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Review on Energy Efficiency and Throughput Optimization in UAV Networks for AI-Driven Smart Construction

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Abstract - Unmanned Aerial Vehicles (UAVs) are used as an important element of smart construction and infrastructure management. These systems have been helpful for real time monitoring, site inspection, and safety assessment. The challenge is, however, optimization of energy consumption while maintaining a high data throughput in dynamic and resource constrained environments. This paper reviews several AI-driven approaches, such as deep reinforcement learning, multi-agent frameworks, and resource allocation techniques, which improve the efficiency of UAVs in construction applications. The review focuses on recent works from 2017 to 2024, selected through a structured methodology involving keyword-based searches, citation analysis, and relevance filtering from databases such as IEEE Xplore, Scopus, Web of Science, and Google Scholar. The paper covers the key aspects, including trajectory planning, UAV swarm coordination, and adaptive decision making for construction site monitoring. The review of current research gaps will be proposed for future directions on AI enhanced UAV systems in sustainable and energy efficient construction projects.

Key Words: UAV-based construction monitoring, AI in construction, Energy efficiency optimization, Smart infrastructure, UAV communication networks, AI driven site management.

1.INTRODUCTION

The revolution in UAV integration into smart construction is changing the conventional mode of site operations, thereby improving productivity, safety, and sustainability. UAVs are widely applied for structural health monitoring, automated material transport, environmental assessment, and real time progress tracking. Such applications entail continuous UAV operation and, therefore, depend on energy efficiency and throughput optimization to ensure long-term feasibility. Although battery constraints are still a major issue, wireless energy transfer is a potential solution. Its feasibility, however, depends on technological readiness, environmental conditions, and UAV operational limitations. In contrast to conventional battery swapping techniques, wireless charging infrastructure is still in the early stage of deployment. Hence, complexity at the construction site demands AI driven management of UAV systems that can adapt themselves dynamically to their environment and the actual needs that may emerge during the project execution. Deep reinforcement learning, evolutionary algorithms, and multi-agent systems are the techniques used for the purpose. With AI being applied, optimization of flight path, energy saving, and in real time data communication can contribute to better decisions and automation on the construction sites. This paper reviews the state-of-the-art methodologies towards energy efficient UAV operations in construction, thus focusing on the contribution of AI to maximize network throughput and operational sustainability. The review is based on works from 2017 to 2024, selected through a structured methodology involving keyword-based searches, citation analysis, and relevance filtering across IEEE Xplore, Scopus, Web of Science, and Google Scholar. It depicts how smart frameworks designed into UAVs contribute to the digital transformation of construction and infrastructure management.

2. LITERATURE REVIEW

This review is grounded in a systematic method of selection in order to assure the collection of high quality and pertinent research. The selection was attained through a systematic approach involving keyword searching on IEEE Xplore, Scopus, Web of Science, and Google Scholar. Inclusion criteria were (i) research published between the years 2017-2024, (ii) smart construction related research on UAV applications in terms of energy efficiency, network performance, and automation, and (iii) peer reviewed journal and conference articles. Research on UAV integration in smart construction that was irrelevant was excluded.

A power efficient UAV communication architecture with circular trajectories for throughput and energy optimization was proposed by Zeng & Zhang (2017). Their paper introduced a model for propulsion energy in fixed wing UAVs that exhibited significant energy efficiency and communication throughput enhancement. However, when it comes to UAV-based construction, there is some constraint as there is no rotary wing model of energy that is necessary to support hovering and precise maneuvering in dynamic construction scenarios. Future research will focus on trajectory optimization for rotary wing UAVs with regards to additional constraints such as payload variations, obstacle avoidance, and real time adaptability in construction sites [1].

