VOL. 16, NO. 21, NOVEMBER 2021 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

USE OF NEW GEOMATICS TECHNOLOGIES IN THE AUSCULTATION OF FLEXIBLE PAVEMENTS

Saieth Baudilio Chaves Pabón[1], Hugo Alexander Rondón Quintana[2] and Carlos Alfonso Zafra Mejía[2]
[1]Programa de Ingeniería Civil, Facultad de Estudios a Distancia, Universidad Militar Nueva Granada, Cajicá, Colombia
[2]Facultad del Medio Ambiente y Recursos Naturales, Universidad Distrital Francisco José de Caldas, Bogotá D. C., Colombia
E-Mail: saieth.chaves@unimilitar.edu.co

ABSTRACT

The purpose of this article is to conceptualize the use of Drones and Remote Sensors technology in pavement evaluation, which have allowed to advance in the development of different methods to detect deterioration with precision and reliability. Thus, through the use of images, data collection with high precision and the ease in traveling long distances have made the drone-remote sensor integration a tool that can undoubtedly be used today in road projects such as improvement, rehabilitation and conservation. The methodology consisted in the interpretation and explanation of the relationship between Drone, Remote Sensors and their application in the visual evaluation of pavements. For this purpose, several normative documents, academic and research works at national and international level have been consulted. As results and discussion, the importance and conceptualization of the subject in question is shown. Finally, it was concluded by showing the need to implement these technologies in the development of road projects and the possible advantages in the immediate future.

Keywords: visual pavement assessment, remote sensing, drone, pavements, geomatics.

1. INTRODUCCIÓN

Roads are the most extensive, valuable and important structures for a country, because they are a source of development and evolution, they improve the quality of life of the inhabitants, so it is very important to perform timely maintenance ensuring safety, comfort and convenience conditions for users [1] [2]. That is why is necessary that Governmental Entities allocate annual resources for the conservation, improvement and exploitation of road infrastructures that due to different factors, such as natural deterioration, traffic aggression, technical obsolescence and rough environmental conditions, suffer damages that sometimes, if are not detected in time, can be irreversible.

Secondary and tertiary road networks make up approximately 90% of Colombia's roads and are undoubtedly the engine of urban and rural development, and contribute to poverty reduction [3]. According to data from the Colombian Chamber of Infrastructure [4], single carriageway roads account for about 94% of the total kilometers of the aforementioned road networks, and paved roads account for about 19% of the total kilometers. Currently, the roads that connect the main cities, both in the rural and urban sectors, show the backwardness and lack of provision of logistics and transportation infrastructure, which has been repeatedly pointed out as one of the main obstacles to economic development and the consolidation of peace in our country [5]. Regarding the quality of roads in Colombia, users have given a score of 38 out of 100 points, and in relation to other 140 countries consulted, Colombia ranks 102 [6], data that evidences the need to have a road infrastructure with optimal and acceptable levels of quality.

It is for these reasons that roads need a scheduled maintenance, to provide the community in general with a quality service, comfort and safety when transporting, to fulfill the necessary specifications, to support regional social and economic development, adequate mobility and reduce costs for users, therefore it is important to use the diagnosis of pavements in order to obtain the true state of the roads and implement phases of prevention and rehabilitation, according to the type of affectation that is present. One of the important tasks within this process is the evaluation of the surface condition of the pavement structure where a visual inspection is performed followed by a deterioration report. This information can currently be performed manually based on the regulations of the Instituto Nacional de Vías [7] and also by implementing new technologies with tools such as the Drone and its Remote Sensors that allow the capture of images of the study area and that serve to feed the databases of the PMS (Pavement Management Systems), for the subsequent analysis and processing of the information captured, facilitating the processes, organization and display of the inspection results. These new technologies with Remote Sensors are important to be studied and evaluated to know and determine the results they offer compared to traditional methods of pavement inspection, allowing a more accurate interpretation of the information collected, reliability and efficiency of the information, work times and costs.

Likewise, technological advances have allowed great improvements in different sciences and techniques developed by human beings, and Civil Engineering has not been alien to this [8]. Currently, there are different tools (digital databases, software, machinery, communication systems, materials, additives, etc.) that seek to provide efficiency and agility in civil engineering projects. Civil works such as the construction of a highway require a demanding information gathering and analysis process (previous studies), which is fundamental and will define the success or failure of the construction process [9] [10]. In addition to that, apart from carrying out an adequate construction, it is necessary to guarantee the conservation,

for which an analysis of the behavior of the structure throughout the useful life period must be carried out.

