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Integrating artificial intelligence in unmanned vehicles: navigating uncertainties, risks, and the path forward for the fourth industrial revolution

Md Altab Hossin [1✉], Songtao Yin[2], Ruibo Dan[3] & Lie Chen[1]

Artificial intelligence (AI) has been a field of research for nearly 80 years. Relevant technologies and products have widely been used in our daily lives, scientific research, and military fields. AI is a technology that is likely to be the strongest driving force of the 4th industrial revolution. The widespread adoption of AI requires collaborative efforts across various sectors. However, frequent accidents involving unmanned vehicles (UVs) have exposed loopholes, uncertainties, and risks in the rapid development of AI. This study analyzes the assessment phases of AI for UVs, technological advancements, uncertainties, and risks and proposes strategies for moving forward. First, we extract the hidden patterns of uncertainty and risk associated with AI and then provide rational suggestions for the development of AI based on UVs by using natural language processing and data visualization techniques. Results show that real-time detection, processing, prediction, and decision for UVs are of utmost importance and need to be developed with the integration of AI for greater adoption. The assessment phases include detection, process, prediction, decision, and performance, each playing a crucial role in enhancing UV capabilities. However, despite rapid technological advancements in AI for UVs, uncertainties and risks persist, such as economic implications, ethical dilemmas, and safety concerns. Strategic roadmaps, collaboration among industry and regulators, public engagement initiatives, ethical AI frameworks, and innovation ecosystems are proposed as strategies to address current challenges and foster a sustainable integration of AI in UVs.

Introduction

Artificial Intelligence (AI), also known as machine intelligence, differs from the natural intelligence exhibited by humans and animals. In computer science, AI research is defined as the study of "intelligent agents", devices that can perceive situations and take actions to achieve their goals successfully (Bathla et al. 2022). In essence, when a machine mimics human-like functions such as learning and problem-solving, it is considered AI (Ernest and Carroll, 2016). AI is one of the fastest-growing sectors, enhancing effectiveness and

[1]School of Innovation and Entrepreneurship, Chengdu University, No. 2025, Chengluo Avenue, 610106 Sichuan, Chengdu, P.R. China. [2]Office of International Cooperation and Exchange, School of International Education, Chengdu Aeronautic Polytechnic, No. 699, East 7th Road, Checheng, 610100 Chengdu, Longquanyi District, P.R. China. [3]London School of Economics and Political and Political Science, Department of Philosophy, Logic and Scientific Method, Houghton Street, London WC2A 2AE, UK. ✉email: altabbd@cdu.edu.cn

efficiency across a wide array of markets. It has revolutionized technological development in various sectors, including the economic, social, and industrial realms (Rauf et al. 2024). For example, Europe is home to a robust automotive industry (Bikeev et al. 2019), where companies like Volvo and Mercedes-Benz are at the forefront of integrating AI into vehicle safety and navigational systems. Asia has rapidly become a hub for AI-based technology and innovation, especially in China and Japan. Significant investments by corporations such as Baidu and Toyota in AI research and autonomous driving technologies are notable examples.

Automated vehicles can revolutionize how we travel in many ways, including reducing the number of human-caused accidents on the road (Czech, 2024). Unmanned vehicles (UVs) equipped with AI's real-time data processing and decision-making capabilities can respond more rapidly and accurately than human drivers in road scenarios, making them an excellent way to increase traffic flow, reduce congestion, and enhance transportation infrastructure performance (Oruc, 2022). Through coordinated vehicle-to-vehicle and vehicle-to-infrastructure communication, UVs can maintain optimal speeds, decrease stop-and-go traffic patterns, and contribute to smoother, more predictable flows of traffic, which not only benefits the driving experience (Lu and Dai 2024) but also promotes environmental sustainability by decreasing fuel usage and emission production (Nikitas et al. 2020).

With the constant development of AI-related sciences and technologies, machines are endowed with more capabilities (Gallab et al. 2024). However, many automated devices are regarded as "smart" products only for a short period before being phased out. AI might be everywhere but is not yet fully developed. The pursuit of high standards has always driven the rapid development of AI-related sciences and technologies. As of 2017, the acknowledged AI technologies mainly include human speech understanding and recognition, high-level competition in strategic games (e.g., chess, Go), UVs, military simulation, and others (Hu et al. 2022).

An unmanned vehicle (also known as an autonomous vehicle or self-driving vehicle) is a kind of vehicle that can perceive its surroundings and navigate without human intervention (Thrun 2006; Mourtzis et al. 2024). It combines various technologies to help perceive its surroundings, including radar, lasers, the global positioning system (GPS), distance measurement, and computer vision (Pajares, 2015). It processes sensory information through an advanced control system to recognize appropriate routes from GPS data, obstacles, and other relevant signs. It has numerous advantages, such as lowering infrastructure costs, enhancing security and flexibility, improving passenger satisfaction, decreasing traffic accidents, increasing traffic efficiency and flow, and decreasing vehicle-related crimes (Bathla et al. 2022). Moreover, it can provide more favorable transportation for children, the elderly, the disabled, and the poor; alleviate driving fatigue during travel and reduce high fuel consumption caused by inappropriate driving; enhance parking efficiency; and lower pressures on parking lot construction. Finally, it can facilitate the development of a sharing economy (Xue and Pang, 2022).

Recent research has investigated many aspects of AI incorporation into UVs, from technical issues and solutions (sensor fusion, decision-making algorithms) to policy and social implications (Figueroa et al. 2023; Al Radi et al. 2024). Research undertaken to gauge public opinion about autonomous vehicles (AVs) provided greater insights into this complex realm of excitement, doubt, and anxiety (Howard, 2014). Perko (2021) conducted an in-depth examination of moral dilemmas presented by AVs under crisis circumstances and proposed an open procedure for ethical decision-making. Taeihagh (2021) conducted research on public trust in AVs. These findings demonstrated how AI decision-making processes must include clear accountability standards to gain widespread acceptance. Golbabaei et al. (2021) investigated how UVs affect urban mobility and infrastructure, including ways that UVs may assist in alleviating congestion while simultaneously increasing road safety in urban settings. Researchers found that increasing the use of UVs could result in substantial shifts in traffic flow patterns, necessitating significant investment to realize their full benefits (Yoganathan and Osburg, 2024). Recent research has focused on addressing regulatory compliance challenges and developing comprehensive policies to ensure the safe integration of AVs into existing transportation systems (Atakishiyev et al. 2024). Ribeiro et al. (2022) conducted extensive research on AV regulations across various countries and identified any gaps or inconsistencies that impede coordination or standardization. They advocated for a framework that addresses privacy standards, security concerns, and cybersecurity threats.

Technological development and advancement have undoubtedly brought significant progress, yet AI implementation in UVs still faces significant obstacles due to technological, ethical, and legal concerns (Bikeev et al. 2019; Xue and Pang 2022; Zhai, 2024). One of the main issues associated with AV development is the creation of robust security measures to defend systems against cybercrime (Al Radi et al. 2024). As AI becomes an ever more integral component of vehicle decision-making processes, its effects on privacy, accountability, and ethical concerns must be carefully considered. Guidelines need to be established to address these issues efficiently and legally (Nikitas et al. 2020). Implementing complex legal frameworks, such as those outlined by the General Data Protection Regulation (GDPR), presents autonomous vehicle manufacturers with unique data processing challenges. Controller and processor obligations pose distinct challenges (Bathla et al. 2022).

Though many relevant articles have been published, there is an inability to integrate technical aspects with ethical considerations and policies into a comprehensive understanding. This issue is further compounded by an absence of laws specifically targeting AI development and use on AVs that need immediate regulatory attention (Taeihagh, 2021). Further, even though advances in AI machines and machine-learning algorithms have allowed cars to adapt more quickly to real-world conditions, safety concerns, cybersecurity threats, and the lack of unifying regulations hinder widespread acceptance (Hu et al. 2022). Unfortunately, current literature does not adequately explore how these three spheres interact and impact one another or provide a comprehensive roadmap for understanding AI integration into UVs within an environment of the Fourth Industrial Revolution (4IR).

