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(Review Article)

Autonomous Vehicles and UAVs: A Comprehensive Review of Technologies, Applications, and Future Challenges

S. V. Viraktamath, Mallikarjun S Jigalur * and Prarthana R Chikkalkar

Department Of Electronics and Communication Engineering, S D M College of Engineering and Technology, Dharwad, Karnataka State, India.

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Abstract

Autonomous vehicles (AVs) and unmanned aerial vehicles (UAVs) are transforming mobility, logistics, agriculture, and public services through advancements in sensing, navigation, planning, and artificial intelligence. This paper provides a comprehensive review of recent technological developments, including multi-sensor fusion, AI-driven perception, GNSS-based and vision-based navigation, and motion planning strategies. Applications in precision agriculture, last-mile logistics, and healthcare delivery are discussed, alongside hardware optimization for UAV platforms. Furthermore, the paper examines societal and economic implications such as accessibility, regulation, and the disruptive impact on industries and employment. Key challenges including trust, cybersecurity, scalability, and equitable integration are highlighted, with future research directions identified to ensure safe, efficient, and socially responsible deployment of autonomous systems.

Keywords: Autonomous vehicles; UAVs; Sensor fusion; Navigation; Motion planning; Logistics; Socio-economic impact

1. Introduction

Autonomous systems—including self-driving cars, connected autonomous vehicles, and unmanned aerial vehicles are rapidly transforming mobility, logistics, agriculture, and broader socio-economic landscapes. Recent reviews highlight enabling technologies such as advanced sensors, AI-driven perception, edge/cloud computing, and blockchain-based cybersecurity, which collectively underpin the development and deployment of autonomous vehicles (AVs) across multiple sectors [1]. At the same time, stakeholder perspectives reveal contrasting assumptions and expectations about electrification, regulation, accessibility, and safety, while also noting risks such as over trust and congestion, emphasizing the need for inclusive dialogue among policymakers, industry, and researchers [2].

Central to autonomy is environment perception, where fusing complementary sensors such as LiDAR and millimetre-wave radar through techniques like the Unscented Kalman Filter (UKF) enhances detection, tracking, and reliability compared to single-sensor systems [3]. Beyond ground vehicles, UAVs equipped with AI-based sensing have shown promise in precision agriculture, particularly in integrated weed management, where machine learning enables selective and sustainable weed control [4]. UAVs are also being used for multi-target tracking, where radar feedback integrated with Kalman filtering and ant colony optimization algorithms improves path planning and route efficiency [5].

Localization and navigation remain critical challenges for autonomous mobility. Smartphone-based Precise Point Positioning (PPP) demonstrates meter-level accuracy for land navigation, showing potential for low-cost solutions when integrated with MEMS sensors [6]. To ensure resilience against spoofing, advances in GNSS signal authentication

* Corresponding author: Mallikarjun S Jigalur

methods—such as “Authentication of navigation messages and spreading codes (SCA)” are under active development [7]. For UAVs operating in situations where GNSS signals cannot be accessed, robust localization is increasingly achieved through vision-based techniques and hybrid frameworks combining IMUs, radar, LiDAR, and AI-supported semantic mapping [8]. In practical applications, GNSS- and compass-based navigation systems have been successfully tested for drone-based medical delivery and agricultural support, achieving sub-meter landing accuracy [9]. Meanwhile, cloud–edge collaboration frameworks are being explored to offload deep neural network (DNN)-based relocalization tasks, reducing onboard computation while maintaining route performance [10].

In terms of motion planning and decision-making, strategies for intersection management, cooperative lane changes, and trajectory prediction are advancing rapidly. Graph-based, optimization-driven, prediction-enhanced, and machine learning methods are being applied to address mixed traffic conditions and improve safety at both signalized and unsignalized intersections [11]. Lane-exchange strategies leveraging Gaussian Mixture Models with model predictive control (MPC) have proven effective in ensuring collision-free maneuvers [12]. Graph Neural Networks (GNNs) integrated with MPC further enhance trajectory prediction in complex traffic scenarios such as merging and roundabouts [13]. Other robust approaches, such as invariant tube-based planning with pseudospectral techniques, offer computationally efficient and safe motion planning under uncertainty [14]. In UAVs, classical PID-based control systems enhanced with collision detection frameworks provide foundational control strategies, with future work targeting adaptive obstacle avoidance and mission-level autonomy [15].

