pavimentos; Processamento de imagem; Avaliação remota de pavimento

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1 Introduction

Designers estimate that distresses on the surface of asphalt pavements, such as rutting and cracking, will develop throughout the service life of the structure. As these distresses evolve, it becomes imperative to plan periodic intervention measures to restore the road's trafficability at strategic times, i.e. seeking to optimize the resources used (Yoder & Witczak 1975; Hass, Hudson & Zaniewski 1994; Balbo 2007; Papagiannakis & Masad 2008; Medina & Motta 2015). Therefore, pavement condition diagnosis must be accurate to support maintenance strategies and restoration projects (DNIT IPR – 720 2006).

Decision-making in road projects is motivated by cracking levels of around 20 to 30% (DNIT IPR – 720 2006; DNIT 2023a). Thus, the National Department of Transport Infrastructure (DNIT) presents four regulations that guide methods for detecting distresses by walking: DNIT 005/2003 – TER, DNIT 006/2003 – PRO, DNIT 007/2003 – PRO e DNIT 433/2021 – PRO.

The major limitation of these methods is the need for trained human resources and long data collection times in the case of long stretches. In addition, it is worth noting that field surveys put the safety of surveyors at risk, as they remain in close contact with the traffic on the studied road. Furthermore, their results are affected by the training level of the operator or data collection team, and by the normative procedure used as a reference (Osorio 2015; Trevisan 2023; Bueno 2019).

In addition, it is known that fatigue is a difficult phenomenon to control, model and monitor, as it depends on both the asphalt mixture's properties and the structure that supports it, and the existence of different standards for measuring the cracked area makes the study and monitoring of the coating even more inaccurate, as they generate divergent results. This poses a challenge for road managers, as the occurrence of cracking affects pavement intervention decisions. The DNIT 007/2003 - PRO standard measures the effective area of cracks, and DNIT 433/2021 - PRO counts the cells containing cracks in relation to the total number of cells into which the pavement is divided. This procedure also focuses on experimental sections and calibration of the Brazilian pavement design method (MeDiNa) (DNIT IPR - 749 2023).

On the other hand, continuous and automated technologies in pavement surveying are on the rise. One example is the new vehicle tested by DNIT, the iPAVe (Intelligent Pavement Assessment Vehicle), which provides functional and structural data on the road's operating speed (DNIT 2023b), based on laser and video imaging equipment (Pavesys 2013; Freitas & Nobre Jr. 2020; Strata 2020). In addition, surveying techniques using spatial analysis and artificial intelligence tools are also emerging themes (Lázaro et al. 2022; Dalla Rosa et al. 2020).

Unmanned Aerial Vehicles (UAVs), popularly known as drones, are part of this scenario by helping to improve the quality of services performed on the construction sites, minimizing rework, and increasing the efficiency of the construction process. In addition, they have been widely used for inspecting construction sites, mapping risk areas, environmental monitoring, and automated collection of vehicle trajectories (Chen et al. 2021; Peng et al. 2021; Han, Liu & Xu 2022; Araújo et al. 2023; Ding et al. 2023; Mahmoodzadeh, Gretka & Mukhopadhyaya 2023).

In the paving context, the use of this equipment to survey surface distresses is proving promising due to the speed with which data is acquired and the reduction in human resource costs (Branco 2016; Ersoz, Pekcan & Teke 2017; Parente, Felix & Picanço 2017; Barros et al. 2019; Atencio et al. 2022; Zhu et al. 2022; Astor et al. 2023). However, it remains to be seen whether this technology is in line with traditional surveying methods since design standards and maintenance triggers depend on the results found by surface assessments.

Based on the above scenario, since the evaluation of pavement surfaces is the starting point for decisions made within the scope of pavement management, there is a need to update the tools used in surveys to optimizing time and resources. The UAV used in this work could be a technically viable alternative, provided that the results are consistent with traditional surveying methodologies. On the other hand, given that fatigue phenomena are that usually affects Brazilian highways, any divergences in the cracked areas measured by different standards could lead to discordant decisions during the strategic planning of road maintenance, making this verification necessary, in parallel with the UAV surveys.

In this regard, this research seeks to compare the results of the pavement surface evaluation from DNIT 006/2003 – PRO, DNIT 007/2003 – PRO and DNIT 433/2021 – PRO standards, considering data acquired from local and Unmanned Aerial Vehicle (UAV) inspections. It also aimed to compare the cracked area obtained by the two standards proposed by the DNIT (DNIT 007/2003 - PRO and DNIT 433/2021 - PRO).

2 Research Method

2.1 Research Planning

Figure 1 shows the general outline of the research, which has four main topics. The following sections will consider each stage: definition of the study section and demarcations, surface surveys, and comparisons between results.

2.2 Surveyed Segment

The road segment used as the basis for the study was Roraima Avenue, the access road to the Federal University of Santa Maria (UFSM) in Rio Grande do Sul (Figure 2). The stretch is made up of asphalt pavement, which was resurfaced in December 2012.