This study aims to address several research questions: (a) What are the current technological advancements and challenges in integrating AI into unmanned vehicles? (b) How do ethical considerations and public perceptions influence the development and acceptance of unmanned vehicles? (c) What policy and regulatory frameworks are necessary to support their safe and effective deployment?

By offering an in-depth review of AI applications in AVs, this research intends to explore the uncertainties and risks associated with AVs during the 4IR. It contributes to existing knowledge by presenting an integrative perspective on AI for AVs, encompassing ethical, technical, policy, and multidimensional debates. Through a combination of case studies and theoretical analysis, this study proposes an alternative path toward creating and utilizing automated vehicles, making it a truly holistic investigation.

The remainder of the article is divided into various sections. The second section describes the Methodology that outlines the systematic review process based on PRISMA guidelines as well as

Table 1 Research protocol.

Items	Description
Research problem	(a) What are the current technological advancements and challenges in integrating AI into unmanned vehicles? (b) How do ethical considerations and public perceptions influence the development and acceptance of unmanned vehicles? (c) What policy and regulatory frameworks are necessary to support their safe and effective deployment?
Databases	Web of Science
Search terms	Artificial intelligence, unmanned vehicles, autonomous vehicles, uncrewed vehicles, driverless vehicles
Time frame	Studies published until September 15, 2024
Search strategy	A comprehensive search using a combination of keywords and Boolean operators
Inclusion criteria	Peer-reviewed articles focusing on the Uncertainty, Risks, and Suggestion of AI from the Accidents of Unmanned Vehicles
Exclusion criteria	Non-English articles, incomplete texts, preprint, studies not focusing on the specified themes
Types of studies	Review, empirical, and theoretical studies addressing the impact of science fiction movies on AI
Geographical scope	No geographical limitation
Language	Studies published in English
Data extraction	Standardized form capturing authors, year of publication, study context, methodologies, and main findings
Quality assessment	Methodological rigor, clarity of reporting, and relevance to the review questions
Analytical approach	Thematic analysis to distinguish key themes and patterns

Table 2 Criteria of analysis for document review.

Criteria	Description
Key phrases selection	Identifying keywords relevant to the research goals, such as artificial intelligence, unmanned vehicles, autonomous vehicles, uncrewed vehicles, driverless vehicles, risk, uncertainty, suggestion, and development.
Term sheet development	Creating a term sheet listing themes and sub-themes to guide the literature analysis.
Document reading strategy	Each document was cross checked by two expert reviewers to understand the narrative and find sections resonating with the term sheet.
Codification of terms	Employing thematic analysis, categorizing literature excerpts under relevant themes using the term sheet, and refining themes throughout the review.

the process of thematic analysis. The third part discusses the outcome, which includes technological advances, focusing on sensors, decision-making systems, and the integration of communication. The fourth section provides a debate that covers uncertainties and risks, discussing the challenges of technological uncertainty security concerns, as well as the legal implications. This section also outlines how to take the path forward, proposing strategic pathways, collaboration between industry regulators as well as ethical AI frameworks. The final section concludes the article with a synopsis of findings, suggestions as well as limitations and research direction.

Methodology

Research design. This research employs a systematic review method to investigate how Artificial Intelligence (AI) integrates into UVs as part of the 4IR. Adhering to the guidelines (Moher et al. 2009) of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), four key steps were followed during this investigation - identification, screening assessment of eligibility, inclusion as well as development of a specific research protocol that streamlines this review procedure (Table 1). Subsequently, a thematic analysis was undertaken to extract information from the selected documents.

Search string. A search string was developed to collect relevant research on AI integration into unmanned vehicles using terms such as autonomous vehicles, unmanned vehicles, artificial intelligence integration, and 4IR.

Search strategy. A literature-based search was performed using the Web of Science database due to its wide coverage of quality and multidisciplinary research. Search terms have been selected based on importance and relevancy to this issue, with special consideration given to articles only written in English.

Inclusion and exclusion criteria. This list was composed solely of peer-reviewed papers that explore AI integration into AVs, providing information on issues in technology, policy implications, and societal effects. Non-English text articles or research that was not directly focused on AI integration into AVs were excluded from consideration.

Criteria of analysis for document review. The document review aims to provide a comprehensive and adaptable analysis, as shown in Table 2. Key phrases are chosen according to research objectives. A term sheet is then created to facilitate the investigation of subthemes and themes, with two experts conducting document analyses in-depth for any documents identified as potentially relevant topics for AI integration in unmanned vehicles. The thematic analysis allows the identification and narrowing down of topics as well as ensures there is comprehensive knowledge regarding AI integration implications in unmanned vehicles.

Qualitative aspects of analysis. Thematic analysis was employed to uncover patterns related to AI integration into AVs. The process began with familiarizing ourselves with the data, creating initial codes, identifying themes, assessing coherence between themes, and reviewing the results in relation to our research questions before synthesizing the findings.

Data extraction and synthesis. Data selection and extraction were conducted using a standard form to record key details about authors and publication years, study context, methods used, main

Table 3 The term sheet for thematic analysis.

Theme	Sub-themes	Remarks	Sources
Assessment phases	Detection phase Process phase Prediction phase Decision phase Performance phase	Explore the sequential phases involved in assessing and managing tasks or situations, from initial detection to final performance evaluation.	Sandino et al. (2021) Ulusoy et al. (2023) Huang et al. (2021) Sun et al. (2015) Hossain et al. (2022)
Technological advancements in AI for UVs	Sensor technologies, Machine learning algorithms, Decision-making systems, Integration of AI with Vehicle-to-Everything (V2X) communication, Advances in computational power and data analytics	Explore advancements in AI technologies that enhance the capabilities of autonomous vehicles.	Taeihagh (2021) da Silva et al. (2022) Kruger and Steyn (2024) Garikapati and Shetiya (2024) Gallab et al. (2024)
Uncertainties	Technological unpredictability, AI behavior in novel scenarios, Dependence on data quality, Integration challenges with existing infrastructure, Legal and ethical precedents	Explore the uncertainties surrounding AI integration in AVs, including technological, legal, and ethical aspects.	Cox (2020) Hartmann et al. (2023) Gallab et al. (2024)
Risks	Cybersecurity threats, Liability in accidents, Misuse of AI technologies, System failures and malfunctions, Negative societal impacts	Investigate potential risks associated with AI in AVs, focusing on security, liability, and societal concerns.	Bogumil and Vlasov (2018) Bikeev et al. (2019) Galaz et al. (2021) Namian et al. (2021) Peng et al. (2024)
Path forward	Strategic roadmaps for AI in AV development, collaboration between industry and regulators, Public engagement and education, Ethical AI frameworks, Innovation ecosystems for AV technologies	Outline strategies and initiatives for navigating the future of AI in AVs, emphasizing ethical, regulatory, and societal considerations.	Dietterich (2017) Tahir et al. (2023) Milidonis et al. (2023) Nowakowski and Kurylo (2023)

results, and main conclusions. This approach facilitated the rapid synthesis of the data.

Quality assessment. A quality evaluation was conducted to ascertain the reliability and validity of the studies included, with particular attention paid to methodological validity and relevance. Any study failing to meet standard quality requirements was dismissed.

Thematic analysis. Thematic analysis was used to analyze data compiled from studies that study AI integration within AVs, as outlined in Table 3. This qualitative method helps identify, analyze, and report patterns (themes) within data. The process is repeated until comprehensive knowledge is gained regarding the complexity and implications of AI integration. The following steps establish its implementation.