In recent years and thinking about the control of works that cover large areas (such as roads), new technological tools commonly known as UAV (Unmanned Aerial Vehicle) or better known as drones have been adopted, which were initially developed for military surveillance purposes but due to its high efficiency and versatility have been implemented within the field of civil engineering [11] [12]; taking great importance and being used with a variety of applications.

This research article will address the main characteristics of drones, the importance acquired by these devices in the development of daily activities performed by man [13] and the variety of applications so far implemented in the work of Civil Engineering, specifically in the field of Pavement Engineering, studying the possible improvements that would lead to a systematized implementation of this technology in addition to other tools and its comparison to traditional methods of observation and evaluation of pavements.

2. METHODOLOGY

The proposed research is a state of the art on the conceptualization of the use of Drones and Remote Sensors in the visual assessment of pavements. In this aspect, it reflexively recovers and transcends the accumulated normative documents on the importance and introduction of new technologies in pavement monitoring[14], assuming a critical position on what has been done and what is yet to be done[15]. Therefore, this is framed within the documentary research of hermeneutic approach, given the purpose of knowing and appropriating reality in order to discuss and problematize it [16], through the interpretation and explanation of the existing relationships between the contents of public mental health policies and the context [17]. For Gadamer, "interpretation always begins with previous concepts that will have to be progressively replaced by other more adequate ones. Here there is no other objectivity than the validation obtained by previous opinions in the course of their elaboration" [18]. This anticipation of meaning, instead of being an obstacle to hermeneutic understanding, is its condition of possibility, since it is the one that allows a first orientation, a guide, which will have to be contrasted in the path of inquiry [19].

The search for articles was carried out in databases such as ScienceDirect, ProQuest and Scielo, focusing on articles published in scientific journals that have been conducted on the topics under study.keywords such as "UAV and Pavement", "Drone and Pavement" and "UAV and Drone and Pavement" were used to locate the article. At least 50 scientific articles from high impact journals and reports from official Colombian state institutions were included in the literature review of this text.

3. RESULTS

3.1 Remote Sensing and Pavement Evaluation

Remote Sensing technology dates back to 1854 [20], however the low quality and difficulties in interpretation made this procedure materialize only until the First World War [21].With the advances in the development of photographic machines and aerial means of navigation, it became possible to obtain information about what was happening on the ground from a perspective different from that of the human eye and with a greater degree of detail that allows classifying the information according to its relevance and making decisions in different fields of application. The use of this information had a primarily military focus and the different wars throughout history drove the development of this technology to the present days [22] [23]. However, its important characteristics have been adopted for application in different disciplines, including Pavement Engineering.

Remote sensors are the complement to the Drone equipment, increase its functionality, efficiency and make this set a novel, versatile and excellent tool that currently has been incorporated to the inspection and evaluation of pavement structures [24] [25]. Adequate maintenance, and in turn the preservation of the road structure, depends on the evaluation, hence the importance of implementing an effective and reliable system that contributes to meet the objectives of proper management, focused on the construction and maintenance of roads, which in the case of countries such as Colombia are the engine of the economy. Currently, several countries have advanced programs for the implementation of Drone tools [26] [27], and they have also demonstrated that their use will allow improving processes and obtaining quality results on issues related to pavement evaluation [28].

The Remote Sensing technology in conjunction with drones, allows for a general evaluation of preliminary data [29], such as location, geometry, topography, climatic, environmental and geological conditions, among others, which can then be filtered according to their relevance, giving the possibility of concentrating the inspections on specific points where the existence of problems of the structure is evident, thus, a focused work will be performed, and that will lead to a review of exhaustive and detailed character. With the information collected, its subsequent processing and due analysis, the corresponding decisions will be made according to the evaluation made and depending on the case under study, both in maintenance and in possible rehabilitation of existing pavements.

For example, in the research of [30] they developed an innovative methodology based on digital images, called Overlaid Digital Image Analysis (OIA), to better understand the role of the reactivated binder in the cracking behavior of Hot Mix Asphalt with Reclaimed Asphalt Pavement (HMA-RAP), where important results in terms of cracking behavior have been evidenced.

[31] They point out that the most important and available sensors, with payload, are mainly classified into

three classes according to the spectral length and the number they can record: RGB (red, green, blue) or VIS (visible) sensors, multispectral sensors and hyper spectral sensors. In the case of RGB or VIS sensors, as proposed by [32] [33], they are the most common and widely available commercial cameras, as shown in Table-1. Their potential applications have been the focus of most research for years due to their potential, operational requirements and low cost.

