ADVANCES IN RESEARCH ON THE USE OF DRONES IN PRODUCTION AND TRANSPORTATION ENGINEERING IN THE HYDROCARBONS INDUSTRY: A BIBLIOMETRIC ANALYSIS

LUIS ROMÁN-PIEDRA[1], JOSELYNE SOLÓRZANO[2,3] & PAÚL CARRIÓN-MERO[2,3]
[1]Facultad de Ciencias de la Ingeniería, Universidad Península de Santa Elena, Instituto de Posgrado, Ecuador
[2]ESPOL Polytechnic University, Centro de Investigaciones y Proyectos Aplicados a las Ciencias de la Tierra, Ecuador
[3]ESPOL Polytechnic University, Facultad de Ingeniería Ciencias de la Tierra, Ecuador

ABSTRACT

Unmanned aerial vehicles are considered a part of emerging technologies designed to facilitate, improve, and transform the operational efficiency of industries with significant capital and assets, such as hydrocarbons. Hydrocarbon projects require comprehensive management in the production and transportation processes, where the application of drones plays a fundamental role by minimizing the exposure of personnel in high-risk activities, improving the efficiency of operations and the integrity of assets, and significantly reducing costs and time in the field. This study aims to conduct a bibliometric analysis and systematic review of the relationship between drones and the hydrocarbon industry, focusing on production and transportation processes through bibliometric techniques and evaluation of case studies for the analysis, classification, and description of key issues, methodologies, and trends worldwide. The research methodology consisted of three phases: (i) conceptualization of study variables and database combinations; (ii) bibliometric analysis using VOSviewer and bibliometric software; and (iii) focalization on systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method. Bibliometric analysis collected data from 1985 to 2023, with 143 scientific publications indexed in the Scopus and WoS databases. The results showed a growing trend in the annual publications of drones and their application in the hydrocarbon industry, focusing on safety issues, pipeline inspections and storage tanks, and environmental monitoring generated by methane emissions and oil spills. In the case study analysis, the use of drones with different sensors was demonstrated, among which, the thermal camera, gas detector, LiDAR, EMAT, RGB camera, SWIR, RTK, and methane sensors stood out.

Keywords: remote pilot aircraft system, unmanned aerial vehicle, oil industry, Industry 4.0, inspections and monitoring, pipelines, refinery.

1 INTRODUCTION

The hydrocarbon sector plays a fundamental role in the global economy and modern societies' energy demand [1]. In 2021, fossil fuels will constitute approximately 54% of the global energy supply [2]. In recent decades, competition between global oil and gas production companies has intensified, generating technological progress in process optimisation issues for better management in oil fields [3]. The rapid development of the fourth industrial revolution, or Industry 4.0, aims to transform traditional industries into smart ones by incorporating innovative technologies. Industry 4.0, applied in the hydrocarbon industry, is called 'Oil & Gas 4.0' (O&G 4.0) implemented to improve field operations [4].

O&G 4.0 is characterized by the implementation of intelligent systems in digitization and automation processes [5]. This industry implements technology such as Internet of Things (IoT), artificial intelligence (AI), machine learning [4], digital twin [6] and robotic advances [7]. According to the systematic review carried out by Aydin and Temizel [8], drones, known as remote piloted aircraft systems (RPAS) or unmanned aerial vehicles (UAVs), are part of

WIT Transactions on Ecology and the Environment, Vol 261,
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/ESUS230201

the robotic advances adapted to the O&G 4.0 industry. Implementing RPAS technology in oil fields is beneficial for the automation and modernization of internal production and distribution processes, increasing productivity and high quality and flexibility [9].

There are academic studies that have conducted systematic reviews in domains related to emerging technologies, drones, gas, and oil [10], [11]. Shukla and Karki [12] mentioned that UAVs are used for external automation in pipeline inspection, thereby generating greater security for sensitive O&G facilities. Bibliometric studies with systematic reviews using software specialized in statistical analysis will allow the evaluation of the progress of research on the use of drones in production and transportation processes in the hydrocarbon industry [13].

Considering the literature review on the advancement of the technological use of drones in the hydrocarbon industry, the following research questions arise. What are the evolution and trends in research on the use of drones in the production and transportation processes of the oil and gas industry? What are the most widely used techniques in the hydrocarbon industry, and how do they contribute to improving infrastructure monitoring and inspection processes? This research aims to determine the intellectual structure of scientific publications in the production and transportation processes of the hydrocarbon industry through the VOSviewer software application, bibliometrix, and a systematic review for the analysis of its evolution and trends.

2 MATERIALS AND METHODS

Bibliometrics and systematic reviews provide a comprehensive view of the growth of a research topic, supported by quantitative analysis [14]. The study methodology was divided into three phases (Fig. 1): (i) conceptualization of study variables and database combination; (ii) bibliometric analysis; and (iii) focus on systematic review.