Acquaintance with the data. To gain an in-depth knowledge of the data collection, the first time, through an extensive reading and writing exercise designed to familiarize one with their collected information and expose any key patterns or insights that may pertain to AI incorporation into UVs.

Generation of initial codes. An intensive code-making effort were taken place to categorize and organize it based on interesting features for AI and UVs when creating initial codes for data. This involved gathering relevant information from each code within the data.

Finding themes. Each code was organized into different themes with accompanying data collected on that theme. This process helped to uncover patterns across all codes while providing valuable information.

Review of themes. Coherence between themes and their coded data were assessed, and an "idea map" was created to graphically represent both analysis results as well as any connections among themes.

Naming and delineating themes. Each theme was defined clearly and named, providing detailed descriptions while outlining which factors constitute its boundaries.

Producing the report. Finally, the report summarized and linked the results of the thematic analysis with research questions related to AI for AVs. It offered fresh insights into the application of AI in AV control systems.

Results

Content preprocessing, analysis, and statistics of selected documents

Document selection. The document selection was carried out using the PRISMA flow diagram, as illustrated in Fig. 1. In the initial phase, an exhaustive literature search for studies related to AI integration into unmanned vehicles (UVs) identified 318 records through database searches. During the screening phase, titles, keywords, and abstracts were carefully evaluated, resulting in the exclusion of 154 documents for various reasons, such as being off-topic, missing data, or lacking full-text access. After eliminating duplicate records, 164 unique records were retained for further consideration. Each underwent an eligibility assessment process, where full-text documents were carefully evaluated for relevance and depth, specifically focusing on uncertainty, risks, and the path forward regarding AI in UVs during the 4IR. Following this rigorous screening process, 73 documents were deemed eligible for inclusion in the analysis. At the final inclusion stage, 24 documents were eliminated because they did not explicitly focus on unmanned vehicles, autonomous vehicles, or

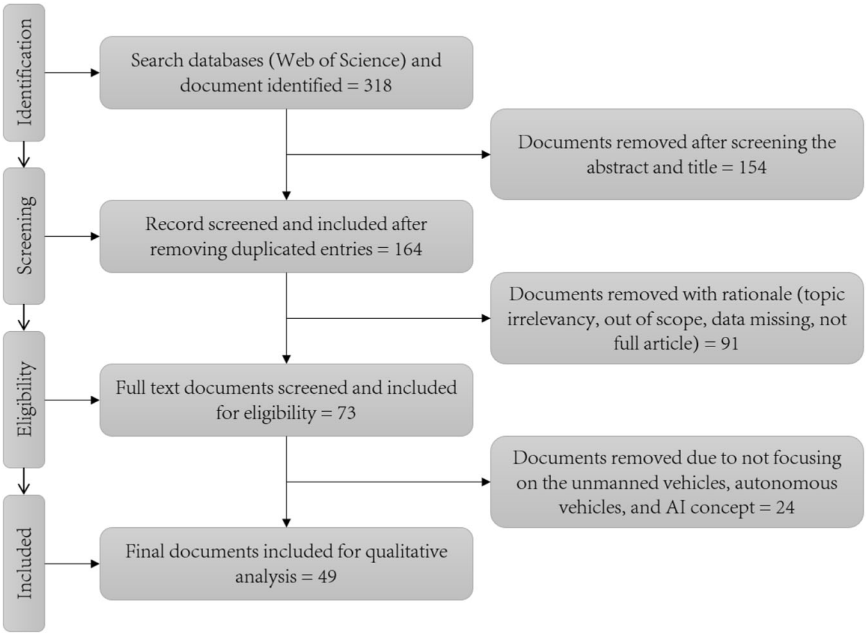

Fig. 1 Selection of documents by PRISMA approach. This figure outlines the document selection process using the PRISMA flow diagram. It shows how the documents are extracted in various steps, including identification, screening, eligibility, and final inclusion of the documents in the analysis.

AI concepts, narrowing the selection to a highly relevant set of studies. After meeting the stringent criteria set for this study, 49 documents were carefully selected for qualitative analysis, fulfilling the rigorous standards. These documents covered essential aspects of thematic exploration and were instrumental in understanding AI integration within UVs, its multifaceted uncertainties and risks, and creating an optimal path forward during the technological revolution.

Content preprocessing. Unstructured contents from selected documents were preprocessed (i.e., data completion, noise reduction, transformation, reduction, and validation) using Python and natural language processing (NLP) techniques to feed for reliable analysis, visualization, and scientific measurements. Missing data (i.e., publication year, keywords, abstracts) was handled in the data completion stage. Text cleaning (i.e., special characters, white spaces) and noisy data were handled in the noise reduction process. In the process of transformation, contents were tokenized to feed for the corpus of each selected document in lowercase format and lemmatized (e.g., models converted to models) to unify the tokens. In the process of reduction, unnecessary and redundant words, including the keywords used for searching documents (i.e., AI, artificial intelligence, autonomous vehicles, driving) were removed by using a stop words list. Finally, contents were validated in each corpus by manually checking in visualization and counting in frequency statistics.

Descriptive statistics of the selected documents. Figure 2 depicts increased academic interest surrounding AI research for UVs over the last decade, evidenced by increased literature production. Starting in scattered reports in 2000 before producing one single research study in 2004, publication frequency remains low, signaling early stages of investigation. However, in 2019, the number of documents increased significantly, indicating an increasing interest in this topic. 2020–2022 was marked by a steady rise in publications, with 11 new documents appearing by 2022; academic papers continued this upward trend further, with 12 papers

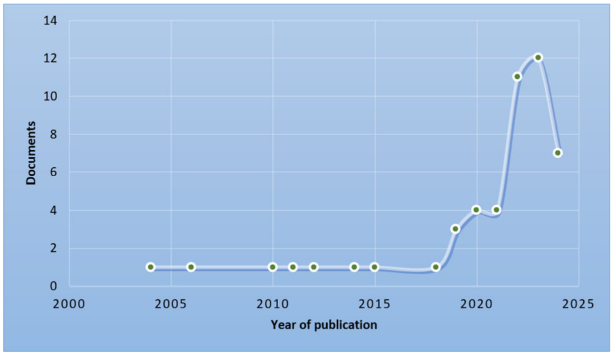

Fig. 2 Distribution of documents based on year. This figure shows the distribution of documents over the year and demonstrates a rising awareness among both academic and industrial communities regarding AI's critical role in UVs, particularly within the context of 4IR.

published during 2023, providing evidence of growing recognition of AI integration into autonomous systems as a topic worthy of greater study and discussion.

This trend demonstrates a rising awareness among both academic and industrial communities regarding AI's critical role in UVs, particularly within the context of 4IR. An increase in research between 2022 and 2023 could signal an important moment in unmanned system AI applications that are aligned with technological advancement and the growing conversation surrounding risks and uncertainties management. Studies conducted in this field provide a window into what lies ahead for AI applications within UVs to create a secure path toward their future use.

Network of the keyword concepts. Network visualizations created with VOS Viewer were instrumental in unraveling the complex topic of relationships among key concepts of AI in UVs (Fig. 3). The likelihood of two concepts being related increases with the number of shared references, signifying their equal importance within the research landscape. VOS viewer compiled these relationships into co-occurrence maps before creating two-

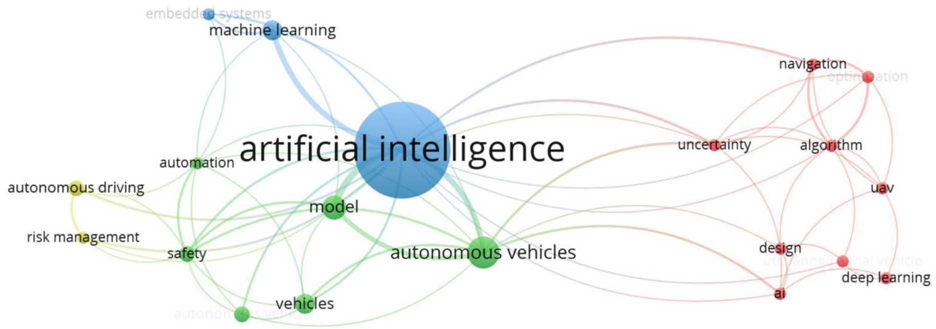

Fig. 3 Network visualization of the relevant concepts. This figure illustrates the keywords most frequently used during scholarly analysis, unraveling the complex topic of relationships among key concepts of AI in UVs and showing their association of co-occurrence strength in the reviewed literature using VOS Viewer.