Applying Nash bargaining game theory, Mkiramweni & Yang (2018) formulated energy efficiency in UAV networks and introduced adaptive beacon scheduling to minimize power usage. In construction using UAVs, effective energy management is essential to provide connectivity in extensive, dynamic worksites. Although this approach improves wireless network coverage and connectivity, it offers trade-offs in energy usage during beacon transmission time. This work indicates the advantages of cooperative UAV approaches compared to constant communication, recommending future investigation of adapting scaling adaptive scheduling techniques to multi-UAV coordination within the context of construction settings where persistent data exchange and power savings are also paramount [2].

Hua et al. (2019) studied energy efficiency in UAV assisted cellular networks in resource allocation and user distribution, but they did not address throughput directly. They decomposed optimization problems to achieve energy efficiencies beyond benchmark points, but the process was a complex non convex one. In UAV based construction, with real time data transmission and network reliability being important, UAV trajectory optimization and adaptive user distribution approaches could further improve communication reliability and energy efficiency. These areas should be investigated in future studies to support smooth UAV operations in changing construction conditions [3].

Tang et al. (2021) reduced delay in data collection in UAV based IoT systems with joint trajectory and resource planning to maximize energy efficiency. Efficient data collection from the sources of different kinds—e.g., sensors, equipment, and manpower—is critically essential in building construction from UAVs for automation and monitoring onsite. can investigate novel data aggregation methods for large Future scale research IoT driven construction sites, enhancing real time decision making and operation al performance [4].

Do et al. (2022) improved federated learning performance in UAV networks through the application of deep reinforcement learning, efficiently minimizing energy consumption in federated operations. This method has great potential for UAV based construction, where decentralized learning supports adaptive decision making among UAV fleets. The inclusion of energy harvesting methods could further aid the sustain ability of UAVs, with prolonged operation in resource scarce construction environments [5].

Jouhari et al. (2023) utilized deep reinforcement learning in order to optimize the performance of LoRa-based UAV gateways for IoT. Real time dynamic resource allocation will significantly prolong network lifetime and outperform benchmark methods. In construction, this method can be adapted to optimize UAV based communication infrastructure, ensuring efficient data transmission for structural health monitoring and safety inspections. However, dealing with the energy requirements of different construction environments requires further adaptation of DRL techniques for broader applications in smart construction IoT framework [6].

Lee et al. (2023) applied a deep learning algorithm for network wide energy optimization for ultra-dense small cell networks (UDSCN). Their novel structure of DNN attains near optimal energy efficiency with minimal computation time, though it has not yet been applied to large scale dynamic scenarios. Such an approach would bene fit the construction industry as one could incorporate AI enabled UAV networks for coordinated working in large infrastructure projects to optimize communication with in multi-UAV surveillance and site mapping [7].

Li et al. (2023) proposed an energy efficient task offloading and trajectory planning model in UAV enabled MEC networks. Their deep reinforcement learning based approach, EE PPO, converges fast and enhances the energy efficiency of UAVs by jointly considering task offloading and resource allocation. This method is highly applicable to construction where UAVs have to coordinate material transport, structural inspections, and safety surveillance while maintaining optimal energy consumption [8].

Feng et al. proposed a MADRL model for UAV assisted NOMA IoT data collecting in 2023. This model maximizes energy efficiency and communication dependability by providing the best UAV trajectory designs and power distribution in hybrid NOMA networks. This technique can be used by UAVs to collect data autonomously on big construction sites, effectively managing energy resources and sending real time progress data to centralized control systems [9].

To enhance the energy efficiency of UAV relaying systems, Guo et al. (2023) have proposed a joint optimization methodology integrating trajectory de sign, power control, and scheduling. The authors greatly improve energy management by using an iterative algorithm created using the block coordinate descent methodology. These methods can be very important when UAV relays are needed in construction settings [10].

Kim et al. (2024) considered optimization of AoI for minimizing the energy consumption for data transmission at multi-UAV networks. They performed a hierarchical placement of UAVs, which aids in real time cooperative trajectory planning in dynamic environment using Deep Q Networks. This mechanism is well suitable for applying construction sites whereby the UAV requires coordinating with fewer energy consumptions for monitoring its progress, observing anomalies, and improving real time decision-making ability [11].