The chosen pavement segment for this study starts at the entrance to UFSM (Federal University of Santa Maria) and extends to the RSC – 287, as shown in Figure 2. The road is a dual roadway (each lane is 3.6 m wide), and the surveys were restricted to the most heavily loaded lanes (the right ones). Each segment extends over 400 meters in the first stretch (direction leaving UFSM), plus another 400 meters in the second stretch (direction entering UFSM), totaling 800 meters. Stake markings were added to the track every 20 m (starting 50 m from UFSM), totaling 20 stakes in each direction (Figure 3). The markings on the road also served as a reference for the virtual tracing of the stations using UAV images.

2.3 Surface Surveys

The surface condition survey of Roraima Avenue was based on the terminology provided by DNIT 005/2003 - TER standard. The DNIT 006/2003 - PRO standard was applied, with all distresses counted to calculate the Global Gravity Index (GGI), including the presence and measurement of rutting. The surveys were carried out at stations measuring 3.6 m wide and 6 m long at each stake, totaling 40 stations.

For the other standards, however, only cracks (isolated and interconnected) were counted a more objective comparison with the subsequent survey carried out with a UAV. For DNIT 007/2003 - PRO, besides the definition of homogeneous stretches and sub-stretches, distress manifestations have their extent counted through the area affected by them. The surveys were also carried out on each stake, at stations 3.6 m wide and 6 m long.

Lastly, for DNIT 433/2021 - PRO standard, the length studied is divided into a standardized grid, considering are totally affected by the cells in which there are distresses associated with fatigue cracking. The standard stipulates subdivisions with dimensions of 1/3 the width of the roadway in the transverse direction, and 2 m long

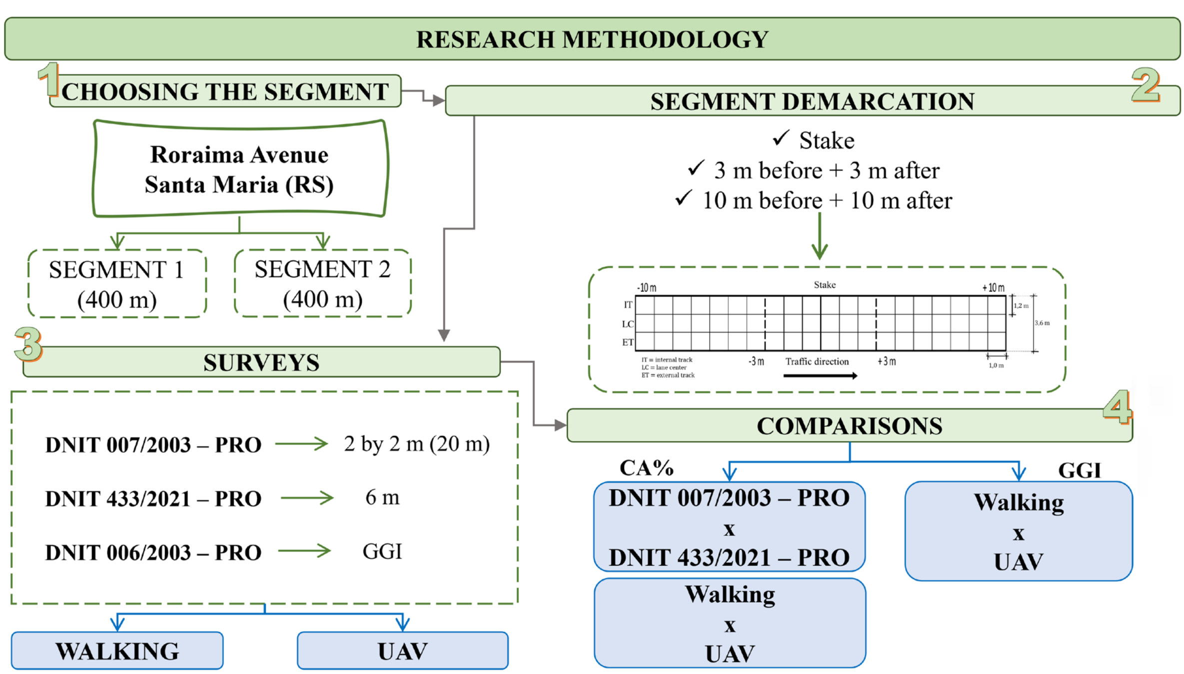

Figure 1 General outline of the research.

Figure 2 Location of the segment studied.