Table-1. RGB cameras and their main specifications. Source: authors.

Camera model	Sensor type and resolution [Mpx]	Sensor format	Sensor Size [mm]	Weight [gr]
Zenmuse P1	8192×5460; 45	Full Frame	35.9x24	787
Zenmuse L1	CMOS; 1280×960; 20	Full Frame	---	900
Hasselblad A6D-100c	11600×8700; 100	Full Frame	53,4x40,0	1360
Zenmuse X7	CMOS; 24	Small Frame Mirrorless	23.5×15.7	449
Zenmuse X5s	CMOS; 20,8	Small Frame Mirrorless	---	461
Zenmuse X5r	CMOS; 16	Small Frame	17.3x13.0	450
Zenmuse Z30	CMOS: 30	Small Frame Mirrorless	---	450

Regarding multispectral sensors, [34] [35] highlight that due to a lower resolution of the sensors, compared to RGB, a lower flight altitude and adequate horizontal and vertical overlap of the recorded images must be taken into account to obtain an adequate resolution, on the ground, for the object of study and to avoid data loss. In the case of hyper spectral sensors in UAVs, based on the study of [36], the size of the images, like the data stream, is larger than the images originated by multispectral and RGB sensors. Also, these sensors can acquire a large amount of data, but the payload limitations of UAVs may not allow adequate transport of file storage systems. Table-2 shows the main specifications of hyper spectral cameras.

Table-2. Hyperspectral cameras and their main specifications. Source: [31].

Camera model	Lens	Spectral range [µm]	Spectral bands [number and µm]	Weight [kg]
CUBERT	Snapshot + PAN	450-995	125 (8 µm)	ca. 0.5
Cornirg microHSI 410 SHARK	CCD/CMOS	400-1000	300 (2 µm)	ca. 0.7
Rikola Ltd. hyperspectral camera	CMOS	500-900	40 (10 µm)	ca. 0.6
Specim-AISA KESTREL16	Push-broom	600-1640	350 (3 - 8 µm)	ca. 2.5
Headwall Photonics	InGaAs	900-1700	62 (12.9 µm)	ca. 1.1
Micro-hyperspec X-series NIR				

3.2 Drone or UAV in Pavement Evaluation

A drone is an unmanned aircraft on board, equipped with a digital photography system capable of transmitting images in real time, its control and operation is performed by a remote system on the ground and its main feature is to provide the possibility of performing a visual inspection to places of difficult access. The use of drones to perform surveys through images has also been considered in previous works and applications of civil infrastructure inspections [37] [38] [39]. This is due to the ability of drones to cover a large area without having to interact directly with the physical elements of the pavement structure [40]. Additionally, through the use of drones, offered in the current market, it is possible to acquire images with high resolutions that result in a data archive in shorter periods of time and at lower costs than traditional approaches, as has been seen in studies on pavement structure conditions by [41] [42] [43] [44]. In a study by [45], they have unveiled an innovative monitoring method where they applied a UAV-based digital image acquisition system, with the purpose of measuring the surface condition of a paved road with high

efficiency data collection. The results have been able to provide a 3D model to show clearly the surface deteriorations. The accuracy of the UAV was very high, up to half a centimeter of ground accuracy in length and height measurements. The results have also revealed that the monitoring system had a very accurate measurement, especially in detecting potholes and cracks in the road surface. The advantages of the model were the low cost and that it could be used in traffic studies. In Figure-1, a deterioration detected in a flexible pavement can be seen.

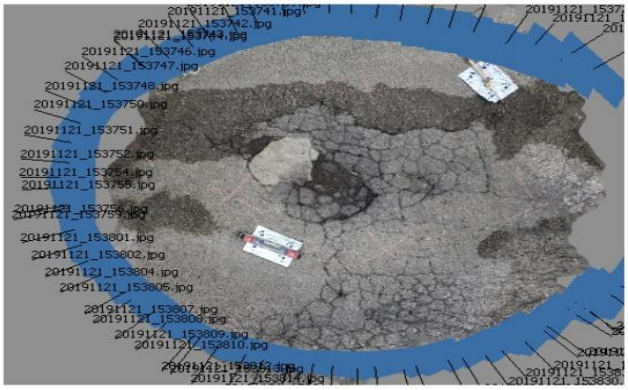

Figure-1. Example of a photographic data set obtained during a survey of a pavement section. Source: [40].