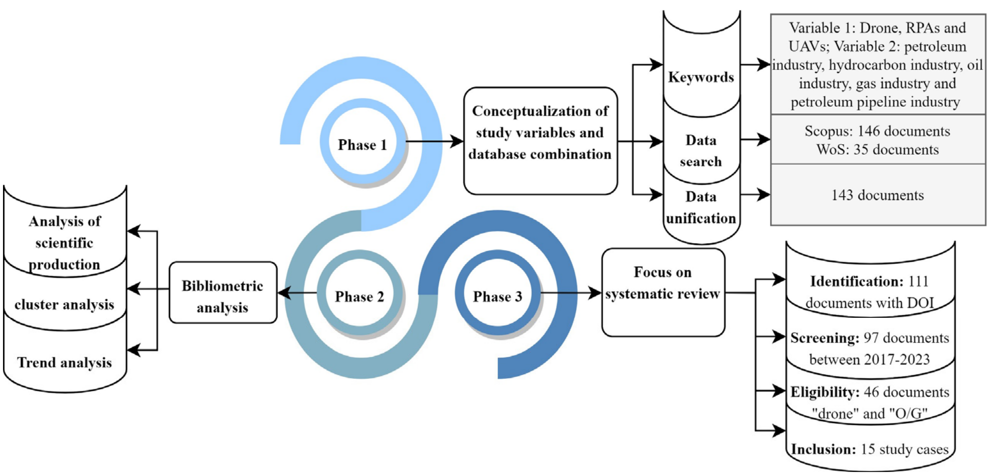

Figure 1: Methodological scheme of the bibliometric analysis and systematic review.

2.1 Conceptualization of study variables and database combination

In the conceptualization of the research topic, drones and the oil industry have been considered as study variables to determine their relationship in depth. With the application of Boolean operators, the following search equation was used in Scopus and WoS: ((TITLE-ABS-KEY ("petroleum industry*") OR TITLE-ABS-KEY ("hydrocarbon industry*") OR TITLE-ABS-KEY ("oil industry*") OR TITLE-ABS-KEY ("gas industry*") OR TITLE-ABS-KEY ("petroleum pipeline industry*"))) AND ((TITLE-ABS-KEY ("remote pilot aircraft system*") OR TITLE-ABS-KEY ("RPAs*") OR TITLE-ABS-KEY ("drone*") OR TITLE-ABS-KEY ("UAVs*") OR TITLE-ABS-KEY ("unmanned aerial vehicle*"))).

2.2 Bibliometric analysis

From the unification and cleaning of the database, a detailed analysis of scientific production was carried out using bibliometrix software. This R programming software presents statistical analysis tools in its biblioshiny interface, which has allowed the generation of graphs based on its scientific production since its first publication. Using the keyword data, a trend map was created, considering a frequency of at least five times in the analysed articles. In addition, a graph was constructed to identify the predominant motor themes and niches during the analysis. Through the application of the VOSviewer software (version 1.6.17), the map of the clusters within the research topic was generated; considering the occurrence of keywords at least twice, this program represented a tool for constructing and visualising maps linking author keywords and identifying their relationships [15].

2.3 Focus on systematic review

In the systematic review, the PRISMA method was used to focus the search on databases. PRISMA considers four stages of research for the synthesis of scientific publications. The first stage, called 'identification', consisted of discriminating the publications that did not present DOI within their registry to access the articles and obtain 111 available documents. For the second stage, 'screening', the publications of the last six years (2017–2023) were considered, resulting in 97 documents. Regarding the third stage, eligibility', the criteria of the 'drone', and 'oil and gas' keywords in the abstract were considered, yielding 46 articles. In the last phase of PRISMA 'Inclusion', the case study criteria were used to identify the application of different methodologies and results in oil-producing countries, resulting in 15 documents.

3 RESULTS

3.1 Analysis of scientific production

A statistical analysis was carried out on the 143 documents generated by the unification of the databases, identifying 493 authors and 402 keywords. In stage A (1985–2018), the first publication on the application of drones in the oil industry was recorded in 1985, evidencing the use of submersible robots [16], and drones for inspections of transmission pipeline groundwater [17] and topographic surveys. Subsequently, no articles related to the subject were registered for 7 years, and from 2005 to 2018, there were 33 publications related to the use of UAVs for data acquisition at sea, at low altitudes, and in remote locations [18], UAVs with sensors for external automated inspection of pipelines and UAVs equipped with a methane detector for detection and monitoring in large and remote areas. In Period B, most documents published in 2019 and 2020 (Fig. 2) correspond to conference papers. In the last five years, studies have focused on the use of drones to improve the quality of digital outcrop models (DOMs) in the oil industry [19], offshore oil spills and leaks, pipeline monitoring and the application of UAVs with laser detectors to monitor and quantify methane emissions.