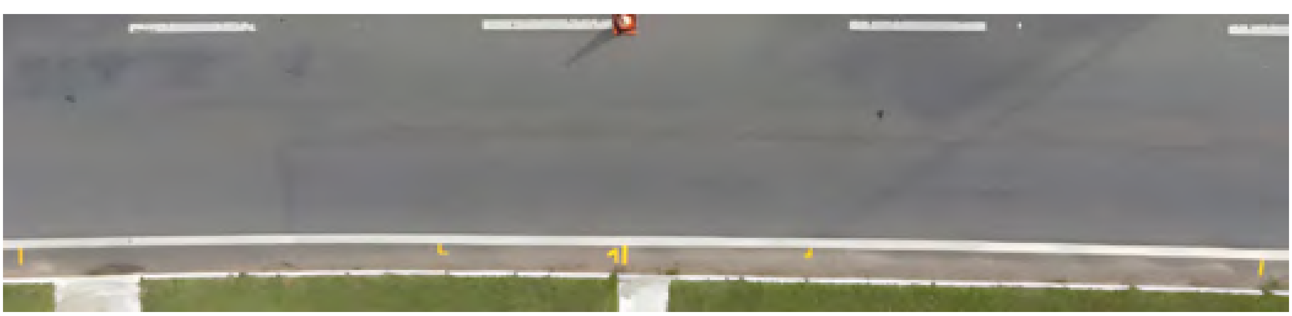

Figure 3 Auxiliary markings for surveys.

in the longitudinal direction, along the 20 m of the station at each stake.

The distress survey was carried out using an Unmanned Aerial Vehicle (UAV) with equipment and a trained operator from Santa Maria Air Base. The model used was the Mavic Air 2, with a maximum flight time per battery of around 34 minutes. The UAV contains a DJI FC3170 camera, capable of taking photographs with a maximum resolution of 8000 x 6000 pixels (48 MP), generating high-quality images.

All the stations were photographed in the center, at a height of 16 m (Ground Sample Distance - GSD - of 0.11 cm/px in × and 0.14 cm/px in y), so that each station could be seen with just one photograph and considering the lowest possible operational altitude. Distresses seen near the stakes, such as adjacent roadway, vegetation, and sidewalks, were manually discarded. The images were studied using AutoCAD® software, representing the 1.2 m × 1.0 m cells and the distresses inside and outside the 3 m following the stake marking. The UAV used, and the raw image example are shown in Figure 4A. An example of an image processed by AutoCAD is shown in Figure 4B.

3 Results and Discussions

3.1 Cracking

The cracked area percentage is one of the design criteria used by the new Brazilian pavement design method (MeDiNa), which sets a 30% limit for asphalt surfacing as a failure criterion (DNIT 2023a). The evolution of this percentage helps to plan maintenance and restorations and, along with other distresses, influences surface conditions (DNIT IPR – 720 2006). In addition, it is worth noting that the DNIT 005/2003 standard differentiates the cracks observed into distinct classes: FC-1, cracks with an opening greater than that of the fissures and less than 1.0 mm; FC-2, cracks with an opening greater than 1.0 mm and without erosion at the edges; and FC-3, cracks with an opening greater than 1.0 mm and with erosion at the edges.

Both standards (DNIT 007/2003 - PRO and DNIT 433/2021 - PRO) are in force for measuring the percentage of cracked area, but they generate results that diverge (Rodrigues 2023; Beckert 2020). To compare the results, the CA% values calculated by the two protocols were compared (Figure 5A), showing that the point cloud deviates from the equality line.

The values measured by the DNIT 433/2021 - PRO standard are higher (points below the equality line). For the first and second sections (green points in Figure 5B), average cracked area values of 8.71% and 3.53% were calculated according to DNIT 007/2003 - PRO, and 23.17% and 18.83% according to DNIT 433/2021 - PRO.

On average, DNIT 433/2021 - PRO standard calculates cracked areas 3.43 times higher than DNIT 007/2003 - PRO standard. In this sense, it should be noted that the DNIT 433/2021 - PRO standard is more conservative, since the existence of a crack, no matter how small, compromises the entire cell studied, i.e. an area of 2.4 m² (1.2 m x 2 m), and does not consider the area really affected as recommended by DNIT 007/2003 - PRO standard.

Figure 6 shows the average CA% values. Since the 2021 standard is recent and still needs to be validated, attempts were made to adapt the protocol, in terms of the length of the section assessed and the longitudinal dimension of the cells. Therefore, 4 measurement methods