Some drone systems that integrate multispectral and thermo graphic camera sensors are capable of carrying out assessments that account for the condition of the pavement in the road network, collecting field data that verify the current characteristics of roadways and sidewalks, and are able to examine situations where there are longitudinal cracks, transverse fissures, potholes among others [46] [47]; all from image configuration, which offers a less intensive resource compared to the traditional one that is performed manually and eventually leads to human errors; this new method, much more reliable, could constitute a database for future work and comparisons that may be required. [48] Developed a UAV-based system to collect high-resolution 3D photogrammetric images of unpaved road surface deterioration. Other studies have focused on the detection of surface cracks in pavement structures using image processing [49][50][51]. Although UAV systems do not offer the same territorial coverage as satellites, they have been able to provide spatial and temporal resolution that other systems do not possess [52] [53]. In this study [54], it was investigated the possibility of using different methodologies for the automatic detection of the pattern of an articulated pavement based on UAV photogrammetric and the possibility of inserting them in an urban pavement management system, for the automatic detection two approaches were used: supervised classification using Semiautomatic Classification Plugin (SCP) and Convolutional Neural Network (CNN), with images obtained with RGP sensors, being the SCP the ones that yielded the best results. Figure-2 shows the deteriorations in the image taken with an RGB sensor on an articulated pavement.

Figure-2. Image captured with an RGB sensor on an articulated pavement. Source: [54].

From the economic perspective, it can be mentioned that the use of drones requires a significant investment to purchase. An UAV with at least one RGB camera with a resolution of approximately 0.1 cm/pixel, a trained pilot for flight management and software with a high post-processing capacity [55] [31]. The initial investment for the acquisition of an UAV is compensated by the number of flights that can be performed, which increases the frequency of the data sets obtained, and a higher spatial and radiometric resolution compared to other systems [55] [56].

The use of this equipment makes possible the work of recognition of objects and phenomena that could be present in a pavement [57], thanks to the high and good resolution that their images have reached, allowing to visualize in detail specific points that require attention in favor of the solution of the problems, highlighting that day by day work continues in the introduction of improvements to this tool that has been gradually incorporated, by different organizations and entities, to the work of pavement evaluation. Drones oriented to Geomatics are usually equipped with non-metric digital cameras that represent a lower acquisition cost; however, other remote sensors such as thermovisors, LIDAR and infrared sensors have recently started to be implemented in drone platforms, increasing the geospatial information captured through the mentioned technology [58].

Current drones have advanced remote systems such as infrared and multispectral thermography, these sensors work in conjunction with on-site systems and other technological tools such as the Global Positioning System (GPS) and satellite imagery [59]. Together these tools have made it possible to track and analyze conditions in detail and identify potential failures, reducing the duration of the decision-making process.

In addition to the advantages mentioned above, there is another one that is relevant, and that is that the collection of data taken with this equipment is highly reliable with reference to traditional methods of visual inspection of pavements. Thanks to the innovations and improvements that have been achieved in recent times for this tool, thus contributing to the analysis and timely decision making, to provide immediate responses to phenomena or dangerous situations that could generate major emergencies, such as a failure that causes

subsidence or landslides that could end up claiming the lives of those who travel on these roads. [53] mention that UAV systems also have other advantages: (1) the possibility of collecting easily deployable data in real time (excluding post-processing); (2) they can be used to inspect areas with high level of danger and/or difficult access; (3) they allow operators to collect data even in unfavorable weather conditions, such as on very cloudy or foggy days, where satellite detection systems fail or produce very disturbed data sets.

On the other hand, it is important to highlight the fact that these small devices allow making revisions or evaluations in areas of difficult access, where they generally represent a risk for the personnel, a situation that represents this inconvenience could occur on a bridge, as evidenced in the study [60], where it is complex to perform visual inspections of the surface of the pavement structure and its components; with this tool the risk disappears, since while the overflights of the Drones, and their powerful photography equipment allow the taking of information pointing out the elements of interest, in order to identify if there are damages in the structure.

The tasks of surveillance and control [61] [62], to the behavior of pavements, with this technology is taken to a plane of maximization where it is possible to observe from a privileged perspective the phenomena and changes that could occur in small or large spaces, allowing to keep records and compare their evolution over time without compromising the integrity of the structures, thanks to the accurate and effective information that is obtained from these tools.

One of the main objectives of the evaluation of pavements through this new methodology is the optimization of the road network, which is achieved thanks to the functionality that these equipments have by being able to integrate the collection of diverse information and unify it easily through appropriate software for this purpose. This eliminates the tedious task of taking traditional photographic records and their subsequent referencing, which could take months for a stretch of considerable length, and also speeds up the work of the personnel, who rigorously examine the pavement to find possible damage that could compromise the proper functioning of these elements, a task that can also take quite a long time.