From a hardware perspective, UAV design optimization involves balancing frame design, motors, ESCs, propellers, and power supply requirements. Quadcopters remain versatile for general applications, whereas hexacopters and octocopters are favoured for payload-intensive missions [16]. At a systems level, autonomous delivery robots (ADRs) and UAV-based logistics are reshaping last-mile delivery by improving efficiency, reducing costs, and minimizing environmental impacts, though infrastructure adaptation and regulatory frameworks remain barriers [17]. Large-scale drone delivery studies in Europe show significant but uneven potential coverage, with economic viability depending on product margins and consumer adoption rates [18].

Beyond technical advances, the societal and economic implications of autonomous mobility are profound. Shared autonomous vehicles (SAVs) offer potential to reduce accessibility gaps and improve equity in urban contexts, as demonstrated in studies of major European cities [19]. Similarly, analyses in Spain show that AVs could disrupt industries representing nearly 40% of national GDP, reducing car ownership and accident rates while reshaping transport economics. However, the transition requires phased government-led planning to mitigate social disruption and ensure equitable integration of autonomous technologies [20].

Together, these studies underscore that while technological innovations in sensing, navigation, planning, and system integration are accelerating, challenges related to regulation, equity, trust, and scalability must also be addressed. Achieving widespread, socially responsible adoption of autonomous mobility will depend on bridging stakeholder perspectives, advancing participatory research, and fostering collaboration across industry, policymakers, and society [1–20].

2. Foundational Reviews & Challenges (broad overviews before diving into specifics)Selecting a Template

Explores stakeholder perspectives on autonomous vehicle implementation in Sweden, focusing on Future Users, Urban Planners, and Developers. Using focus group discussions, it identifies differing assumptions about electrification and regulation, expectations of improved accessibility and safety, and concerns related to over trust and potential urban congestion. Results reveal a lack of communication between these groups, which may hinder effective adoption. The study emphasizes the importance of inclusive stakeholder dialogue, recommending that policymakers facilitate interaction, industry promote transparent communication, and researchers apply participatory methods to ensure socially responsible AV integration.[2]

Recent developments in planning and decision-making for CAVs at intersections are reviewed, particularly addressing uncertainties linked to heterogeneous traffic. The study classifies existing approaches as graph-based, prediction-based, optimization-based, or machine learning-based, and highlights vehicle–infrastructure cooperation made possible through wireless connectivity. Both signalized and unsignalized intersections are considered under mixed and fully automated traffic settings. The review brings together prevailing strategies, addresses key challenges, and reveals research gaps, offering direction for future work in automated intersection management.[11]

Presents a MATLAB-simulated UAV flight control system that employs a classical proportional–integral–derivative (PID) algorithm for attitude and position control, combined with an enhanced collision detection method. The detection framework integrates grid technology with a k-dimensional tree to accelerate bounding-box checks in complex virtual environments. Simulation results show effective UAV trajectory tracking and improved collision detection performance. While limitations in PID tuning and robustness are acknowledged, the study provides a foundational framework for advancing UAV autonomy through future integration of adaptive obstacle avoidance and complex mission execution capabilities.[15]

This literature review examines the potential of autonomous delivery robots (ADRs) to transform last-mile logistics by reducing operational costs, improving efficiency, and lowering environmental impact. Key factors influencing ADR adoption include infrastructure requirements, regulatory frameworks, operational feasibility, and societal acceptance. Despite promising advancements, challenges such as regulatory gaps, infrastructure adaptation, and uncertain public trust remain significant. Current research in this domain is largely theoretical, underscoring the need for empirical investigation and real-world validation.[17]

Paper provides a comprehensive review of recent advancements in autonomous vehicles (AVs). It discusses enabling technologies such as advanced sensors (LiDAR, radar), AI-driven perception and control, real-time data processing, and edge/cloud computing Fig. 1. The survey highlights applications in logistics, public transportation, and healthcare, while acknowledging persistent challenges regarding reliability, consumer trust, cybersecurity, privacy, regulatory frameworks, and standardization. Additionally, it examines AI-based computer vision, machine learning approaches to decision-making, blockchain integration, and cyber threat protection. The study concludes that further research on component compatibility, simulation accuracy, large-scale training, and user-centered design is essential to achieve widespread AV commercialization. [1]