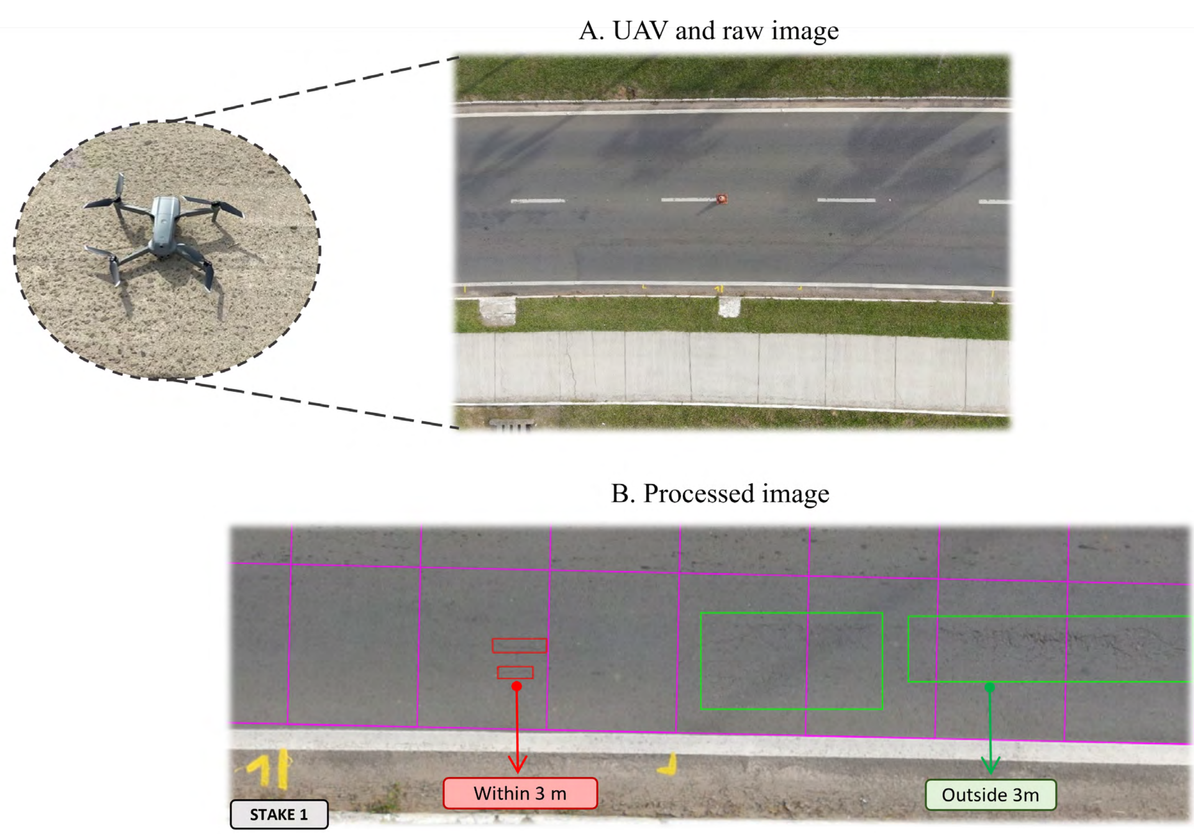

Figure 4 A. UAV used and raw image; B. Example of processing in AutoCAD.

were tested: 2 methods on the entire stake (20 m), with cells measuring 1.2 m x 1.0 m and 1.2 m x 2.0 m; and 2 methods on just 6 m (from DNIT 007/2003 - PRO standard), with the same variation in cell dimensions.

In this sense, Figure 6 shows that the average values found by DNIT 433/2021 - PRO standard and its adaptations are higher, considering the standard error also shown in the figure. This standard, used by MeDiNa, would already warn of the need to restore these roads, while DNIT 007/2003 - PRO, also in current use in field practice, indicates that the pavement is in good functional condition in terms of cracking. However, it is worth noting that DNIT 433/2021 - PRO optimizes assessments by walking and calibrates cracked area evolution models, such as the model adopted in MeDiNa.

In addition, as expected, the surveys in larger cells by DNIT 433/2021 - PRO provide higher average results compared to the 1 m cell at the corresponding station (6 or 20 m), since the presence of a crack compromises twice the area. However, the standard error bars indicate that the sampling variability does not allow one to confidently conclude that the averages found for the adaptations to DNIT 433/2021 - PRO standard are different. Therefore, surveys at each meter are not justified, as they are more time-consuming and laborious to carry out.