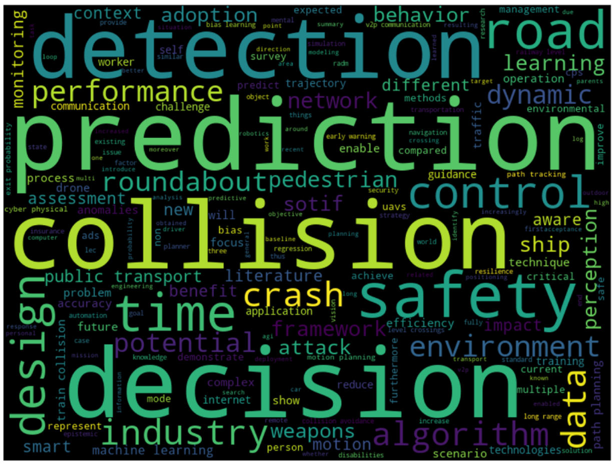

Fig. 4 Word cloud for the role of AI role in risk and uncertainties. This figure demonstrates the AI's role for the risk and uncertainties in UVs using Word Cloud. It shows the strength of each term and distinguishes that detection, decision, prediction, collision, and performance are the most important terms.

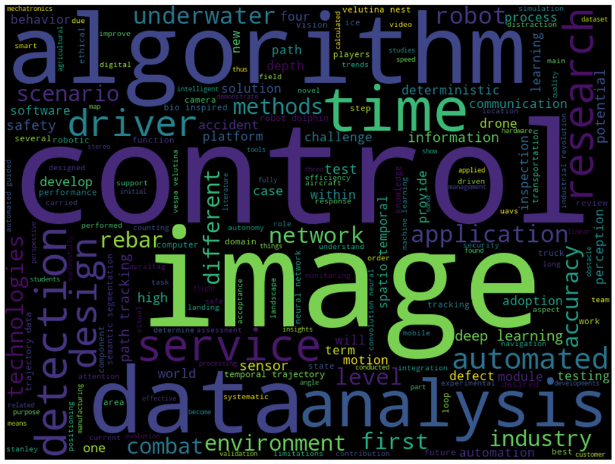

Fig. 5 Word cloud for the development and suggestions of AI role in UVs. This figure demonstrates the AI's role for development and suggestions in UVs using Word cloud. It shows the strength of each term and distinguishes that image, control, automated algorithm, data, driver, detection, and services are the most important terms.

dimensional visual maps showing groups of related terms (Zeng et al. 2022). Each cluster provides a visual representation of topics typically explored together, and proximity to the map indicates more of a thematic relationship, making it easy to spot closely related concepts within research fields. Within "Integrating Artificial Intelligence in Unmanned Vehicles," network visualization maps key phrases like autonomous car, unmanned aerial vehicle, deep learning security, and risk assessment, showing their strong interconnections.

Figure 3 also illustrates the keywords most frequently utilized during scholarly analysis, showing their frequency in the reviewed literature. This visualization not only showcases the significance of AI but also illuminates an emerging debate regarding safety, decision-making, and risk management, as well as the larger implications of machine learning-based automation within unmanned systems. These visual maps help pinpoint emerging research areas and highlight those requiring further investigation, particularly in a rapidly advancing field marked by uncertainty and risks.

Visualization and frequency statistics of meaningful words. Clean unstructured text from selected documents was visualized using the Python WordCloud library to extract, view, and distinguish the intensity of the frequent, prominent, and meaningful words in

Table 4 Display of frequency statistics for the top 20 words.

SL	Words	Word frequency	Term frequency	Document frequency	TFIDF
1	learn	86	0.012045	22	0.00911
2	control	62	0.010264	18	0.009724
3	time	50	0.00672	22	0.005083
4	data	47	0.006728	22	0.005088
5	design	47	0.007615	22	0.005759
6	decision	44	0.006397	13	0.008014
7	network	44	0.00598	16	0.00633
8	algorithm	43	0.005769	15	0.006457
9	safety	40	0.005483	14	0.00649
10	collision	37	0.005812	8	0.009848
11	tracking	37	0.00522	8	0.008846
12	drive	33	0.004476	10	0.006687
13	path	33	0.004745	7	0.0086
14	industry	29	0.004269	10	0.006378
15	analysis	27	0.003436	12	0.004559
16	automate	27	0.003109	10	0.004645
17	driver	27	0.003273	5	0.006874
18	image	27	0.003367	7	0.006102
19	process	26	0.003688	15	0.004128
20	prediction	25	0.003678	6	0.007157

the content. Figure 4 distinguished that detection, decision, prediction, collision, and performance were the most important terms for the role of AI in UVs to address risk and uncertainties, while Fig. 5 distinguished that image, control, automated algorithm, data, driver, detection, and services are the most important terms for the development and suggestions of AI based on the applications of UVs, respectively.

Table 4 presents the Word Frequency, Term Frequency, Document Frequency, and Term Frequency-Inverse Document frequency (TF-IDF) to show the relevancy of meaningful words using statistical data (Hossin et al., 2023; Zhang et al., 2011). Term Frequency-Inverse Document Frequency (TF-IDF) is computed to analyze the relevance of words in each document extracted from the reviewed literature. Term Frequency (TF) refers to the number of times a term appears in a document, normalized by the total number of terms in that document, reflect the term's importance in the specific context. TF-IDF, on the other hand, adjusts the frequency by considering how common or rare the term is across all documents in the dataset. This technique involves multiplying TF with inverse frequency of document (IDF), with IDF being defined as the logarithm (with base 2) ratio between the total document count divided by the number of documents containing the term. This process also underpinned the validation process by finding the frequency statistics, redundant, and outlier keywords. Finally, a comparison of term frequency and TF-IDF for the top 20 words was carried out using the bar chart of these two parameters in Fig. 6.

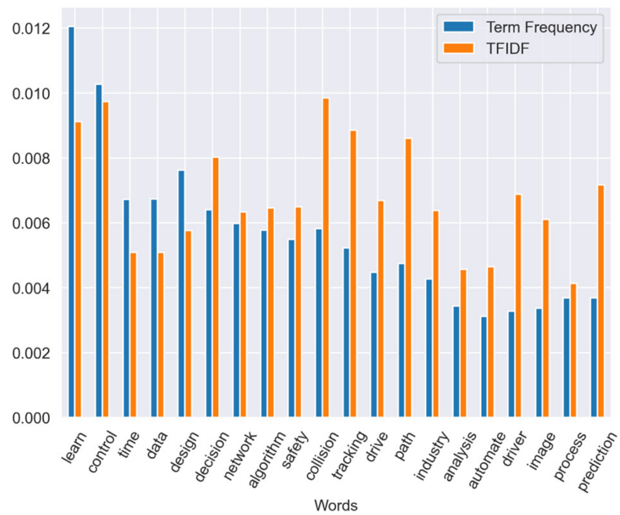

Fig. 6 Bar chart of top 20 words for term frequency and TF-IDF. This figure demonstrates the bar chart for term frequency and TF-IDF (Term Frequency-Inverse Document Frequency) of the top 20 words. It shows that collision, control, learn, path, tracking, decision, and prediction are the most relevant terms, comparing their respective term frequency.