4. CONCLUSIONS

One aspect to take into account after glimpsing the great advantages and versatility of these technologies is the great importance of having an operator with sufficient knowledge and training to be able to handle and maneuver the drones correctly. It is absolutely necessary that the personnel employed in these tasks have a good level of training, firstly to protect the work equipment and secondly so that the inspector has full knowledge of the parameters to follow and the information required, ensuring a post-processing with high quality results, allowing an objective analysis.

In general, properly constructed infrastructure, under the corresponding standards and specifications, whether national or international, leads to pavement structures with excellent finishes and functional and structural requirements suitable for an appropriate service life; however, their maintenance will depend on guaranteeing a useful life without compromising the quality and level of service, ensuring the safety of users and reducing the operational costs of vehicles.

It can be concluded that the incorporation of these technological tools within pavement evaluation will lead to address limits until recently unknown and little possible, without leaving aside the concept and the fundamental opinion of specialists, but now assisted by the available technological tools capable of showing a complementary perspective to that of the human eye, reducing analysis and evaluation times, and providing the possibility of having a visual overview as relevant as necessary.

Although the initial investment to include this technology in pavement evaluation seems to have a high value, it should be taken into account that maintenance costs are reduced, since corrective actions could be taken in a timely manner, and in addition to this, the quality of the data and the agility with which they are obtained would be improved, allowing the intervention in a greater number of areas, with fewer personnel and the almost complete reduction of the risk to which the inspectors in charge of performing the evaluation have been exposed, in terms of occupational safety.

ACKNOWLEDGMENTS

In the case of the author Saieth Baudilio Chaves Pabón, it is mentioned that it is a product of his academic work as a professor at the Universidad Militar Nueva Granada. Likewise, the authors give credit to the Universidad Militar Nueva Granada and the Universidad Distrital Francisco José de Caldas for the support received in the development of this research and in the preparation of this scientific document.

REFERENCES

[1] L. F. Andrade. 2017. Estrategías estatales para el mejoramiento de la red terciaria. Revista de Ingeniería, (45): 88-92, https://ojsrevistaing.uniandes.edu.co/ojs/index.php/revista/article/view/946.

[2] G. Ospina. 2016. El papel de las vías secundarias y los caminos vecinales en el desarrollo de Colombia. Revista de Ingeniería, (44): 20-27, http://dx.doi.org/10.16924%2Friua.v0i44.911.

[3] Ministerio de Transporte. 2019. Sector de la Infraestructura de Colombia. Bogotá D. C., Disponible en: https://www.mintransporte.gov.co/.

[4] Camara Colombiana de la Infraestructura. 2019. Bitacora de la Infraestructura. Bogotá D. C., Disponible en:

https://issuu.com/camaracci/docs/20190529_bitacora mayo.

[5] Departamento Nacional de Planeación. 2019. Plan Nacional de Desarrollo 2018-2022. Bogotá D. C., disponible en: https://www.dnp.gov.co/DNPN/Paginas/Plan-Nacional-de-Desarrollo.aspx.

[6] Camara Colombiana de la Infraestructura. 2018. Informe de gestión 2018. Bogotá D. C., disponible en: http://infraestructura.org.co/2017/#.

[7] Instituto Nacional de Vías. 2006, Oct. INVIAS. [Online]. https://www.invias.gov.co/index.php/archivo-y-documentos/documentos-tecnicos/manuales-de-inspeccion-de-obras/974-manual-para-la-inspeccion-visual-de-pavimentos-flexibles/file

[8] Victor Torres Campo. (2016, Febrero 19) droningenieria. [Online]. http://www.droningenieria.com/coex-mantenimiento-y-explotacion-de-carreteras-mediante-drones/

[9] Corporación Tecnológica de Andalucia. 2016. El uso de drones reduce más del 25% el coste y hasta 10 veces el tiempo empleado para trazar carreteras, puentes y vías. Sevilla, https://www.corporaciontecnologica.com/es/sala-de-prensa/noticias/El-uso-de-drones-reduce-mas-del-25-el-coste-y-hasta-10-veces-el-tiempo-empleado-para-trazar-carreteras-puentes-y-vias/.

[10] H. D. Gomez and A. Orobio. 2015. Efectos de la incertidumbre en la programación de proyectos de construcción de carreteras. DYNA, 82(193): 155-164, https://doi.org/10.15446/dyna.v82n193.47453.