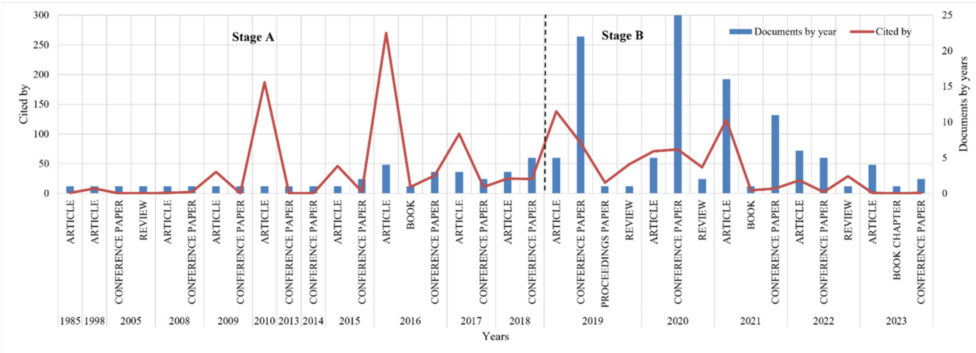

Figure 2: Scientific production from 1985 to 2023, with the number of citations and type of documents.

3.2 Scientific contribution by country

In the analysis of the countries with the highest production and citations (Fig. 3(a)), the United States was first reported with 37 publications and 380 citations, with topics related to the use of UAVs with an airborne sensor node in the oil fields of North Dakota for air quality monitoring and CH_4 detection [20]. In addition, aircraft are used to quantify methane in oil and gas tanks in West Texas [21] and to strengthen maritime and port security for acts of terrorism [22]. China ranks second with nine publications and 27 citations, highlighting its research carried out in the Sichuan Basin, where robots and UAVs are integrated to establish an intelligent management model for the development of gas fields, ensuring their long-term production. The UK ranks third, with 86 publications on UAVs for external inspection of visible pipeline sections [23] and real-time monitoring of conditions on offshore structures

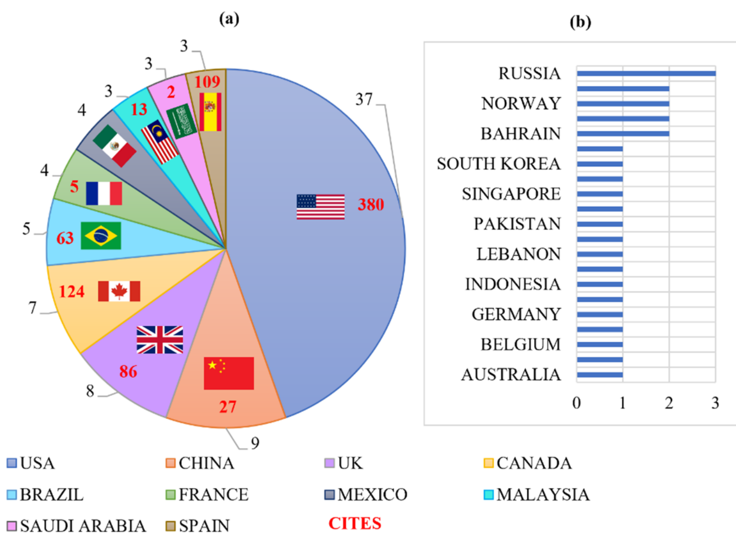

Figure 3: (a) Top ten number of documents (black) and citations (red) by country; and (b) Countries with less than three documents registered.

by installing a multi-sensing platform [24]. In Canada, the application is based on the detection and repair of methane leaks [25], inventory of equipment in oil fields, rescue missions and disaster management. Brazil uses short-range photogrammetry for the visual inspection of risers [26]; in France and Mexico, it is used mainly for environmental inspection and monitoring [27], and Malaysia, Saudi Arabia, and Spain for pipe inspection owing to its low cost [28]. There are countries with fewer than three registered articles (Fig. 3(b)) that have issues related to the monitoring and control of disasters and pollutants.

3.3 Study clusters

For the analysis of the clusters in VOSviewer software version 1.6.17, two occurrences were considered, identifying 32 keywords and seven clusters (Fig. 4). The first cluster in red, called ‘digital technologies’, involves the transformation of the oil and gas industry through the implementation of technologies such as IoT, robotics, AI, machine learning, and digital twins, improving monitoring, inspection, and security systems for the prevention of disasters or oil spills [29]. The green cluster called ‘digital transformation’ covers research on digital modernisation in the oil and gas industry through the use of UAVs [30], as non-destructive testing (NDT) technology in pipeline inspection, route planning [5], and methane and leak monitoring in subsea pipelines [8]. The blue cluster, called ‘oil and gas industry’, covers topics related to thickness measurement and hydrocarbon leak detection through optical gas imaging (OGI), 3D mapping of structures through laser imaging detection and ranging (LiDAR), photogrammetry, and long-range operations [31]. The fourth cluster in yellow, called ‘Unmanned Aerial System’ considers studies using spectral data from unmanned aerial systems (UAS) to detect hydrocarbon emulsions in almost real-time [32]. The applicability of EO/IR optical and infrared sensors implemented in UAVs for the detection, characterisation, and mapping of hydrocarbons has also been highlighted, such as the case study of Nunavut in Canada [33] and a multi-rotor vertical takeoff and landing drone [34]. The fifth cluster, called ‘environmental monitoring’, uses UAVs to detect and quantify methane leaks, as in case studies in the US and Canada [35]. The light blue cluster named ‘UAV’ reflects its combined use with motion photogrammetry to create a DOM in the Apsheron–Azerbaijan Peninsula [36] and the application of RPAS in the visual inspection of pipelines. The orange cluster called ‘drone’ includes studies of a hybrid system of monitoring, detection and cleaning of spills, detecting the level of contamination in maritime regions [37].