Gómez-DelaHiz et al. (2024) improved the throughput and energy consumption of UAV networks for IoT applications under the framework of microservices. The proposed mixed-integer linear programming model maximized throughput while minimizing energy consumption, which appears to point out the relevance of UAV placement strategies in the architecture: the results can directly influence construction site management, wherein optimal UAV positioning improves resource allocation, real time site assessment, and smart infrastructure planning [12].

Alsalmi, Navaie, and Rahmani (2024) compared two routing algorithms, DRL OLSR and self-organizing map (SOM)-OLSR, to identify the best approach for optimizing network performance in terms of throughput and energy consumption. Their results showed that DRL-OLSR outperformed SOM-OLSR in terms of throughput and energy efficiency, which can be crucial in construction sites where UAV networks must balance high data rates and long operational durations. Implementing these routing techniques in construction UAV frameworks can enhance real time communication and surveillance efficiency [13].

Andreou et al. (2024) integrated Federated Learning (FL) and Deep Deterministic Policy Gradient (DDPG) algorithms into UAV networks to enhance throughput and energy efficiency. Their ENUO-ASP algorithm optimizes UAV placement, resource allocation, and latency reduction. Construction environments, particularly smart city developments, can integrate these techniques to ensure robust UAV operations in infrastructure assessment, material transport coordination, and automated safety inspections [14].

Song, Kim, and Kim (2024) considered improving energy efficiency in UAV assisted joint communication and radar systems. By utilizing a reinforcement learning scheme for UAV positioning, enhancement energy efficiency was considered along with system performance. These kinds of methodologies, based on RL, are very applicable to construction in terms of advanced safety monitoring, environmental impact assessments, and precision tracking of critical infrastructure developments. These AI-driven methodologies can be adapted by UAVs to enhance automation, reduce manual intervention, and improve construction site intelligence for more sustainable and efficient infrastructure development [15].

While research focuses a great deal on the optimization of UAV energy efficiency and throughput, stable communication remains a significant parameter for UAV construction tasks. General network protocols such as 5G and LoRa offer high rate and long-range connectivity, respectively, but are not adapted to dynamic UAV environments. Flying Ad Hoc Networks (FANETs), wireless mesh networks (IEEE 802.11s), Terahertz (THz) communication, and LiFi (Light Fidelity) are the emergent technologies offering inertiable, high bandwidth, and interference resistant solutions. Conversely, issues such as signal interference, latency, and susceptibility to data insecurity matters require effective encryption structures and resilient transfer protocols for easy UAV operation. Overcoming such communication barriers is important to wards effective UAV cooperation in massive constructions.

3. COMPARATIVE ANALYSIS

Table -1: Comparative Analysis

Reference	Author	Methodology	Advantages	Limitations	Remarks
[1]	Zeng & Zhang (2017)	Optimizes UAV circular trajectory with energy efficiency	Good advancements in terms of energy efficiency and throughput	Fail to achieve efficiency in some paths; does not develop rotary-wing model New UAV models	Trajectory optimization should be further researched
[2]	Mkiramweni & Yang (2018)	Nash bargaining for power control in UAV networks	Enhanced connectivity and coverage	Energy use trade-offs based on beacon duration	Extending cooperative strategies to multi-UAV systems
[3]	Hua et al. (2019)	Optimization of resource allocation and user distribution in cellular networks	Improved energy efficiency over benchmarks	Complex, non-convex optimization	Refinements in UAV trajectory and user partitioning strategies
[4]	Tang et al. (2021)	Data collection optimization in UAV-aided IoT networks	Energy-efficient results with robust trajectory management	Limited to small IoT networks	Future research to scale the method for larger IoT applications
[5]	Do et al. (2022)	Enhancing federated learning in UAV networks using deep reinforcement learning	Reduces energy use in federated tasks	Battery constraints remain	Suggested focus on energy harvesting and sustainable UAV network practices
[6]	Jouhari et al. (2023)	Deep reinforcement learning for LoRa-based UAV gateways in IoT	Extends network lifetime and outperforms benchmarks	Challenges with energy demands across diverse networks	Suggested future research on adaptive DRL techniques for broader IoT applications
[7]	Lee et al. (2023)	Deep learning for network-wide energy optimization in ultra-	Near-optimal energy efficiency with	Challenges in large-scale, dynamic scenarios	Future work on scalable architectures for large UDSCNs