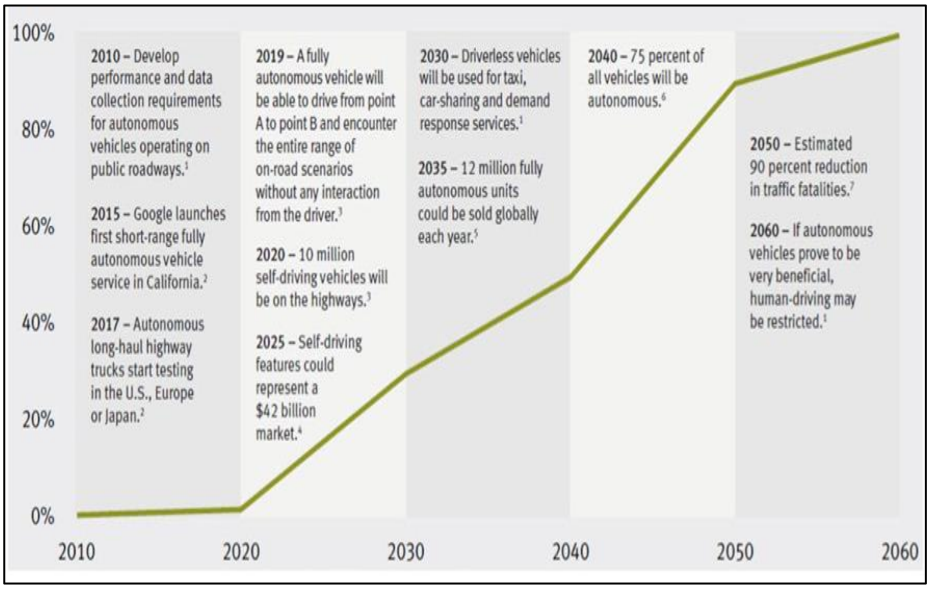

Figure 1 Projected Evolution of Autonomous Vehicles (2010–2060). This figure shows the expected progression of vehicle autonomy across several decades. The x-axis covers years 2010 through 2060, and the y-axis denotes autonomy levels from 0% (no automation) to 100% (complete automation). The curve starts at 0% in 2010 and gradually reaches 100% by 2060, highlighting both the accelerated pace of technological development and its profound implications for transportation.[1]

3. Perception & Environment Sensing

Proposes a sensor fusion approach for autonomous vehicles that integrates LiDAR and millimeter-wave radar data using the Unscented Kalman Filter (UKF). While LiDAR provides high-precision positional information and radar offers accurate velocity measurements, fusing the two overcomes individual limitations. Real-world vehicle tests conducted under multiple scenarios demonstrate that the method significantly improves target detection, tracking accuracy, and overall perception reliability compared to single-sensor systems.[3]

4. Localization & Navigation Systems

The feasibility of smartphone-enabled real-time Precise Point Positioning (PPP) for land vehicle navigation was assessed using Huawei Mate30 and P40 devices, as shown in Fig. 2. Experiments involved roof-mounted and dashboard-mounted setups under urban driving scenarios. Despite reduced signal quality and higher noise in in-vehicle placements, horizontal accuracies of 1–1.5 m (RMS) were achieved. These results indicate that smartphones are capable of meter-level positioning, with ongoing research directed toward combining GNSS PPP with MEMS sensors to enhance performance and reliability. [6]