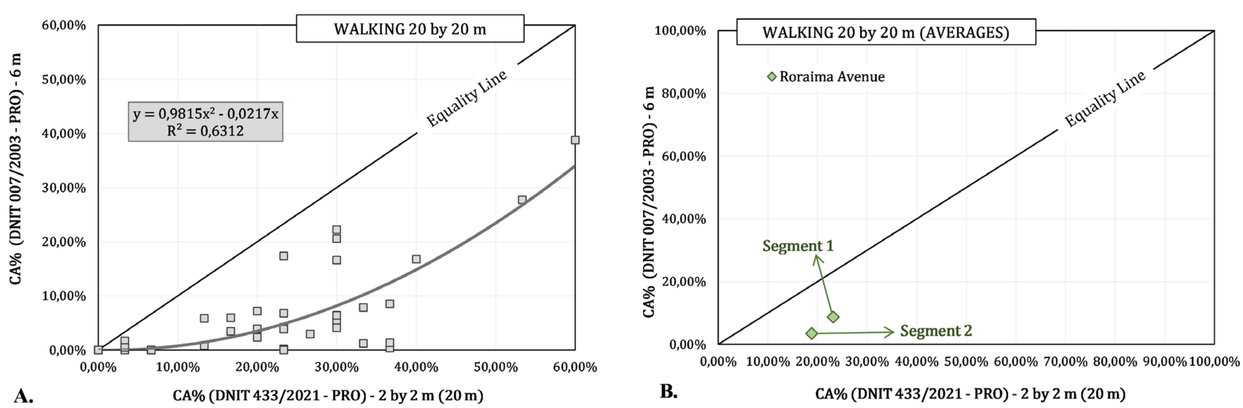

Figure 5 CA% comparison between DNIT 007/2003 (crack area) and DNIT 433/2021 (CA% frequency): A. Per stake; B. Averages for each section.

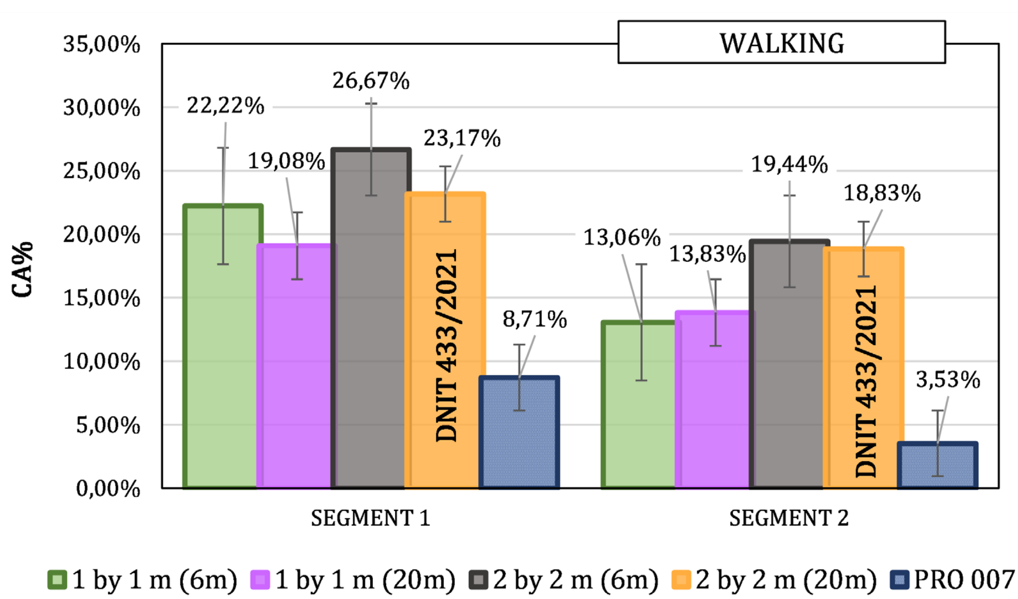

Figure 6 Average CA% values for standard DNIT 007/2003 - PRO and adaptations of standard DNIT 433/2021 – PRO.

On the other hand, the quantification of the cracked area also differed according to DNIT 007/2003 - PRO protocol between walking and UAV. The values per stake (Figure 7A) show that the points are close to the equality line, especially for less than 20% cracked areas, as occurs in the second section. From this value onwards, greater differences were seen, especially as the first section (CA% up to 40%) had more FC-1 cracks (cracks with an opening of less than 1.0 mm), possibly not identified in the images, even though the equipment has high resolution. In addition to this factor, AutoCAD's area measurements are more precise than the tape measure survey, leading to lower CA% values.

The average CA% for all the stretches evaluated (total CA% in Figure 7B) that the UAV could only achieve 78% of the value found by walking. It is worth noting again that the biggest difference between the methods is in the first section, with the greatest presence of smaller cracks, which were not visualized by the equipment. To calculate the total percentage of cracked area, in order to make decisions about whether or not to carry out maintenance or restoration work on the pavement, the visualization of these cracks is relevant.

In addition, it is worth noting that although the standard error bars with 1 standard deviation around the mean (68% of the data within this range) suggest that there is statistical similarity, FC-1 cracks were not visualized by the UAV. For this reason, it is clear that strategic intervention planning cannot be based solely on average values or on pure statistical similarity, as identifying cracking at an early stage is important for more cost-effective interventions.

The same occurred when the cracked area survey was carried out using DNIT 433/2021 - PRO standard. In this case, section 1 had points above or below the equality line, and the walking method tended to identify a more significant number of cracks (Figure 8A). For the second section, the points are more dispersed around the equality line, but no clear trend exists.