[11] J. D. Pinzón. 2017. Drones en las Geociencias. Guía de Implementación en la Cartografía. Universidad de Cundinamarca, Bogotá, Trabajo de Grado Pregrado 2017, http://hdl.handle.net/20.500.12558/550.

[12] Comunidad de Madrid. 2015. Los Drones y sus aplicaciones a la Ingeniería Civil. [Online]. https://www.fenercom.com/pdf/publicaciones/Los-Drones-y-sus-aplicaciones-a-la-ingenieria-civil-fenercom-2015.pdf

[13] Notiamerica.com. 2015. Cinco usos de los drones que te sorprenderán, visionado de obras. [Online]. http://www.notimerica.com/sociedad/tecnologia-ciencia/noticia-cinco-usos-drones-te-sorprenderan-20151016115847.html

[14] C. Mettas *et al*. 2015. Monitoring Asphalt Pavement Damages using Remote Sensing Techniques. In Third International Conference on Remote Sensing and Geoinformation of the Environment, Paphos Cyprus, 2015.

[15] M. Galeano and O. Vélez. 2000. Estado del Arte sobre fuentes documentales en investigación cualitativa. Medellín, Colombia: Universidad de Antioquia.

[16] O. Londoño, L. Maldonado and L. Calderón. 2014. Guia para construir Estados del Arte. Bogotá, Colombia: International Corporation of Networks of Knowledge.

[17] L. Hidalgo. 2016. Confiabilidad y Validez en el Contexto de la Investigación y Evaluación Cualitativas. SINOPSIS EDUCATIVA. Revista venezolana de investigación, 5(1-2): 225-243, http://www.ucv.ve/uploads/media/Hidalgo2005.pdf.

[18] Hans-Georg Gadamer, Verdad y Método, Volumen I ed. Salamanca, España: Sigueme, 1993.

[19] J. Amador B. 2019. Hans-Georg Gadamer: Historicity of the comprehension of history. Estudios políticos (México), (46): 45-70, https://doi.org/10.22201/fcpys.24484903e.2019.46.68287.

[20] Mundo Drone. 2014. Historia de los Drones. [Online]. http://mundrone.blogspot.com.co/p/historia-de-los-drones.html

[21] E. Luján. 2016. Drones: sombras de la guerra contra el terror. PAPELES de relaciones ecosociales y cambio global. (134): 163-175.

[22] R. S. Rushby. 2017. Armed drones and the use of lethal force: New technologies and known challenges. Revista CES Derecho, 8(1): 2-47, http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S2145-77192017000100003&lng=en&nrm=iso.

[23] M. Sanz Gismero. 2015. El papel del uso de los drones de combate en la perpetuación y el aumento de terrorismo en Pakistán. Universidad Pontificia Comillas, Madrid, Trabajo de Fin de Grado: Grado en

Relaciones Internacionales, http://hdl.handle.net/11531/358.

[24] M. Herold, D. Roberts, V. Noronha and O. Smadi. 20085. Imaging spectrometry and asphalt road surveys. Transportation Research Part C: Emerging Technologies, 16(2): 153-166, https://doi.org/10.1016/j.trc.2007.07.001.

[25] S. Pascucci, C. Bassani, A. Palombo, M. Poscolieri, and R. Cavalli. 2008. Road Asphalt Pavements Analyzed by Airborne Thermal Remote Sensing: Preliminary Results of the Venice Highway. Sensors, 8(2): 1278-1296, https://doi.org/10.3390/s8021278.

[26] A. Mei, R. Salvatori, N. Fiore, A. Allegrini and A. D'Andrea. 2014. Integration of Field and Laboratory Spectral Data with Multi-Resolution Remote Sensed Imagery for Asphalt Surface Differentiation. Remote Sensing, 6(4): 2765-2781, https://doi.org/10.3390/rs6042765.

[27] E. Schnebele, B. F. Tanyu, G. Cervone and N. Waters. 2015. Review of remote sensing methodologies for pavement management and assessment. European Transport Research Review, 7(7): 07, https://doi.org/10.1007/s12544-015-0156-6.

[28] M. Varela-González, M. Solla, J. Martínez-Sánchez and P. Ariasa. 2014. A semi-automatic processing and visualisation tool for ground-penetrating radar pavement thickness data. Automation in Construction, 45: 42-49, https://doi.org/10.1016/j.autcon.2014.05.004.