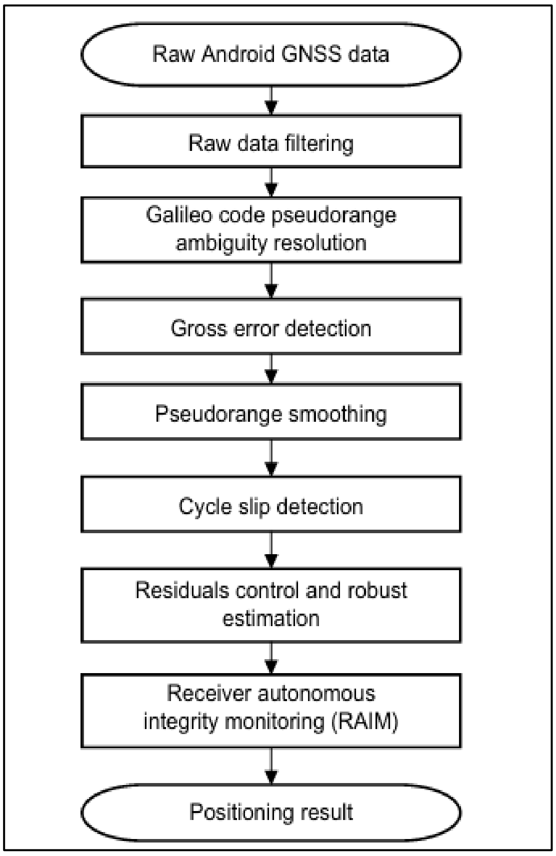

Figure 2 Flowchart illustrating data quality control in smartphone-based PPP.[6]

Provides a comprehensive review of navigation signal authentication methods designed to protect civilian "Global Navigation Satellite System (GNSS)" services from spoofing attacks. The theoretical foundations of authentication, including secure code generation, embedding, and verification, are outlined. Prominent schemes such as "Navigation Message Authentication (NMA)" and "Spreading Code Authentication (SCA)" are compared in terms of strengths, weaknesses, and performance using a design/performance matrix. The review concludes by recommending improvements in robustness, security, and implementation efficiency to safeguard future GNSS services, thereby ensuring reliable positioning and timing in safety-critical applications.[7]

This survey reviews UAV localization techniques for outdoor GNSS-denied environments, classifying them into absolute and relative approaches. Vision-based methods are identified as the most effective single-sensor solutions; however, the study emphasizes that no individual technique can ensure robust navigation. Instead, hybrid approaches combining multiple sensors—such as cameras, IMUs, radar, and LiDAR—are recommended, supported by algorithms like Visual-Inertial Odometry (VIO), SLAM, and terrain-aided navigation methods (TERCOM, DSMAC). Additionally, the role of AI-enabled semantic mapping is highlighted for enhancing environmental perception and advancing UAV localization.[8]

Develops a GNSS- and compass-based navigation system for autonomous drones tasked with delivering medical supplies and supporting agriculture in Indonesia. Flight tests demonstrate that the standard GNSS and compass-based navigation system achieves a landing accuracy of 1.11 m, outperforming a proposed course-over-ground algorithm for short flights. The Proposed system architecture is shown in the Fig.3. The system integrates altitude and speed control, supports delivery sensors, and includes a mobile app for operation without a ground station. While effective for short missions, future work will focus on longer-distance navigation, managing larger drone fleets, and scaling the approach to larger UAV platforms.[9]

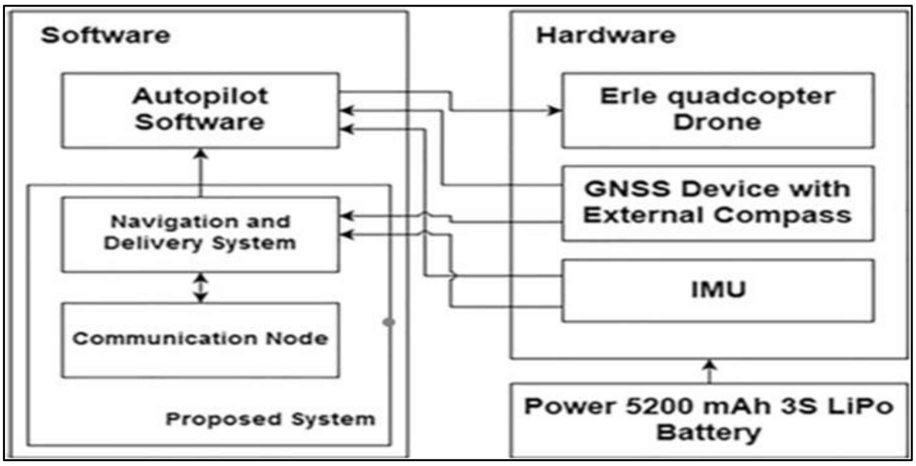

Figure 3 Design Architecture of the Proposed System [9]