Synthesis results

Assessment phase of AI for unmanned vehicles (UVs). Table 5, the thematic analysis provides a concise snapshot of the results from the assessment phase. This phase shows the systematic progress through its various stages for integrating and using AI technologies in AVs. Furthermore, this approach illustrates advances in AI technologies while simultaneously showing methods used to assess and increase the capabilities of these AVs.

Each phase plays an essential part in ensuring UVs operate safely and effectively using advancements in AI and sensor technologies. These phases also emphasize the importance of reducing risks and managing uncertainties associated with autonomous navigation, providing valuable starting points for further research into AI developments related to the 4IR.

Technological advancements of AI for UVs. AI technology has seen massive advancements recently, contributing significantly to the advancement and security of UVs. Each topic in Table 6 represents an integral sector where AI technology can significantly advance UVs' capabilities while at the same time mitigating risks associated with autonomous navigation. Sensor technologies and machine-learning algorithms have become essential tools for accurately observing and comprehending one's environment (Zhao et al. 2024). Decision-making systems and their integration with AI and V2X communications enable vehicles to make secure, well-informed choices more efficiently. Computing technology advances and data analytics ensure that these complex processes can be completed in real-time, which is particularly important given the fast-paced nature of motoring (Lu and Dai, 2024). The identified technologies offer extensive details on each technological advancement that is contributing to full AVs under the 4IR framework.

Table 5 Synthesis of assessment phase in AI for UVs.

Sub-themes	Description	Implications for assessment	Sources
Detection phase	Advanced sensors (LiDAR, radar, cameras) combined with pattern recognition, machine learning, and deep learning algorithms detect environmental elements.	Sets the foundational layer for AI to analyze and respond to surroundings accurately, ensuring initial recognition of obstacles and road conditions.	Ulusoy et al. (2023) Kim et al. (2023) Winkle et al. (2018)
Process phase	AI processes the detected information, utilizing algorithms and computational models to interpret data from sensors and V2X communication.	Enhances the vehicle's understanding of its environment, allowing for a comprehensive assessment of traffic patterns and potential hazards.	Pan et al. (2022) Ma et al. (2020) Gallab et al. (2024)
Prediction phase	AI not only predicts real-time movements but also forecasts future movements of surrounding vehicles and pedestrians using deep learning and pattern analysis.	Enables AVs to anticipate potential obstacles or changes, improving the decision-making process for safer navigation.	Sefidgar and Landry (2022) Candela et al. (2023) Garikapati and Shetiya (2024)
Decision phase	Decision-making systems in AVs analyze possible actions, employing AI to determine the best course of action based on safety and efficiency.	Critical for executing safe maneuvers and route adjustments, considering various factors, including traffic laws and passenger comfort.	Kim et al. (2023) Yang et al. (2023)
Performance phase	The performance of AVs is assessed through feedback loops, focusing on refining AI algorithms based on real-world data.	Allows for continuous improvement of AI systems, enhancing detection accuracy, prediction reliability, and decision-making effectiveness.	Ulusoy et al. (2023) Gallab et al. (2024) Garikapati and Shetiya (2024)

Table 6 Technological advancements in AI for unmanned vehicles.

Sub-themes	Description	Implications for navigating uncertainties and risks	Sources
Sensor technologies	Exploration of cutting-edge sensor technologies including LiDAR, RADAR, and cameras, crucial for environmental perception in AVs.	Enhances a vehicle's ability to perceive and interpret its surroundings, reducing uncertainty in navigation and safety.	Ulusoy et al. (2023) Kim et al. (2023) Winkle et al. (2018)
Machine learning algorithms	Execution of machine and deep learning algorithms for processing sensor data, predicting behaviors, and making driving decisions.	Improves decision-making in complex scenarios, adapting to novel situations with better accuracy.	Bergies et al. (2022) Sands (2020) Yang et al. (2023)
Decision-making systems	Development of AI-based decision-making systems that enable AVs to make efficient and real-time safe driving decisions.	Mitigates risks by ensuring reliable and ethical decision-making in unforeseen traffic conditions.	Pan et al. (2022) Yang et al. (2023) Kim et al. (2023)
Integration of AI with V2X communication	Integration of V2X communication with AI to enhance coordination among AVs and with infrastructure.	Reduces dynamic traffic environment uncertainties and improves overall efficiency and safety.	(Pan et al., 2022) (Cho et al., 2021)
Advances in computational power and data analytics	Advancements in computational capabilities and big data analytics to process vast amounts of data in real-time from AV sensors.	Supports the processing of complex data sets in real-time, enhancing the reliability and performance of AV systems.	Pan et al. (2022) Liu et al. (2014) Gallab et al, (2024) Mourtzis et al. (2024)

Table 7 Major uncertainties in unmanned vehicles.

Sub-theme	Description	Implications	Sources
Technological unpredictability	The behavior of AI in UVs can be unpredictable in novel scenarios not encountered during training, leading to unexpected outcomes.	Challenges in ensuring consistent and safe UVs operation across diverse and unforeseen driving conditions.	Milidonis et al. (2023) Sarathy et al. (2019)
AI behavior in novel scenarios	AVs may encounter situations that were not included in their training data, leading to uncertainty in how the AI will respond.	Potential safety risks when UVs face scenarios they cannot recognize or for which they have no programmed response.	Alshaafee et al. (2021) Figueroa et al. (2023) McLean et al. (2023)
Dependence on data quality	The effectiveness of AI systems in AVs extensively depends on the comprehensiveness and quality of the training data.	Inadequate or biased data can lead to misjudgments and errors in autonomous operation, affecting UV reliability.	Langford et al. (2023) Ren and Xi (2022)
Integration challenges with existing infrastructure	AVs must integrate with current transportation infrastructures, many of which were not designed with AVs in mind.	Difficulties in UVs navigation and communication within infrastructures lacking modernization to support autonomous technology, possibly leading to operational inefficiencies.	Bathla et al. (2022) da Silva et al. (2022)
Legal and ethical precedents	The legal framework and ethical guidelines for AVs are still under development, leading to uncertainties in liability and responsibility.	Ambiguities in regulation can hinder UV development and deployment, affecting public trust and acceptance.	Cervantes et al. (2020) (McLean et al. (2023)

Uncertainties in UVs. This study has highlighted several issues regarding AI use in UVs, particularly focusing on navigation and risk management concerns (Table 7). Due to AI technology's ever-evolving applications for autonomous cars, constant research and development efforts must be conducted to resolve them. Collaboration among technologists, policymakers, and law experts is essential for creating an AV framework that ensures their safe use in society.

Risks in UVs. The applications of UVs in different areas, such as transportation, construction, and surveillance, present several risks that must be considered before implementation. This section highlights major dangers associated with UVs using recent research findings to paint a clearer picture of potential issues and their implications for stakeholders in this industry. AI in UVs has many technological and operational benefits but also presents risks and challenges. Table 8 summarizes the risks that have arisen with the deployment of UVs, subthemes of risk or potential outcomes, and relevant research sources.

Risks of UVs highlight the need to address security, liability, system reliability, and social issues as part of an overall integration strategy for AI in UVs (Bathla et al. 2022). The mentioned sources provide foundational insights into these threats, guiding future research efforts aimed at mitigating negative consequences and ensuring the safe implementation of AI-driven UVs across industries.

Path forward for AI in UVs. The future of integrating AI into AVs involves a multifaceted approach focusing on technological, regulatory, societal, and ethical advancements (Xue and Pang, 2022). The path forward requires a collective effort from industry stakeholders, policymakers, and the public to navigate the complexities of safely and efficiently implementing AI-driven systems (Table 9).

Discussion

Assessment phases. AI can play a vital role in UVs through various phases, particularly five phases such as detection, process,

Table 8 Major risks in unmanned vehicles.