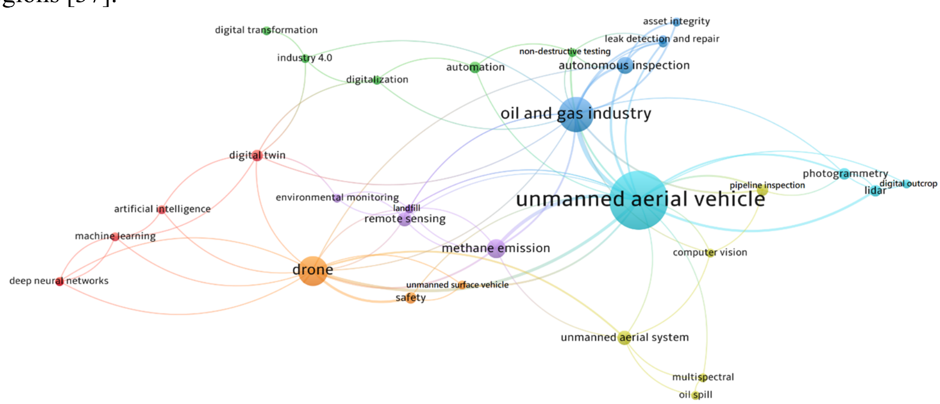

Figure 4: Map of keyword clusters considering one occurrence of two in VOSviewer.

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3.4 Thematic evolution

Fig. 5 analyses the thematic evolution of the author keywords used in research published from 1985 to 2023 with two occurrences. In Fig. 5(a), the first period from 1985 to 2018 was considered based on scientific production (Fig. 2), identifying the gas industry and the application of UAVs as motor themes with high centrality and density in themes mainly related to the monitoring of transmission lines, preventive maintenance, and oil and gas leaks through fast full-spectrum cameras [38]. With high density and low centrality, issues related to the use of remotely operated vehicles to perform high-quality inspections of subsea assets, equipped with a state-of-the-art vision camera to navigate autonomously through a pre-programmed inspection viewer [39]. The themes of low density and centrality that indicate low development of the theme are related to the profitability of the application of UAV in different areas, such as the prevention of pollution that affects the environment. Fig. 5(b) highlights the application of UAVs in the monitoring and management of the oil industry due to marine pollution generated by hydrocarbon spills and the inspection of pipelines as niche issues within the analysis between 2019 and 2023. Emerging issues highlight the use of deep learning as an intelligent tool for monitoring oil infrastructures, and as motor issues in studies on pollution and environmental monitoring generated by methane emissions.

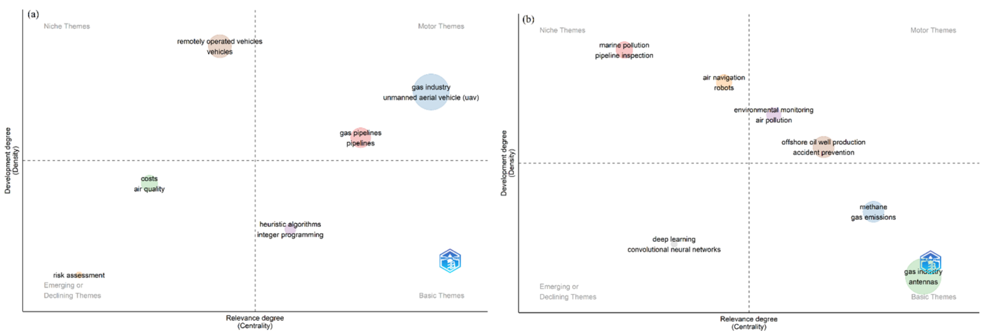

Figure 5: (a) Thematic evolution between 1985 and 2018; and (b) Thematic evolution between 2019 and 2023.

3.5 Systematic review using PRISMA

In the context of this systematic review, 15 case studies were examined to analyses the predominant applications and sensors used by drones in the oil and gas industry. In Fig. 6, the UAV tools applied in the production and transportation processes in the O&G industry are classified, reflecting their applications in inspection, monitoring, exploration, and security. The analysis of UAV applications showed that in Middle Eastern countries, such as Bahrain, the Tawtweer Petroleum company uses AI-based drones equipped with thermal camera sensors and gas detectors for equipment monitoring, pipeline inspections, security, and mapping [40]. In Saudi Arabia, studies on the implementation of drones in the O&G industry focus on security and defence issues, being equipped with weapons [41]. In the United Arab Emirates, gas leaks in oil fields are the main problem in the industry, therefore, Short-wave infrared (SWIR) sensors were implemented in the monitoring and inspections of oil assets [42]. On the European continent, Stupnikov et al. [43] mentioned that Russia developed an automatic landing system in 2017, where the use of drones with gas detectors