Addresses the computational challenges of Deep Neural Network (DNN)-based camera relocalization in autonomous vehicles by proposing an edge–cloud collaborative framework. The system offloads computationally intensive network segments to a cloud server, reducing on-board inference time and improving route performance. Evaluations with the MapNet series validate the efficiency gains of this approach. With practical potential in cloud robotics, the study highlights future directions including improving uncertainty estimation, ensuring data privacy, managing communication overheads, and enabling large-scale DNN model offloading to advance edge–cloud collaboration in autonomous driving.[10]

5. Motion Planning & Decision-Making

This study presents a cooperative lane-exchange strategy for autonomous vehicles that integrates trajectory prediction with motion control. Nearby vehicle trajectories are predicted through a Gaussian Mixture Model coupled with vehicle kinematics, and safe lane-changing is ensured via a potential-field-based MPC framework. Experimental validation using on-road datasets and simulations demonstrates the strategy's ability to enable safe maneuvers. Future developments will address interactions involving multiple surrounding vehicles under dense and complex traffic scenarios.[12]

Presents a safe motion planning framework for autonomous driving that leverages trajectory prediction using a "Graph Neural Network (GNN)" trained on the INTERACTION dataset. The GNN predicts future trajectories of surrounding vehicles and pedestrians, which are then incorporated into a model predictive control (MPC)-based motion planner. Validation in merging and roundabout scenarios shows that the method reduces collision risk and improves driving safety compared to baseline motion planning methods.[13]

Proposes a robust and computationally efficient motion planning framework for autonomous vehicles by extending the concept of Robust Control Invariant (RCI) tubes. The framework explicitly incorporates closed-loop uncertainties into planning, ensuring collision-free and safe trajectories. By minimizing RCI tube volume and applying a pseudospectral collocation technique, the approach enhances tracking accuracy and significantly reduces computational time. Simulation results with both kinematic and dynamic models verify its ability to achieve fast, safe, and robust motion planning under uncertainty.[14]

Discusses the role of drones equipped with advanced sensors and machine learning in precision agriculture for integrated weed management (IWM). By processing aerial imagery with AI, UAVs can accurately identify and classify weed patches, enabling autonomous weeding robots to selectively target harmful weeds. This reduces chemical herbicide use, minimizes environmental damage, and supports sustainable farming practices. The study highlights the need for further research on weed population dynamics and broader adoption of sensing technologies to ensure long-term ecosystem sustainability and safety.[4]

Presents a UAV path-planning method for long-term tracking of multiple moving targets by integrating real-time radar feedback with Kalman filtering for state estimation and prediction. An ant colony optimization algorithm is applied for dynamic route planning, allowing the UAV to proactively adapt its flight path to predicted target movements Fig. 4. Experimental results show that the method enhances tracking efficiency, improves route optimization, and increases the overall intelligence of UAV systems in multi-target tracking scenarios.[5]