Sub-themes	Description	Possible Implications	Sources
Cybersecurity threats	UVs are susceptible to cyber-attacks, including GNSS spoofing, password cracking, and malware injection, posing significant risks to operational safety and data integrity.	Enhanced cybersecurity measures, including the use of solid-state storage components and additional sensors, are essential for mitigating these risks.	McLean et al. (2023) Saha et al. (2022) Garikapati and Shetiya (2024)
Collision risks	Unmanned aerial vehicles (UAVs) in construction and other applications face risks of collision with properties, humans, and other UAVs, potentially leading to injuries or damage.	Implementing strict safety protocols and advanced collision avoidance technologies is a crucial demand for minimizing these risks.	Pan et al. (2022) Candela et al. (2023)
Legal and liability issues	The deployment of UVs raises complex legal and liability questions, especially in the event of accidents involving injuries or property damage.	Developing clear legal frameworks and insurance policies is necessary to address liability concerns and ensure accountability.	Winkle et al. (2018) Alshaafee et al. (2021) Straus (2024) Garikapati and Shetiya (2024)
Privacy concerns	The use of UVs for surveillance and data collection can infringe on individuals' privacy, sparking ethical debates and regulatory challenges.	Establishing privacy guidelines and obtaining consent for data collection are important steps for addressing these concerns.	Alshaafee et al. (2021) McLean et al. (2023) Kruger and Steyn (2024)
Operational challenges	Unmanned ground vehicles operating in off-road environments encounter obstacles that can lead to safety risks and operational inefficiencies.	Research into improving perception systems and obstacle detection is needed to enhance safety in off-road operations.	McLean et al. (2023) Peng et al. (2023)
Regulatory limitations	Current regulatory frameworks may limit the deployment and operational capabilities of UVs, particularly in high-risk industrial sites and urban passenger transport.	Ongoing dialog between industry stakeholders and regulatory bodies is essential for evolving regulations that support innovation while ensuring public safety.	McLean et al. (2023) Kruger and Steyn (2024)

Table 9 Major pathways for unmanned vehicles.

Sub-themes	Description	Possible implications	Sources
Strategic roadmaps for AI in AV development	Developing comprehensive and adaptable roadmaps that guide the integration of AI technologies in AVs, considering technological trends and regulatory landscapes.	Encourages a unified direction for AI advancements, ensuring alignment with safety standards and societal expectations.	Cho et al. (2021) Garikapati and Shetiya (2024)
Collaboration between industry and regulators	Fostering partnerships among AV manufacturers, AI developers, and regulatory bodies to establish guidelines that facilitate innovation while ensuring public safety.	Enhances the regulatory framework, effectively accommodating rapid technological advancements and addressing safety and ethical concerns.	Pan et al. (2022) McLean et al. (2023)
Public engagement and education	Initiating programs to educate the public about the benefits and challenges of AI in AVs, addressing concerns, and building trust in the technology.	Increases public acceptance and awareness, reducing apprehension and fostering a culture of safety and innovation.	Cervantes et al. (2020) McLean et al. (2023)
Ethical AI frameworks	Establishing principles and standards for ethical AI development and deployment in AVs, focusing on transparency, accountability, and fairness.	Guides ethical decision-making in AI development, promoting trust and ensuring that AI technologies benefit society as a whole.	McLean et al. (2023) Langford et al. (2023) Garikapati and Shetiya (2024)
Innovation ecosystems for AV technologies	Creating supportive environments for startups and researchers to innovate in AI and AV technologies, including access to funding, expertise, and testing facilities.	Stimulates technological advancements and accelerates the development of practical, innovative solutions for challenges facing AVs.	Mishra (2023) Studiawan et al. (2023)

prediction, decision, and performance. Figure 7 shows how AI can be integrated and utilized across these five phases to address risk, uncertainty, and developments for UVs. Each phase is briefly explained in the following sections.

Detection phase. The intelligent system gathers data from sensors about the surrounding environment during the input stage, such as vehicle speed, vehicle distance, vehicle state, and lane offset, and then analyzes the data in the detection phase (You et al. 2022). Then, through transparent design, the intelligent system provides important information about its present situation, intentions, goals, and plans, which assist the vehicle in perceiving the present activities and states of the surrounding objects (Thangavel et al. 2024).

Process phase. At this stage, the intelligent system can understand and evaluate data efficiently in two phases, informing the vehicle about its comprehension process in a transparent manner and the mission at hand (Gallab et al. 2024). The information displayed includes whether an approaching vehicle poses a danger and its risk level. It helps the vehicle understand both actions taken by the vehicle and the system's intentions (Pan et al. 2022). Meanwhile, the intelligent system continuously updates environmental details by continuously changing interface element that shows

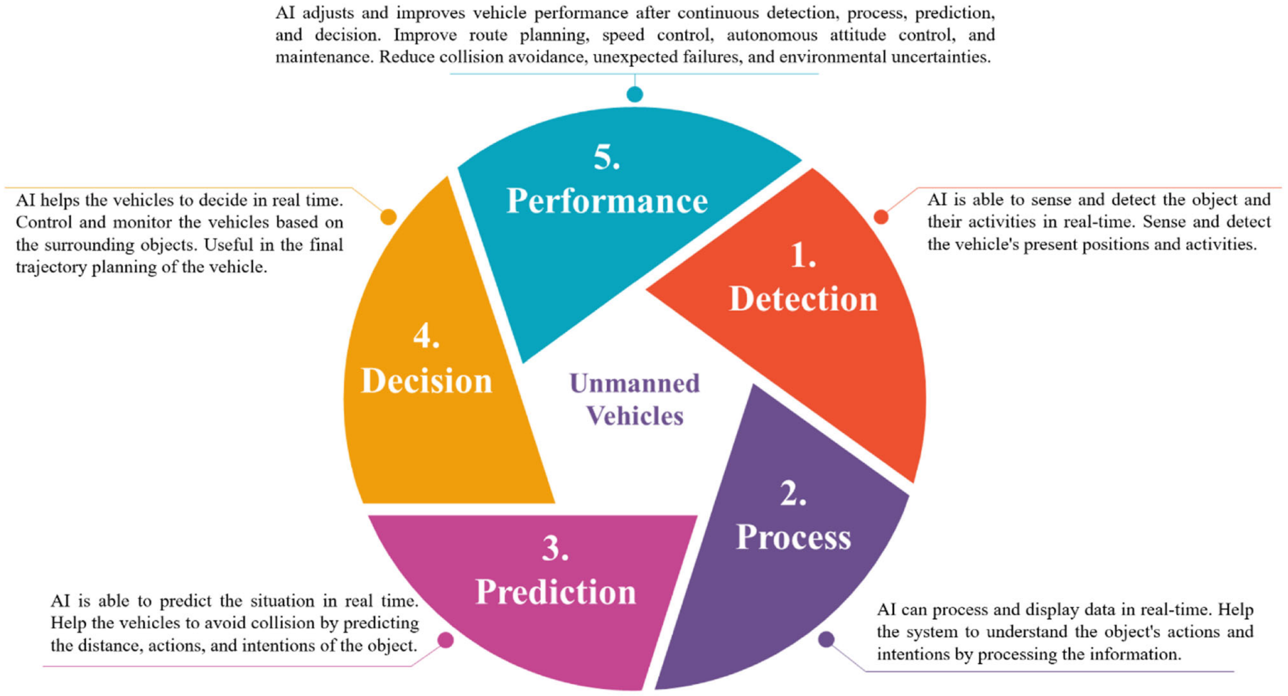

Fig. 7 Role of AI in UVs through 5 phases. This figure illustrates the transformative role of AI in UVs through 5 phases, including performance, detection, process, prediction, and decision. It shows how AI can be integrated and utilized across these five phases to address risk, uncertainty, and developments for UVs.

vehicle statuses, such as whether approaching a car is dangerous and the level of threat presented by each (Ma et al. 2020).