[29] L. Dabbiru *et al*. 2015. Runway Assessment via Remote Sensing. IEEE Applied Imagery Pattern Recognition Workshop (AIPR), pp. 1-4, doi: 10.1109/AIPR.2015.7444545.

[30] A. Roberto *et al*. 2021. Evaluation of the Role of Reclaimed Asphalt Pavement Preheating on Cracking Behavior of Hot Mix Asphalt Recycled Mixtures by Digital Image Analysis. Journal of Testing and Evaluation, 49(03, https://doi.org/10.1520/JTE20200465.

[31] M. Esposito, M. Crimaldi, V. Cirillo, F. Sarghini, and A. Maggio. 2021. Drone and sensor technology for sustainable weed management: a review. Chemical and Biological Technologies in Agriculture, 8(18): 25 https://doi.org/10.1186/s40538-021-00217-8.

[32] J. Torres-Sánchez, J. M. Peña, A. I. de Castro, and F. López-Granados. 2009. Multi-temporal mapping of the vegetation fraction in early-season wheat fields using images from UAV. Computers and Electronics in Agriculture, 103: 104-113, https://doi.org/10.1016/j.compag.2014.02.009.

[33] R. Jannoura, K. Brinkmann, D. Uteau, C. Bruns, and R. G. Joergensen. 2015. Monitoring of crop biomass using true colour aerial photographs taken from a remote controlled hexacopter. Biosystems Engineering, 129: 341-351, https://doi.org/10.1016/j.biosystemseng.2014.11.007.

[34] Micasense Inc. 2021, February 09. Best practices: Collecting Data with MicaSense Sensors. [Online]. https://support.micasense.com/hc/en-us/articles/224893167

[35] M. Louargant *et al*. 2017. Weed detection by UAV: simulation of the impact of spectral mixing in multispectral images. Precision Agriculture, 18: 932-951, https://doi.org/10.1007/s11119-017-9528-3.

[36] A. Brook and E. Ben-Dor. 2015. Supervised Vicarious Calibration (SVC) of Multi-Source Hyperspectral Remote-Sensing Data. Remote Sensing, 7(5): 6196-6223, https://doi.org/10.3390/rs70506196.

[37] D. Giordan, A. Manconi, F. Remondino and F. Nex. 2017. Use of unmanned aerial vehicles in monitoring application and management of natural hazards. Geomatics, Natural Hazards and Risk, 8(1): 1-4, https://doi.org/10.1080/19475705.2017.1315619.

[38] A. Manconi, M. Ziegler, T. Blöchliger and A. Wolter. 2019. Technical note: optimization of unmanned aerial vehicles flight planning in steep terrains. International Journal of Remote Sensing, 40(7): 2483-2492, https://doi.org/10.1080/01431161.2019.1573334.

[39] G. Salvo, L. Caruso and A. Scordo. 2014. Urban Traffic Analysis through an UAV. Procedia - Social and Behavioral Sciences, 111: 1083-1091, https://doi.org/10.1016/j.sbspro.2014.01.143.

[40] R. Roberts, L. Inzerillo and G. Di Mino. 2021. Using UAV Based 3D Modelling to Provide Smart Monitoring of Road Pavement Conditions. Information, 11(12): 568, https://doi.org/10.3390/info11120568.

[41] L. Gézero and C. Antunes. 2019. Road Rutting Measurement Using Mobile LiDAR Systems Point Cloud. ISPRS International Journal of Geo-Information, 8(9): 404, https://doi.org/10.3390/ijgi8090404.

[42] Y. Pan, X. Zhang, G. Cervone and L. Yang. 2018. Detection of Asphalt Pavement Potholes and Cracks Based on the Unmanned Aerial Vehicle Multispectral Imagery. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 11(10): 3701-3712, DOI: 10.1109/JSTARS.2018.2865528.

[43] D. Kang and Y. J. Cha. 2018. Utonomous UAVs for Structural Health Monitoring Using Deep Learning and an Ultrasonic Beacon System with Geo-Tagging. Comput. Civ. Infrastruct. Eng, 33: 885-902, https://doi.org/10.1111/mice.12375.

[44] C. Zhang. 2008. An UAV-based photogrammetric mapping system for road condition assessment. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., 37(627-632), https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.150.8490&rep=rep1&type=pdf.

[45] A. Shtayat, S. Moridpour, B. Best, A. Shroff, and D Raol. 2021. A review of monitoring systems of pavement conition in paved and unpaved roads. Journal of Traffic and Transportation Engineering, 7(5): 629-638, https://doi.org/10.1016/j.jtte.2020.03.004.