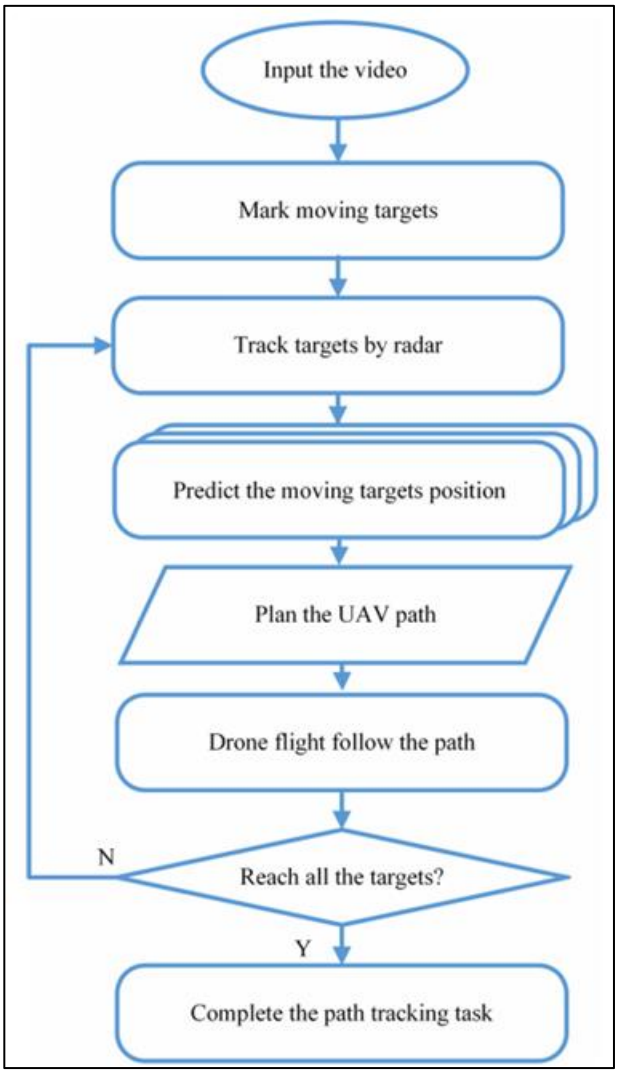

Figure 4 Flow Diagram of the Algorithmic Procedure [5]

6. UAV / Drone-Specific Control & Collision Avoidance

Reviews the fundamental hardware components of multicopter UAVs, including “the frame, motors, propellers, electronic speed controllers (ESCs)”, flight controllers, batteries, transceivers, and sensors Fig. 5. Methods for optimizing key parameters such as motor–propeller configuration and power supply requirements are analyzed to improve efficiency. The paper recommends hardware configurations tailored to applications such as mapping, infrastructure inspection, and search-and-rescue operations. Findings indicate that quadcopters are typically sufficient for general applications, while hexacopters and octocopters provide greater payload capacity and stability. Survey structure is in Fig. 6. Future research is directed toward hardware design for fixed-wing and hybrid UAV platforms.[16]

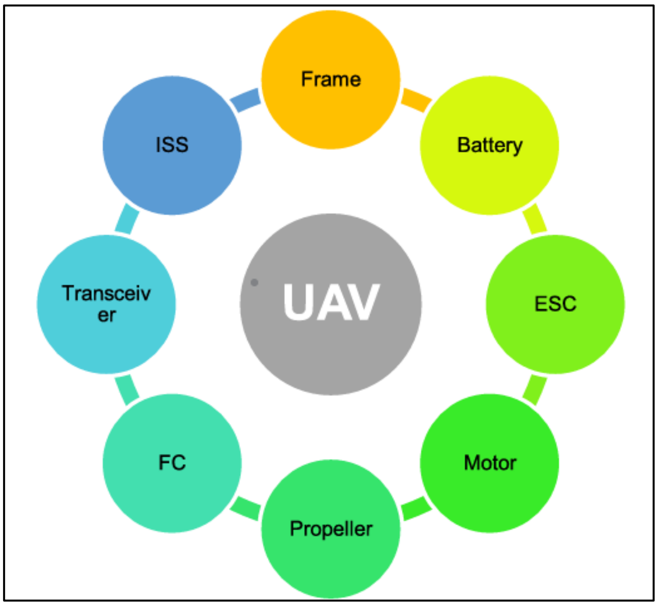

Figure 5 The UAV's hardware parts [16]