The average values (Figure 8B) indicate that the UAV method was inaccurate in the first section, as mentioned above because the images were not sensitive in identifying FC-1 cracks. This difference for the first section

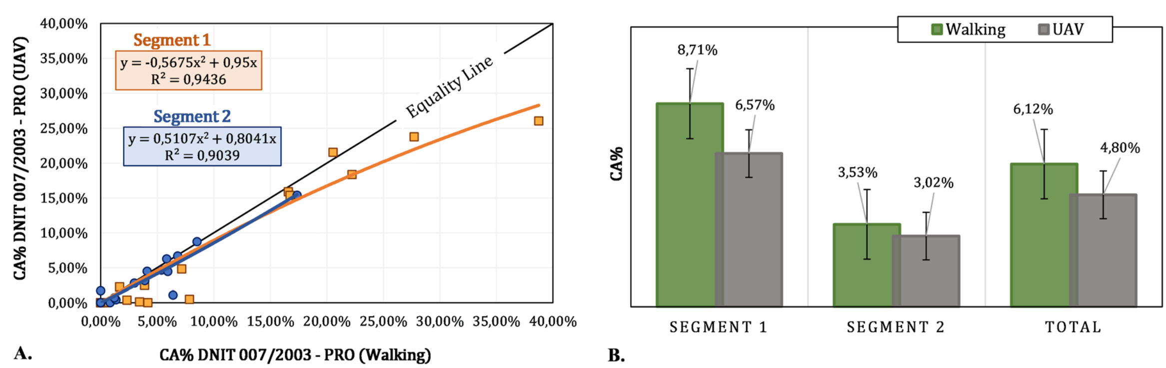

Figure 7 CA% DNIT 007/2003 - PRO (UAV x Walking): A. Per stake; B. Overall.

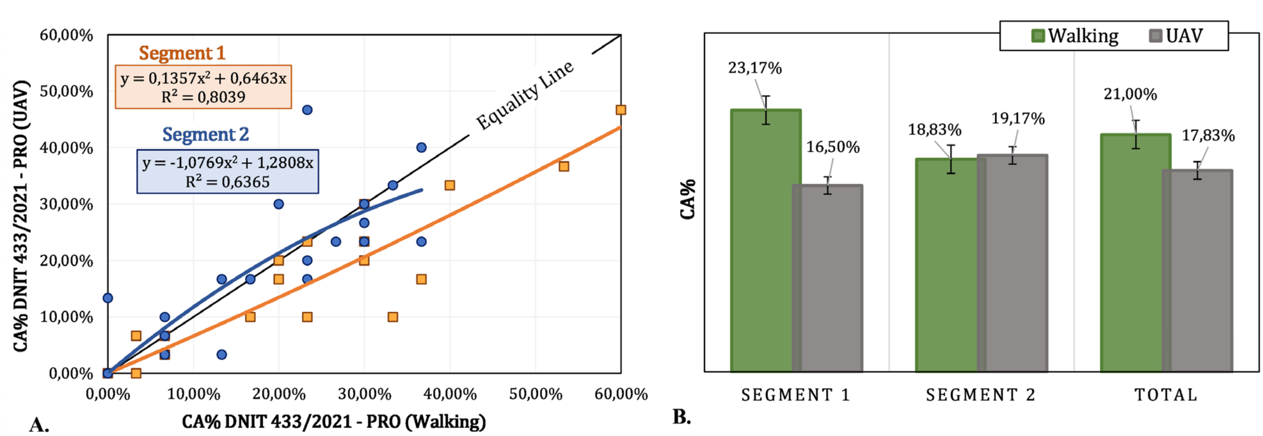

Figure 8 CA% DNIT 433/2021 - PRO (UAV x Walking): A. By stake and B. Overall.

was more significant than that found when comparing with DNIT 007/2003 - PRO standard.

In addition, the differences are also aggravated by the greater precision in tracing the cells when done via software. However, the results for the second section and the overall result showed that the use of the UAV obtained a cracked area similar to the walking method since the visualization of a single crack is enough to count the cell as affected. On average, this technique achieved 85% of the cracked area verified by walking according to DNIT 433/2021 - PRO standard. In this case, the standard error bars (considering 1 standard deviation around the mean) do indeed indicate a statistical difference between measurements by walking and by UAV. For the DNIT 433/2021 - PRO standard, the UAV provided a statistically similar result to walking only in segment 2. This observation confirms the UAV's limitation in observing cracks with an opening of less than 1.0 mm, which were more present in the first section. Once again, it should be emphasized that the assessment of the functional condition of pavements should not be based solely on average cracked area values, and the visualization of FC-1 cracks is necessary for planning interventions.

3.2 Global Gravity Index (GGI)

Regarding the calculation of Global Gravity Index described by DNIT 006/2003 - PRO standard, the walk along Roraima Avenue enabled 84 distresses to be identified along the 40 analysis sections. Table 1 shows the calculation, following the same pattern for the other stretches. Both were classified as poor, with a GGI of 95 for the first stretch and 89 for the second. The combined assessment of the segments resulted in an GGI of 93.