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was implemented to monitor leaks in gas pipelines. On the other hand, Vytovtov et al. [44] implemented a mathematical model in drones with RGB sensors, to identify accidents associated with the combustion of hydrocarbons. In 2022, gas detector sensors were implemented in multirotor drones in Norway to monitor the in-situ burning of hydrocarbons in response to oil spills [45]. In Denmark, Benzon et al. [46] developed digital twin models using LiDAR and real-time kinematic (RTK) sensors in multirotor drones to implement them in the detection, simulation, security, and inspection of oilfields. Dujoncqouy et al. [47] in Spain used fixed-wing and multirotor drones equipped with LiDAR sensors to improve the understanding of underground deposits qualitatively and quantitatively. Regarding the African continent, in Nigeria Alum and Eze [48] used acoustic electromagnetic ultrasonic test sensors (EMAT) for corrosion detection, monitoring, and control of assets in O&G facilities. In Oceania, in Papua New Guinea, the use of seismic sensors in multirotor drones has been reported for the acquisition of geophysical data during exploration stages [49]. On the American continent, case studies focused on the United States, where in 2020, gas detector sensors and thermal cameras were implemented in drones to develop a comprehensive self-piloted drone system [50]. In 2022, methane sensors were used to detect the emission rates at oil and gas production sites [21]. In 2021, Canada's methane sensors allowed the monitoring and inspection of gas leaks [51]. In addition, researchers from Brazil, Norway and Portugal collaborated in the development of a machine learning model, based on convolutional neural networks (CNN) and equipped with an RGB camera, installed on multirotor drones, for the inspection of unburied pipelines [52].

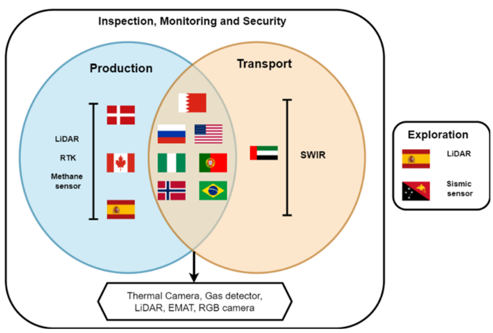

Figure 6: Systematic review scheme of the UAV application in the O&G industry.

4 DISCUSSION

Research and application of drones in the O&G industry began 38 years ago (1985), experiencing a significant increase in scientific production since 2018. Since 2019, 79% of research related to this topic has been published, with 61.7% representing conference papers. Several studies have focused on reviewing the applications of drones in the oil industry, however, the bibliometric analysis combined with systematic reviews focused on case studies, which focused on the research topics, determined the gaps, and centralised the trends within the field of study. Fig. 4 shows the relationship between the application of various digital technologies (red cluster) with drones (orange cluster) and the purple environmental monitoring cluster, highlighting its use in the O&G industry. Sheveleva and Avdeeva [53] mention that digital technologies (mainly digital twin, IA, IoT and drones) have been actively used in the oil and gas industry in recent years as non-intrusive techniques in contaminant detection [54], being resilient with the environment, reducing production costs, increasing

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productivity and energy efficiency. The use of UAVs (light blue cluster) with the implementation of sensors, LiDAR and photogrammetry has allowed autonomous inspections of pipelines (yellow cluster) found in extreme environments and conditions, recognition and data collection, and improvement in the integrity of the oil assets [55]. The systematic review using the PRISMA method allowed us to focus on 15 scientific publications that reflect case studies in different countries (Fig. 6), where inspections and monitoring of infrastructures and safety in oil fields predominated. In addition, other applications arise, such as exploration in oil fields and corrosion detection in pipes. The implementation of UAV technology during hydrocarbon production and transportation processes allows for improving maintenance and predicting damage and defects in infrastructures in the O&G industry using AI, machine learning, digital twin, convolutional neural networks and sensors such as thermal cameras, gas detector, LiDAR, EMAT, RGB camera.

5 CONCLUSIONS

For the general approach to the relationship between UAV applications in the O&G industry, two databases with the largest number of registered scientific publications, such as WoS and Scopus, have been combined. In the unification, 143 documents were determined to significantly grow their scientific production in the last five years due to technological tools such as IA, IoT, digital twin and sensors used in the hydrocarbon industry, improving their pipeline inspection and monitoring processes contaminants. In the analysis of the scientific production by countries, the United States, China and the United Kingdom have been identified mainly on monitoring and preventing oil spills, methane emissions and pipeline inspections, using UAVs as a technology of Non-Destructive Testing in remote environments. In the systematic review using the PRISMA method, 15 case studies were evaluated, highlighting the applications of sensors (thermal camera, gas detector, LiDAR, EMAT, RGB camera, SWIR, RTK and methane sensors) used by drones in oil fields. The main applications of UAVs are reflected in issues of exploration, inspection, monitoring and security in infrastructures such as pipelines, oil pipelines, gas pipelines, storage tanks and separation tanks. These applications directly influence the production and transportation processes of hydrocarbons.

ACKNOWLEDGMENTS

The authors acknowledge the Master's degree in petroleum from UPSE and the project 'Management and Evaluation of Scientific Research in Earth Sciences, Economy, Administration, and its Links with Society' with code CIPAT-7-2022.