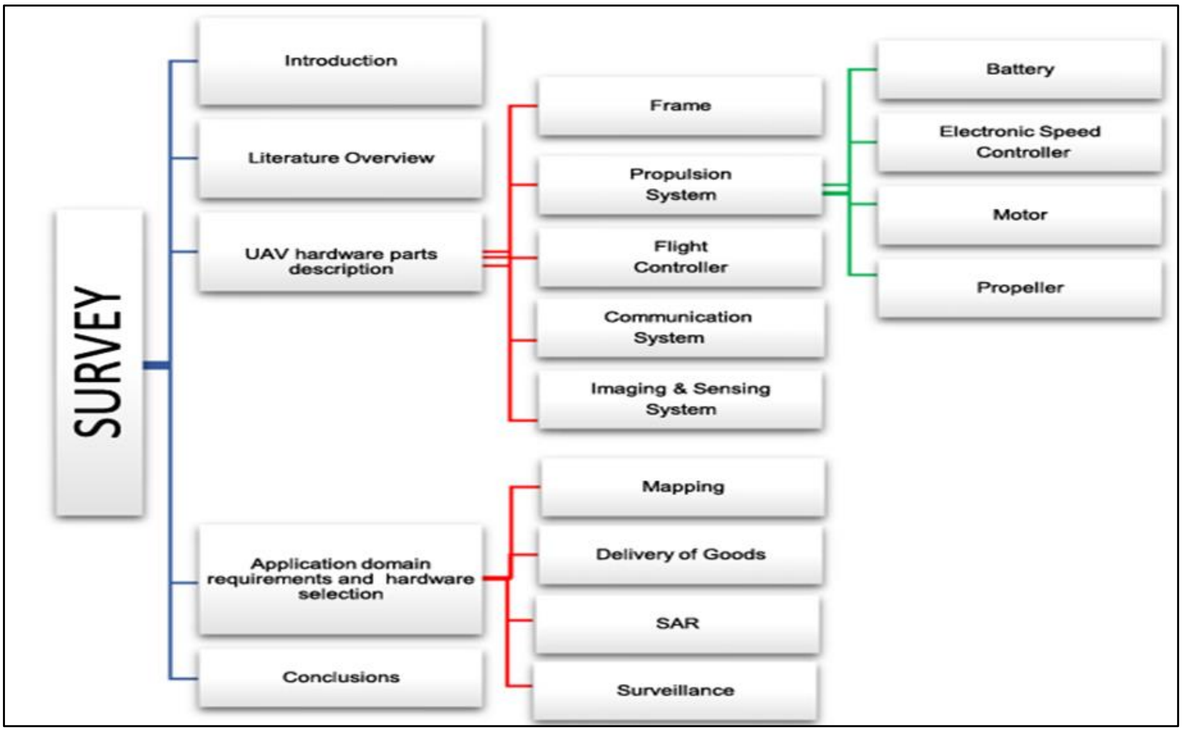

Figure 6 Structure of the survey [16]

Evaluates the economic viability and market potential of large-scale last-mile drone deliveries in Europe by identifying optimal logistic "drone-hive" hub locations using high-resolution population and land-use data. Under present technological capabilities, approximately 7–7.5% of the EU population—concentrated primarily in the UK, Germany, France, and Italy—could be served by drone delivery systems. With technological advancements, this coverage could extend to 27–30% of the population, though significant geographic disparities would remain. The study emphasizes that profitability depends heavily on product margins and consumer adoption rates. It concludes that drone delivery can substantially impact last-mile logistics but requires further research, regulatory development, and public engagement to ensure safe, efficient, and socially equitable implementation.[18]

7. Socio-Economic Impacts

Investigates spatial accessibility and socio-economic disparities in Paris, Berlin, London, and Vienna, focusing on the potential role of "shared autonomous vehicles (SAVs)" in improving equity. Using district-level linear regression, Accessibility via car and public transport is evaluated against socioeconomic factors, including income, unemployment, and education. An "SAV identification matrix" is introduced to identify underserved districts. Results indicate that socio-economic inequalities contribute to accessibility gaps, and SAVs could help address these inequities. The study emphasizes the importance of targeted, data-driven policies and continuous neighborhood-level research to ensure that SAV deployment benefits vulnerable populations and enhances urban accessibility in a fair manner.[19]

Analyzes the economic and societal impact of autonomous vehicles (AVs) on Spain's major industries, representing over 38% of GDP. Three transition scenarios are considered, highlighting the shift toward fleet-based, on-demand shared mobility models. Findings show potential reductions in private car ownership, improved traffic efficiency, fewer accidents, and lower consumer costs. The study stresses that the AV transition will disrupt several industries, particularly automotive and oil, and underscores the need for phased government-led planning and strategic investments. Timely policy actions are recommended to minimize social disruption, support industry adaptation, and safeguard public health and safety during the evolution toward the New Era of Transportation (NERTRA).[20]

8. Conclusion

Autonomous vehicles (AVs) and unmanned aerial vehicles (UAVs) are advancing rapidly through innovations in sensing, navigation, motion planning, and AI-driven control. Their applications in logistics, agriculture, and healthcare highlight the potential to improve efficiency, reduce costs, and expand accessibility.

The journey toward widespread adoption, however, is not without challenges. Cybersecurity risks, regulatory uncertainty, infrastructure limitations, and questions of public trust remain major barriers. Alongside the technical hurdles, the economic and social impact of replacing traditional systems with autonomous ones must be carefully managed to avoid disruption and inequality.

The path ahead calls for collaboration between researchers, policymakers, and industry leaders. When technological progress is matched with thoughtful regulation and ethical responsibility, autonomous mobility can evolve into a system that is safe, sustainable, and beneficial to society as a whole.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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