Prediction phase. Forecasting imminent vehicle movement helps negotiate various traffic situations more successfully. Beyond forecasting basic physical behaviors based on past observations, it is also crucial to think about potential interactions among actors (Sefidgar and Landry, 2022). An intelligent system can display this change through constantly altering interface elements. For instance, changing the state of danger for the rear vehicle and the distance changes between it helps vehicle and drivers be aware of any changes occurring constantly and prevent accidents from happening (Johnson, 2021; You et al. 2022).

Decision phase. In this phase, information pertaining to rear vehicles can change (for instance, the risky state or distance between rear vehicles as well as self-referral vehicles). As a result, vehicles can use this stage as an opportunity to assess potential disrupting factors and when they might take effect (Hu et al. 2022). Doing this allows vehicles and drivers to react better to sudden events. Additionally, it provides an analysis of the potential actions of the self-referral vehicle as well as their implications in relation to the overall driving situation and to determine the final plan or trajectory for the vehicle (Yoganathan and Osburg, 2024).

Performance phase. This phase involves the interface of the above phases for optimal UV performance, exploring how increasing design transparency affects the scheme's usability, driver's workload, and situation awareness (You et al. 2022). Additionally, how improving the interface's usability and overall performance and efficiency leads to improved user satisfaction. In this stage, AI can aid in adjusting and improving the performance of vehicles, route planning, speed control, attitude control, and maintenance after continuous detection, process, prediction, and decision (Gallab et al. 2024).

Technological advancements of AI for UVs. AI has experienced rapid development in the past decade. For example, consider the robot AlphaGo, developed by Google. On March 9, 2016, the AI robot AlphaGo Lee defeated Lee Se-do with a score of 4:1. Since then, the AI robot has had an official World History Ranking (WHR) in the Go world, with a score ranking only second to Ke Jie worldwide. These results make people realize the terrifying potential of AI. Even more remarkable is that, in May 2017, AlphaGo Master defeated Ke Jie, the world's top-ranked player, in the ultimate human-machine competition held in Wuzhen, Zhejiang Province, China.

As the latest version of AlphaGo, AlphaGo Zero is the most skillful and professional Go player. Initially, earlier versions of AlphaGo underwent extensive exercises to learn how to play Go, requiring tremendous investment in hardware and software. However, AlphaGo Zero skipped these steps and learned to play by engaging in random Go games. In doing so, it quickly surpassed the human level and achieved a 100:0 victory in competition against the previous champion version of AlphaGo. During the learning process, AlphaGo Zero became its own teacher. Starting with a neural network that knew nothing about Go, the system combined with a powerful search algorithm to compete against itself. With each iteration, the neural network upgraded, and the system became more powerful, resulting in a more precise neural network and a stronger version of AlphaGo Zero. This iterative process enabled the technology to surpass the limitations of human knowledge and create capabilities beyond the earlier version of AlphaGo. Moreover, AlphaGo Zero could learn from the best player in the world—AlphaGo itself (Silver et al. 2017).

In the field of pediatric diseases, Liang et al. (2019) implemented an AI-based system to help physicians manage vast amounts of data, support diagnostic gauging, and provide clinical decision support for diagnostic uncertainty and complexity. This was the first time that natural language processing (NLP) on Chinese text electronic medical records (EMR) for clinical intelligence diagnosis was published in a top medical journal.

The medical data intelligence application team, led by Professor Xia Huimin from Guangzhou Medical Center for Women and Children, Professor Zhang Kang from the University of California, and other experts, together with the AI research and transformation organization, developed the "Auxiliary Diagnosis Bear" AI diagnosis platform. This platform automatically learned the diagnostic logic from 1.36 million high-quality electronic medical records of 567,000 pediatric patients. It can diagnose a variety of common pediatric diseases with the same accuracy as experienced pediatricians.

AI technologies have played a vital role in UVs' development, giving UVs greater capabilities as well as instantaneous decision-making and navigational systems. UVs enhanced with AI are capable of analyzing complex data streams like Light Detection and Ranging (LiDAR), Radio Detection and Ranging (RADAR), and camera footage to detect vehicles, pedestrians, or obstacles in real-time—an ability that autonomous car manufacturers require (Czech, 2024). Machine learning algorithms have advanced, enabling UVs to anticipate pedestrian and vehicle behavior more accurately and reliably, making decisions with greater confidence. Integrating AI into UVs represents an essential step toward autonomous driving by decreasing accidents caused by human error while increasing overall transportation system efficiency (Tlili et al. 2024).

AI technology has also made significant strides forward in autonomous driving technology, with numerous unmanned vehicles working on applications in various settings across the world (Peng et al. 2024). For example, Waymo, Tesla, and Baidu have each developed and deployed autonomous vehicles for ride-hailing and public transit trials on urban roads (Garikapati and Shetiya, 2024). Logistics vehicles from TuSimple are being utilized for transporting goods over longer distances without human involvement, making life simpler for drivers and transport companies alike (Garikapati and Shetiya, 2024). Agriculture relies heavily on automated drones and tractors for crop growth monitoring, soil analysis, and precise farming (Caballero-Martin et al. 2024). These examples demonstrate UVs' abilities to navigate difficult environments, make instantaneous decisions, and adapt to ever-evolving circumstances alongside sophisticated AI systems. While UVs are operating successfully today, issues related to ethics, security, and regulatory concerns must still be resolved to ensure safe integration into daily usage of UVs.

On October 11, 2020, the world's first AI symphonic variation, "Me and My Motherland," was created by the China Ping An Institute of Artificial Intelligence and premiered by the Shenzhen Symphony Orchestra (Chaudhri et al. 2013). This work uses the automatic variation system (AVM) initiated by Ping An, based on the massive historical music data accumulated by the Ping An AI team, systematic music label engineering, systematic automated variation, music evaluation, and expert rule models. Using AI technologies such as deep learning and reinforcement learning and based on classic tracks like "My Motherland and I" and "On the Field of Hope," it completed the creation of the AI symphony with five variations. In such a case, humans must realize the rapid development of AI (Zhen-Wu, 2022).

Uncertainties for UVs. Embark, the star unmanned truck company plummeted from a market capitalization peak of $5.2 billion (about 36 billion yuan) to $9 million in less than two years, and the company officially announced its complete closure. As the star company of self-driving trucks and the first to start the track, Embark was once on par with TuSimple. Embark is the first self-driving truck company to officially announce liquidation due to bankruptcy, and it is also the first self-driving listed company to go bankrupt. Its withdrawal is considered a significant earthquake in the UVs industry.

The development of UVs is closely connected with economic development (Yigitcanlar et al., 2020). Moreover, the development of UVs will deeply influence transportation, energy, emergency rescue, and medical care. As a result, disparities in UV development between different countries may widen, potentially leading to greater regional differences and conflicts (Mishra, 2023).

Risks of the UVs. Although UVs have witnessed many years of continuous development and possess many advantages, doubts about AI technologies regarding driving safety, technical issues, liability disputes, privacy, cyber hacking, terrorist manipulation, and driving-related job loss in transportation persist. Designers of UVs will need to introduce ethical thinking and reasoning when programming software to determine actions to be taken by the vehicle in an inevitable collision (Ono et al. 2013). The ethics of UVs may spark significant controversy because it requires consideration of the variability of human ethics, background dependence, complexity, and uncertainty (Evans et al. 2020). Human drivers make various moral-related decisions when driving, such as avoiding harm to themselves or risking themselves to protect others, where the driver's emotions can influence the moment or various stress reactions caused by road rage or driving pressure. This emotional aspect remains an unexplored area for AI.

Humans can respond quickly to circumstances, but sometimes, there isn't enough time to detect an impending fatal accident and make correct moral choices while taking appropriate actions. In contrast, AI-equipped UVs can reduce accidents by avoiding behaviors such as fatigued driving, drunk driving, racing, and road rage driving. However, based on current AI technology, it is challenging for UVs to identify complex traffic conditions and the ongoing behaviors of pedestrians and animals on the road, and it is even more difficult to make rapid and correct decisions. When faced with such complexities, human drivers typically respond based on moral judgment at the moment rather than intelligence, memory, or other factors.