REFERENCES

[1] Olawuyi, D.S., Can MENA extractive industries support the global energy transition? Current opportunities and future directions. *Extr. Ind. Soc.*, **8**(2), pp. 0–1, 2021. DOI: 10.1016/j.exis.2020.02.003.
[2] Davies, A. & Simmons, M.D., Demand for 'advantaged' hydrocarbons during the 21st century energy transition. *Energy Reports*, **7**, pp. 4483–4497, 2021. DOI: 10.1016/j.egyr.2021.07.013.
[3] Korovin, I.S. & Tkachenko, M.G., Intelligent oilfield model. *Procedia Comput. Sci.*, **101**, pp. 300–303, 2016. DOI: 10.1016/j.procs.2016.11.035.
[4] Sayani, J.K.S. & Lal, B., Machine learning in oil and gas industry. *Machine Learning and Flow Assurance in Oil and Gas Production*, pp. 7–26, 2023. DOI: 10.1007/978-3-031-24231-1_2.

[5] Yu, L. et al., Inspection robots in oil and gas industry: A review of current solutions and future trends. *ICAC 2019: 2019 25th IEEE Int. Conf. Autom. Comput.*, pp. 1–6, 2019. DOI: 10.23919/IConAC.2019.8895089.
[6] Shen, F., Ren, S.S., Zhang, X.Y., Luo, H.W. & Feng, C.M., A digital twin-based approach for optimization and prediction of oil and gas production. *Math. Probl. Eng.*, **2021**, 2021. DOI: 10.1155/2021/3062841.
[7] Asadzadeh, S., de Oliveira, W.J. & de Souza Filho, C.R., UAV-based remote sensing for the petroleum industry and environmental monitoring: State-of-the-art and perspectives. *J. Pet. Sci. Eng.*, **208**, 2022. DOI: 10.1016/j.petrol.2021.109633.
[8] Aydin, H. & Temizel, C., Latest applications of UAVs, drones and robotics in the oil and gas industry, Apr. 2022. DOI: 10.4043/31735-MS.
[9] Elijahm O. et al., A survey on Industry 4.0 for the oil and gas industry: Upstream sector. *IEEE Access*, **9**, pp. 144438–144468, 2021. DOI: 10.1109/ACCESS.2021.3121302.
[10] Herrera-Franco, G., Montalván-Burbano, N., Mora-Frank, C. & Moreno-Alcívar, L., Research in petroleum and environment: A bibliometric analysis in South America. *Int. J. Sustain. Dev. Plan.*, **16**(6), pp. 1109–1116, 2021. DOI: 10.18280/ijsdp.160612.
[11] Berrezueta, E. et al., Laboratory studies on CO_2-brine-rock interaction: An analysis of research trends and current knowledge. *Int. J. Greenh. Gas Control*, **123**, 103842, 2023. DOI: 10.1016/j.ijggc.2023.103842.
[12] Shukla, A. & Karki, H., Application of robotics in onshore oil and gas industry: A review – Part I. *Rob. Auton. Syst.*, **75**, pp. 490–507, 2016. DOI: 10.1016/j.robot.2015.09.012.
[13] Herrera-Franco, G., Escandón-Panchana, P., Montalván, F.J. & Velastegui-Montoya, A., CLUE-S model based on GIS applied to management strategies of territory with oil wells—Case study: Santa Elena, Ecuador. *Geogr. Sustain.*, **3**(4), pp. 366–378, 2022. DOI: 10.1016/j.geosus.2022.11.001.
[14] Velastegui-Montoya, A., Escandón-Panchana, P., Peña-Villacreses, G. & Herrera-Franco, G., Land use/land cover of petroleum activities in the framework of sustainable development. *Clean. Eng. Technol.*, **15**, 100659, 2023. DOI: 10.1016/j.clet.2023.100659.
[15] Solórzano, J., Morante-Carballo, F., Montalván-Burbano, N., Briones-Bitar, J. & Carrión-Mero, P., A systematic review of the relationship between geotechnics and disasters. *Sustain.*, **14**(19), 2022. DOI: 10.3390/su141912835.
[16] Stoll, J.E., Robots working beneath the sea. *Surv. New York*, **19**(4), pp. 2–7, 1985. https://www.scopus.com/inward/record.uri?eid=2-s2.0-0022150594&partnerID=40&md5=a9c7fe5ff03d65f82b72c1cde09e076c.
[17] Hollingum, J., Robots explore underground pipes. *Ind. Rob.*, **25**(5), pp. 321–325, 1998. DOI: 10.1108/01439919810232468.
[18] Anderson, D.E. & Pita, A.C., Geophysical surveying with GeoRange^{TM} UAV. *Collection of Technical Papers – InfoTech at Aerospace: Advancing Contemporary Aerospace Technologies and Their Integration*, **1**, pp. 471–483, 2005. https://www.scopus.com/inward/record.uri?eid=2-s2.0-33748698292&partnerID=40&md5=a49e329138f2f51d8cc3b46b3a712e49.
[19] Marques, A. et al., Virtual and digital outcrops in the petroleum industry: A systematic review. *Earth-Science Rev.*, **208**, 103260, 2020. DOI: 10.1016/j.earscirev.2020.103260.