The standard application using the UAV data did not identify the 6 stakes with wheel track rutting (WTR) visualized in the survey since the images have only two dimensions. This survey identified 60 distresses. The absence of WTR measurements and identifying a smaller number of isolated and interconnected cracks, rutting, and wear contributed to classifying the stretches under analysis as regular. The GGI was 44 for the first section, 76 for the second, and 60 for the entire section.

Figure 9 highlights the differences in the absolute frequencies of distresses found by the two protocols, with the walking method identifying around 1.4 times more distresses. It is worth noting that the survey was similar when looking at distresses of exudation, ripples, potholes, and slippage. The GGIs of the first and second sections were 114% and 18% higher than the UAV determinations, respectively. For the overall GGI, the walking method provided a 55% higher result.

When comparing the methods, it was again possible to see that the UAV was less efficient at visualizing cracks. This phenomenon can be explained by the technology used to capture the photographs, or the flight altitude chosen. Captures at lower altitudes, covering smaller portions of the stake, could lead to more accurate results.

Another factor that contributed to the differences between the GGI values was the impossibility of identifying and measuring the WTR deflections by the UAV, since this is an analysis in only 2 dimensions. If this information were discarded from the walking method (rutting frequency and WTR measurements), the GGIs for the first and second sections would be 37% higher and 1% lower than the UAV method, respectively, leading to the same classification of the roads. For the overall result, the UAV would achieve 87% of the value found by walking without rutting.

These discussions are confirmed by observing that the difference between the two methods was greater for the first section, which had a greater number of FC-1 cracks, less noticeable in the UAV images. In addition, section 1 had a greater number of rutting (three-dimensional distresses), which were also not visible in the images, as mentioned above, because the images were only taken in two dimensions.

Finally, the data has been summarized in Table 2 to make the results easier to visualize. It was possible to see that the surface assessment methods differ, and the use of UAVs tends to verify fewer distresses for the three standards considered. This phenomenon is possibly due to factors such as the inaccurate capture of some distresses by the images, the impossibility of surveying distresses in 3 dimensions, and the greater precision of cell and area delimitations by AutoCAD.

Therefore, comparisons between the walking and UAV surveys showed that the photographed images do not allow for the identification of longitudinal irregularities and rutting. These indicators, translated into the International Roughness Index (IRI) and the WTR deflections measured in the field, are added to the cracked area in pavement assessment, which culminates in non-intervention solutions, maintenance and conservation techniques, or restoration techniques. Therefore, they should not be neglected in surface surveys.

Table 1 GGI calculation by walking for segment 1.

Segment: Roraima Avenue		**Global Gravity Index (GGI)**				**Initial stake**	**Final stake**
		Stretch: km 0,0 to 0,800					
		Sub-stretch: 1				**1**	**20**
Item	**Defect nature**	**Absolute frequency**	**Considered absolute frequency**	**Relative frequency (%)**	**Weighting factor**	**IGI**	**Notes**
1	Isolated cracks, STC, LTC, SLC, LLC, SC	15	3	15.00	0.20	3	–
2	(FC - 2) AC, BC	12	11	55.00	0.50	28	–
3	(FC - 3) ACE, BCE	2	2	2.00	0.80	2	–
4	LPR, WPR, LCR, WCR	5		25.00	0.90	23	–
5	R, P, S	1		5.00	1.00	5	–
6	EX	3		15.00	0.50	8	–
7	W	3		15.00	0.30	5	–
8	PA	4		20.00	0.60	12	–
9	Arithmetic mean of average deflection values measured in mm TRI and TRE	TRE = 3.55	TRI = 1.93	F = 2.74	1.33	4	
10	Arithmetic mean of the variances of rutting measured on both tracks	TREv = 11.60	TRIv = 4.38	Fv = 7.99	1.00	8	Class:
Number of inventoried stations	20					**95**	**Poor**
1A) IGI = F x 4/3 when F ≤ 30	2A) IGI = FV when FV ≤ 50						
1B) IGI = 40 when F > 30	2B) IGI = 50 when FV > 50						

Notes: FC-1, FC-2, FC-3: class 1, 2 and 3 cracks, respectively, according to DNIT 005/2003 nomenclature.

STC, LTC, SLC, LLC, SC: transverse or longitudinal crack, short or long crack, and shrinkage cracking; AC, ACE, BC, BCE: "alligator" or block crack, with or without erosion; LPR, WPR, LCR, WCR: local or wheel track rutting, plastic or by consolidation; R, P, S: ripple/corrugation, "potholes" and slipping; EX: exudation; W: wear; PA: patch; IGI: individual gravity index.