Moreover, UVs on the road involve several parties, such as production and research and development (R&D) institutions, owners, and users. If a UV violates the interests of others and causes loss of life or property, the uncertainty of confirming an accountable party poses significant difficulties in compensation. AI-based UVs will inevitably raise concerns about terrorist hacking, with such accidents potentially being even more disastrous (Johnson, 2021). From the perspective of labor replacement, AI can impact drivers' livelihoods by replacing professional drivers. With further output increases, UVs may also affect the space and freedom of people who enjoy driving and full-time racing athletes.

The frequent traffic accidents caused by AI-based UVs are particularly concerning. No law currently guarantees the confirmation and investigation of accountability for accidents involving unmanned vehicles, indicating that unmanned technology still lacks a legal basis. Since Google first exposed accidents caused by UVs in 2016, an increasing number of news reports about UV accidents have reminded people that there is still a long way to go for AI-based UVs. On March 18, 2018, an unmanned Uber car collided with a pedestrian during a road test in the suburbs of Phoenix, Arizona, resulting in a fatality. The number of accidents is increasing in parallel with the rising use of autopilot mode. For example, the Washington Post analyzed 2019 data from the National Highway Traffic Safety Administration (NHTSA) and reported that Tesla's self-driving mode was involved in 736 crashes, including 17 fatalities (Siddiqui and Merrill, 2023). Such traffic accidents attracted significant global attention and pushed the debate about AI to the forefront. Accidents frequently occur because the automatic driving system cannot precisely identify objects ahead. These accidents are often due to defects in the perception system of the automatic driving function, including perception blind spots, low discrimination, long feedback time, and weak signals. For the automatic driving function to achieve sustainable development, these existing defects must be addressed alongside continued research and application of relevant technologies.

Path forward for AI in UVs. As part of determining the optimal path for AI integration into UVs, it is critical that regulators, industries, public participation, and innovation ecosystems collaborate together on creating strategic roadmaps. This involves cooperation between these stakeholders in developing moral AI frameworks and fostering innovation ecosystems. This theme highlights the necessary teamwork for successfully dealing with any risks or uncertainties associated with unmanned AI vehicles to ensure ethically aligned advancement into the 4IR.

Strategic roadmaps. In the efforts to advance AI, AV manufacturers should create plans for strategic routes with clear goals and timelines that will guide their development. Such roadmaps should consider technological advancements as well as security protocols newly put into operation, in addition to infrastructure currently present and in use. Studies have highlighted the need for flexible yet forward-thinking planning so technological breakthroughs achieved with AI meet both societal requirements and ethical considerations (Cho et al. 2021).

Collaboration. Collaboration among various parties on the ground, academic institutions and regulatory agencies is integral in meeting AI challenges for UVs. Collective efforts allow the sharing of resources and best practices between collaborators. Speeding technological progress while adhering to regulations and security protocols and meeting legal obligations. Collaboration has led to significant technological advancements and policy advances (McLean et al. 2023).

Public engagement. Engagement in decision-making and discussion processes related to AI and AVs is vital to building trust and acceptance among society as a whole. Public engagement initiatives provide invaluable insights into society's needs and expectations, informing policies and technologies tailored toward meeting those requirements. Research has highlighted the value of engaging people positively so as to create positive perceptions of both AI and autonomous cars while at the same time encouraging open and inclusive communication techniques (Cervantes et al. 2020).

Ethical AI frameworks. The development and application of ethical AI frameworks are crucial to ensuring that unmanned vehicles operate under principles of accountability, fairness, and transparency. Ethical AI techniques must address issues such as bias, privacy concerns, and decision-making independence. Existing literature emphasizes the importance of these frameworks in maintaining public trust and preventing harm from AI technologies (Langford et al. 2023).

Innovation ecosystems. Innovation ecosystems designed to facilitate AI development in UVs are crucial in driving technology-driven creativity and innovation. Such ecosystems offer entrepreneurs, researchers, and innovators funds, mentorship opportunities, and collaboration possibilities; studies examining various innovation ecosystems demonstrate their beneficial impact on speeding AI advancement and commercializing AVs (Mishra, 2023; Studiawan et al. 2023).

Conclusion

AI development can be regarded as the latest achievement of science and technology, and the UV is a typical representative of AI advancement. However, the challenges and complicated risks that have emerged from constant tests remind us that there must be side effects that come along with technological advancements and deployment without exception.

AI technology will speed up the development of the UV industry, but the pros and cons of UVs are likely to coexist for a very long time. We can trust that UVs will be sustainable, environmentally friendly, and beneficial for the planet, increasing mobility, freeing up parking spaces, providing economic benefits, reducing accident rates, and being friendlier to people who dislike driving or cannot drive compared to traditional vehicles. However, they will also have high requirements for driving environments, pose risks such as bugs and hacking, reduce driving enjoyment, and present significant challenges during the transition phase.

As a typical representative of AI-based products, people can see the great capabilities and potential of UVs to greatly change the human world in the era of AI and conceive of a new era initiated by AI. It is not a perfect car and cannot immediately replace existing cars. However, regardless of our willingness, it has gradually become linked to people's lives. Therefore, by actively improving legislation, rigorously testing and perfecting products, and creating a reasonable traffic environment, we can either become comfortable passengers of UVs or coexist with them as human drivers, sharing the roads in the future. Alternatively, humans may one day give up on UVs entirely. Regardless, that moment will signify a deeper understanding of AI.

In the near future, the crisis brought about by UVs might resemble a "gray rhino," impacting various aspects of human life, which we must face and resolve. Michele Wucker, in the book The Gray Rhino, provides strategies for dealing with such crises: First, we must recognize the existence of the crisis; second, define the nature of the risk; third, avoid passivity in the face of the crisis; fourth, learn from the crisis and not waste the opportunity; fifth, stay vigilant, closely monitor potential risks, eliminate hesitation, and optimize decision-making processes; and lastly, the person who identifies the risk of the gray rhino can be the one who controls it.

Limitations and future research directions

This study, while extensive, is not without limitations. Firstly, the rapid pace of technological advancements in AI and UVs means that the landscape is constantly evolving. As such, some findings may become outdated as new technologies emerge. Secondly, the study primarily focuses on integrating AI in UVs from a technological and theoretical standpoint, with less emphasis on empirical data from real-world implementations. This limits knowledge about the practical usefulness of AI in UVs based on actual implementation. Furthermore, the analysis of uncertainties and risks relies solely on current information and, therefore, may fail to consider future challenges or unanticipated advancements in AI technologies or regulatory environments. Finally, given that this study covers multiple areas of AI integration into UV systems, certain issues may not have been examined in sufficient depth.

Therefore, future studies should address the issues raised in current research by empirically verifying theoretical models through actual experiments, further developing AI and UV technologies, creating flexible ethical and regulatory frameworks, analyzing societal impacts, and conducting international collaborations and comparisons. Such efforts would enhance AI integration strategies for UVs, address ethical and regulatory concerns, understand societal implications, and encourage global progress while standardizing UV technology.

Data availability

The datasets used and/or analyzed during the current study can be available from the corresponding author on request.

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Md Altab Hossin (MAH) planned the research and wrote the original manuscript. Md Altab Hossin (MAH) and Songtao Yin (SY) conducted formal analysis and content editing. MAH helped with the resources, investigation, modeling, and visualization. Ruibo Dan (RD) and Lie Chen (LC) contributed to the resource collection, literature review, and content revision. MAH and SY are declared as co-first authors.

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The author declares no competing interests.

Ethical approval
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Informed consent
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Additional information
Correspondence and requests for materials should be addressed to Md Altab Hossin.