[20] Liu, S., Yang, X. & Zhou, X., Development of a low-cost UAV-based system for CH_4 monitoring over oil fields. *Environ. Technol.*, **42**(20), pp. 3154–3163, 2021. DOI: 10.1080/09593330.2020.1724199.
[21] Stokes, S. et al., Reconciling multiple methane detection and quantification systems at oil and gas tank battery sites. *Environ. Sci. Technol.*, **56**(22), pp. 16055–16061, 2022. DOI: 10.1021/acs.est.2c02854.
[22] Cho, J., Lim, G., Biobaku, T., Kim, S. & Parsaei, H., Safety and security management with unmanned aerial vehicle (UAV) in oil and gas industry. *Procedia Manuf.*, **3**, pp. 1343–1349, 2015. DOI: 10.1016/j.promfg.2015.07.290.
[23] Shukla, A., Xiaoqian, H. & Karki, H., Autonomous tracking and navigation controller for an unmanned aerial vehicle based on visual data for inspection of oil and gas pipelines. *Int. Conf. Control. Autom. Syst.*, pp. 194–200, 2016. DOI: 10.1109/ICCAS.2016.7832320.
[24] Sayed, M., Nemitz, M., Aracri, S., McConnell, A., McKenzie, R. & Stokes, A., The limpet: A ROS-enabled multi-sensing platform for the ORCA hub. *Sensors*, **18**(10), p. 3487, 2018. DOI: 10.3390/s18103487.
[25] Fox, T.A., Barchyn, T.E., Risk, D., Ravikumar, A.P. & Hugenholtz, C.H., A review of close-range and screening technologies for mitigating fugitive methane emissions in upstream oil and gas. *Environ. Res. Lett.*, **14**(5), 053002, 2019. DOI: 10.1088/1748-9326/ab0cc3.
[26] Buschinelli, P. et al., Targetless photogrammetry network simulation for inspection planning in oil and gas industry. *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, **5**(1), pp. 285–291, 2020. DOI: 10.5194/isprs-annals-V-1-2020-285-2020.
[27] Dubucq, D., Turon, L., Blanco, B. & Bideaud, H., Earth observation remote sensing for oil and gas: A new era. *Lead. Edge*, **40**(1), pp. 26–34, 2021. DOI: 10.1190/tle40010026.1.
[28] Trujillo, M., Martínez-de Dios, J., Martín, C., Viguria, A. & Ollero, A., Novel aerial manipulator for accurate and robust industrial NDT contact inspection: A new tool for the oil and gas inspection industry. *Sensors*, 19(6), p. 1305, 2019. DOI: 10.3390/s19061305.
[29] Baskaran, V., Singh, S., Reddy, V. & Mohandas, S., Digital assurance for oil and gas 4.0: Role, implementation and case studies. 2019. DOI: 10.2118/196292-MS.
[30] Abukova, L.A., Dmitrievsky, A.N., Eremin, N.A. & Martynov, V.G., On the key role of science and education in the digital modernization of the oil and gas industry of the countries of the Eurasian Economic Union. *News Tula States Univ. Sci. Earth*, **2**, pp. 187–202, 2018.
[31] Alanazi, A.M., Almutairi, N.R., Aseery, A.A., Al Buraiky, S.M., Rafie, A.M. & A.A., Private 5G practice in oil and gas industry, 2022. DOI: 10.2118/210975-MS.
[32] Garcia-Pineda, O. et al., Classification of oil spill thicknesses using multispectral UAS and satellite remote sensing for oil spill response. *IGARSS 2019: 2019 IEEE International Geoscience and Remote Sensing Symposium*, Jul., pp. 5863–5866, 2019. DOI: 10.1109/IGARSS.2019.8900170.
[33] English, J., Zakharov, I., Warren, S., Puestow, T. & Brown, R., Characterization of spectral signatures of various oils on water, 2021.
[34] Andreotti, M. et al., ARIEL: An autonomous robotic system for oil spill detection. *Offshore Technology Conference*, D011S006R007, 2020.
[35] Ravikumar, A.P. et al., Single-blind inter-comparison of methane detection technologies: Results from the Stanford/EDF mobile monitoring challenge. *Elem. Sci. Anthr.*, **7**, 2019. DOI: 10.1525/elementa.373.