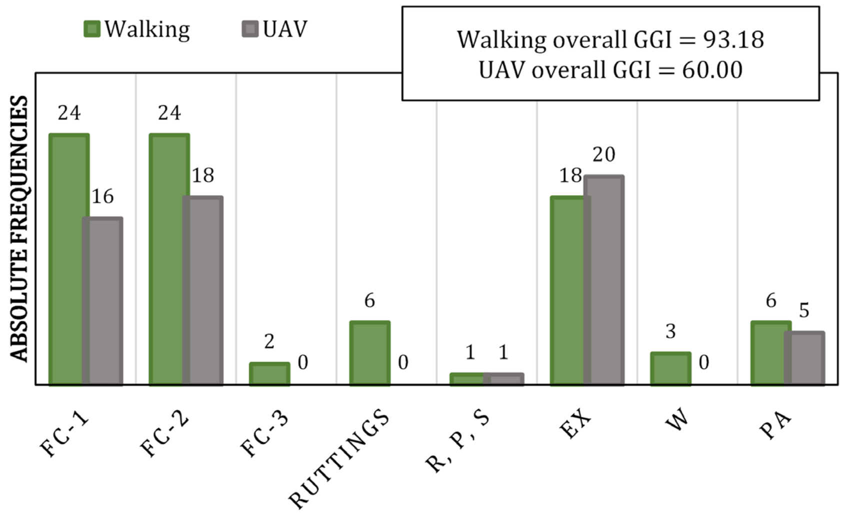

Figure 9 Absolute frequencies of distresses found by walking and by UAV.

Table 2 Summary of results.

Method		**Walking**			**UAV**		
		Segment 1	**Segment 2**	**Overall**	**Segment 1**	**Segment 2**	**Overall**
DNIT 006/2003 - PRO	GGI	With WTR = 95 (Poor) Without WTR = 61 (Regular)	With WTR = 89 (Poor) Without WTR = 75 (Regular)	With WTR = 93 (Poor) Without WTR = 69 (Ruim)	44 (Regular)	76 (Regular)	60 (Regular)
DNIT 007/2003 - PRO	CA% 6 m	8.71%	3.53%	6.12%	6.57%	3.02%	4.80%
	CA% 2 by 2 m (20 m)	23.17%	18.83%	21.00%	16.50%	19.17%	17.83%
DNIT 433/2021 - PRO	CA% 1 by 1 m (20 m)*	19.08%	13.83%	16.46%	–	–	–
	CA% 2 by 2 m (6 m)*	26.67%	19.44%	23.06%	–	–	–
	CA% 1 by 1 m (6 m)*	22.22%	13.06%	17.64%	–	–	–

Note: * DNIT 433/2021 – PRO adaptations

4 Conclusions

This research compared the results of conventional pavement surface assessment methods (DNIT 006/2003 - PRO, DNIT 007/2003 – PRO, and DNIT 433/2021 - PRO) with their respective surveys carried out by an Unmanned Aerial Vehicle (UAV), and compared the cracked areas found by the different DNIT regulations, on two stretches of Roraima Avenue, in Santa Maria/RS (Brazil). The main results found are listed below:

The DNIT 433/2021 - PRO standard is more conservative in determining the cracked area and calculates cracked areas 3.43 times higher than the DNIT 007/2003 - PRO (considering the stretches assessed in this study). The adaptations to the cell sizes in DNIT 433/2021 - PRO standard did not significantly reducing these differences, and do not justify this change;

The UAV reached an average of 82% of the cracked area measured by DNIT 007/2003 - PRO and DNIT 433/2021 - PRO protocols. It was found that the images do not allow precise visualization of cracks with smaller openings (below 1.0 mm, i.e. FC-1);

The GGIs of the first and second sections were 114% and 18% higher by walking than by UAV. The greater difference in the first section is due to the occurrence of more rutting and FC-1 cracks, which were not identified using the UAV. The GGI of the walking method without the rutting generates the same classification as UAV, with values 37% higher and 1% lower for the first and second sections, respectively.

In conclusion, it is understood that the use of UAVs resulted in faster data collection and accurate area measurements when processing the images. It should also be noted that the method does not require traffic interruptions and generates safety for survey operators. However, it should be used sparingly to aid decision-making, as it was impossible to identify cracks with smaller openings (FC-1 and sometimes FC-2) and rutting, nor was it able to measure the longitudinal irregularities of the pavements. These indicators, however, should not be neglected since they determine the decisions for non-intervention, maintenance or restoration of the stretches assessed. In this sense, surveys using laser imaging, thermography and photogrammetry inventory, combined with on-board IRI and WTR measurements (inertial profilometers) could be an option to overcome the limitations of UAV, by combining the benefits of agility and precision in collecting information, including measurements in 3 dimensions.

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Victória Nunes-Ramos: conceptualization; formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization. **Eduardo Vieira Trevisan**: conceptualization; formal analysis; methodology; visualization. **Luciano Pivoto Specht**: conceptualization; formal analysis; methodology; supervision. **Deividi da Silva Pereira**: conceptualization; formal analysis; methodology, supervision. **Lucas Dotto Bueno**: conceptualization; formal analysis; methodology, supervision.

Conflict of interest

The authors declare no potential conflict of interest.

Data availability statement

All data included in this study are publicly available in the literature.

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