[46] V. Noronha, M. Herold, D. Roberts and M. Gardner. 2022. Spectrometry and hyperspectral remote sensing for road centerline extraction and evaluation of pavement condition. National Consortium on Remote Sensing in Transportation - Infrastructure Managemen, no. 12, https://www.researchgate.net/publication/255659176_Spectrometry_and_hyperspectral_remote_sensing_of_urban_infrastructure.

[47] A. Mei, C. Bassani, C. Manzo and A. Allegrini. 2014. Bitumen Removal Determination on Asphalt Pavement Using Digital Imaging Processing and Spectral Analysis. Open Journal of Applied Sciences, 4(6), http://dx.doi.org/10.4236/ojapps.2014.46034.

[48] C. Zhang and A. Elaksher. 2012. An Unmanned Aerial Vehicle-Based Imaging System for 3D Measurement of Unpaved Road Surface Distresses. Comput-Aided Civil Infrastructure Engineering, 27(2): 118-129, 2012, https://doi.org/10.1111/j.1467-8667.2011.00727.x.

[49] Y. Miao, J. Y. Jeon and G. Park. 2020. An image processing-based crack detection technique for pressed panel products. Journal of Manufacturing Systems, 57: 287-297, https://doi.org/10.1016/j.jmsy.2020.10.004.

[50] Y. Miao, J. Y. Jeon and G. Park. 2020. Image-based concrete crack detection in tunnels using deep fully convolutional networks. Construction and Building Materials, 234: 117367, https://doi.org/10.1016/j.conbuildmat.2019.117367.

[51] Y. Wang *et al*. 2019. Research on Crack Detection Algorithm of the Concrete Bridge Based on Image Processing. Construction and Building Materials, 154: 610-616, https://doi.org/10.1016/j.procs.2019.06.096.

[52] A. C. Watts, V. G. Ambrosia and E. A. Hinkley. 2012. Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use. Remote Sensing, 4(6): 1671-1692, https://doi.org/10.3390/rs4061671.

[53] S. Manfreda *et al*. 2018. On the Use of Unmanned Aerial Systems for Environmental Monitoring. Remote Sensing, 10: 641, https://doi.org/10.3390/rs10040641.

[54] E. Garilli, N. Bruno, F. Autelitano, R. Roncella and F. Giuliani. 2021. Automatic detection of stone pavement's pattern based on UAV photogrammetry. Automation in Construction, 122: 103477, https://doi.org/10.1016/j.autcon.2020.103477.

[55] K. Anderson and K. J. Gaston. 2013. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Frontiers in ecology and the environment, 11(3), https://doi.org/10.1890/120150.

[56] K. Whitehead and C. H. Hugenholtz. 2014. Remote sensing of the environment with small unmanned aircraft systems (UASs), part 1: a review of progress and challenges. Journal of Unmanned Vehicle Systems, https://doi.org/10.1139/juvs-2014-0006.

[57] Martin Herold, Dar Roberts, Omar Smadi and Val Noronha. 2014, Enero. Researchgate. [Online]. https://www.researchgate.net/publication/228608996_Road_condition_mapping_with_hyperspectral_remote_sensing

[58] P. Martínez, D. Ojeda, E. Pérez and F. Bravo. Vehículos Aéreos No Tripulados (VANT) en cuba, aplicados a la Geomática. Estado actual, perspectivas y desarrollo. [Online]. http://observatoriogeograficoamericalatina.org.mx/egal15/Nuevastecnologias/Teledeteccion/10.pdf

[59] A. Ozden, A. Faghri, M. Li and K. Tabrizi. 2016. Evaluation of Synthetic Aperture Radar Satellite Remote Sensing for Pavement and Infrastructure Monitoring. Procedia Engineering, 145: 752-759, https://doi.org/10.1016/j.proeng.2016.04.098.

[60] J. Sánchez. 2014. Evaluación del estado del puente de uso de sensores remotos. [Online]. http://www.mosingenieros.com/2010/04/evaluacion-del-estado-del-puente-de-uso.html

[61] Treneando. 2014. Los ferrocarriles franceses usan drones para vigilar zonas vitales de la infraestructura ferroviaria. [Online]. https://treneando.com/2014/01/07/los-ferrocarriles-franceses-prueban-drones-para-inspeccionar-zonas-vitales-de-la-la-infraestructura-ferroviaria/

[62] Vía Libre. 2015. www.vialibre-ffe.com. [Online]. http://www.vialibre-ffe.com/noticias.asp?not=13926