[36] Shahtakhtinskiy, A. & Khan, S., 3D stratigraphic mapping and reservoir architecture of the Balakhany Suite, Upper Productive Series, using UAV photogrammetry: Yasamal Valley, Azerbaijan. *Mar. Pet. Geol.*, **145**, 105911, 2022. DOI: 10.1016/j.marpetgeo.2022.105911.
[37] Bella, S., Belalem, G., Belbachir, A. & Benfriha, H., HMDCS-UV: A concept study of hybrid monitoring, detection and cleaning system for unmanned vehicles. *J. Intell. Robot. Syst.*, **102**(2), p. 44, 2021. DOI: 10.1007/s10846-021-01372-8.
[38] Li, Q., Ban, X. & Wu, H., Design of informationized operation and maintenance system for long-distance oil and gas pipelines. *Proceedings of the 3rd International Conference on Computer Science and Application Engineering*, Oct., pp. 1–5, 2019. DOI: 10.1145/3331453.3360969.
[39] Johansen, K., Taking subsea operations to the next level by applying machine vision to perform autonomous inspections. 2022. DOI: 10.4043/32012-MS.
[40] Alharam, A., Almansoori, E., Elmadeny, W. & Alnoiami, H., Real time AI-based pipeline inspection using drone for oil and gas industries in Bahrain. *2020 Int. Conf. Innov. Intell. Informatics, Comput. Technol. 3ICT 2020*, 2020. DOI: 10.1109/3ICT51146.2020.9312021.
[41] Hijji, M., Using artificial intelligence to protect, detect and mitigate oil and gas sectors of KSA from drones and missiles assaults. *2022 2nd International Conference on Computing and Information Technology (ICCIT)*, Jan., pp. 335–339, 2022. DOI: 10.1109/ICCIT52419.2022.9711599.
[42] Al Hosani, A., Alhmoudi, F., Almurshidi, M. & Meribout, M., Real-time gas leak detection and localization using SWIR camera. *Infrared Sensors, Devices, and Applications IX*, Sep., p. 32, 2019. DOI: 10.1117/12.2537924.
[43] Stupnikov, A.V., Klimov, E.I. & Maiurova, A.S., Receiver unit calibration of the optoelectronic lading system of an air drone used to monitor gas pipelines of the West Siberia gas field. *2018 Int. Conf. Laser Opt.*, p. 2020, 2017.
[44] Vytovtov, A.V., Korolev, D.S., Barankevich, R.V., Sitnikov, I.V. & Russkikh, D.V., Mathematical model for an identifying flaming combustions and accidents by an unmanned aerial vehicle at oil and gas industry facilities. *IOP Conf. Ser. Mater. Sci. Eng.*, **919**(5), 2020. DOI: 10.1088/1757-899X/919/5/052032.
[45] Faksness, L.-G. et al., Offshore field experiments with in-situ burning of oil: Emissions and burn efficiency. *Environ. Res.*, **205**, 112419, 2022. DOI: 10.1016/j.envres.2021.112419.
[46] Benzon, H.H., Chen, X., Belcher, L., Castro, O., Branner, K. & Smit, J., An operational image-based digital twin for large-scale structures. *Appl. Sci.*, **12**(7), 2022. DOI: 10.3390/app12073216.
[47] Dujoncquoy, E. et al., UAV-Based 3D outcrop analog models for oil and gas exploration and production. *Int. Geosci. Remote Sens. Symp.*, **2019**, pp. 6791–6794, 2019. DOI: 10.1109/IGARSS.2019.8900176.
[48] Alum, M. & Eze, T., The new faces of corrosion and damage detection in oil and gas facilities: A brief of what has worked so far and how it can work for you. *Soc. Pet. Eng.: SPE Niger. Annu. Int. Conf. Exhib. 2020, NAIC 2020*, 2020. DOI: 10.2118/203745-MS.
[49] Masoni, I., Pagliccia, B. & Thalmann, G., The use of drones for innovative seismic acquisition: A change of paradigm for HSE. *Int. Pet. Technol. Conf. 2019, IPTC 2019*, 2019. DOI: 10.2523/iptc-19258-ms.

[50] Zhai, X., Liu, K., Nash, W. & Castineira, D., Smart autopilot drone system for surface surveillance and anomaly detection via customizable deep neural network. *Int. Pet. Technol. Conf. 2020, IPTC 2020*, 2020. DOI: 10.2523/iptc-20111-ms.
[51] Fox, T.A., Hugenholtz, C.H., Barchyn, T.E., Gough, T.R., Gao, M. & Staples, M., Can new mobile technologies enable fugitive methane reductions from the oil and gas industry? *Environ. Res. Lett.*, **16**(6), 2021. DOI: 10.1088/1748-9326/ac0565.
[52] da Silva, Y.M.R. et al., Computer vision based path following for autonomous unmanned aerial systems in unburied pipeline onshore inspection. *Drones*, **6**(12), pp. 1–19, 2022. DOI: 10.3390/drones6120410.
[53] Sheveleva, A.V. & Avdeeva, E.A., *Foreign and Russian Experience in the Application of Climate Resilient Digital Technologies in the Oil and Gas Industry*, pp. 287–297, 2023. DOI: 10.1007/978-3-031-28457-1_30.
[54] Ghorbani, Z. & Behzadan, A.H., *Identification and Instance Segmentation of Oil Spills Using Deep Neural Networks*, 2020. DOI: 10.11159/iceptp20.140.
[55] Marcellino, G.C., Buschinelli, P., Santos, J.M., Marinho, C. & Pinto, T.L.F.C., Assessment of close-range photogrammetric parameters for external defects quantification in pipelines in oil industry, 2019. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85148894770&partnerID=40&md5=d651646a34151642fffcc78959bb54f5.