		dense small cell networks (UDSCN)	minimal computation		
[8]	Li et al. (2023)	Energy-efficient task offloading and trajectory planning in UAV-enabled MEC networks	Fast convergence and improved energy efficiency	Computational complexity in real-time scenarios	Focus on managing complexities in real-time, dynamic environments
[9]	Feng et al. (2023)	Multi-agent deep reinforcement learning for optimizing UAV-aided NOMA data collection in IoT networks	Maximizes energy efficiency and communication reliability	Non-convexity in complex network environments	Research on advanced MADRL techniques for broader IoT applications
[10]	Guo et al. (2023)	Joint optimization of scheduling, power control, and trajectory design using an iterative algorithm	Maximizes energy efficiency in UAV relaying	Limited to specific optimizations	Future work on comparing algorithm efficiency with alternative schemes
[11]	Kim et al. (2024)	Real-time decision-making in multi-UAV networks with hierarchical deployment using Deep Q-Network	Significant energy reduction (74.20% in urban scenarios)	Limited scalability and lacks comparison with other techniques	Expanding optimization strategies to diversified environments suggested
[12]	Gómez-DelaHiz et al. (2024)	Mixed-integer linear programming for throughput and energy optimization in UAV networks	Maximizes throughput while minimizing energy consumption	Limited discussion on microservice-based UAV networks	Future work to optimize UAV placement in rural settings
[13]	Alsalmi et al. (2024)	Deep reinforcement learning for routing optimization in UAV networks	47% better throughput and 67% less energy consumption compared to benchmarks	Balancing throughput and energy efficiency in multi-UAV deployments is challenging	Mechanisms to manage energy trade-offs in multi-UAV systems recommended
[14]	Andreou et al. (2024)	Federated Learning (FL) with Deep Deterministic Policy Gradient (DDPG) for UAV optimization	Higher data rates, reduced latency, and energy consumption	Battery limitations and communication overhead	Further optimization of UAV energy strategies and FL applications suggested
[15]	Song et al. (2024)	RL-based energy efficiency improvement for UAV-based joint communication and radar systems	Enhances energy efficiency and system performance	Persistent energy constraints in JCR systems	Future work could address energy efficiency improvements in JCR systems and extended RL applications

4. CONCLUSIONS

The findings of this paper are based on recent developments from 2017 to 2024, specifically in enhancing energy efficiency and network performance in UAV supported smart construction applications. One of the major research directions for this work includes trajectory optimization, resource allocation, deep reinforcement learning, and control algorithms to enhance UAV operations in dynamic construction environments. Although these breakthroughs have enabled enormous strides to be taken, these research efforts and insights still leave several absolutely crucial domains of application quite neglected and awaiting future investigation. Many models work well in controlled settings but tend to scale poorly in complex dynamic environments, such as large construction sites or rapidly evolving projects to rebuild infrastructure in cities. Research efforts must focus on adaptive AI-based UAV frameworks development integrated for seamless applications to real time management of construction sites, automated inspection, and other large-scale development of smart infrastructures. Until now, quite a number of energy-saving methods were proposed for a UAV; the operational distance and endurance are still limited by the capacity of its battery. With the aim of ensuring continued UAV operation over a longer period of time, this may range from continuous monitoring of structural elements to material transport or environmental impact assessment, technological advancement through better battery technology, wireless energy transfer methods, or energy harvesting methods. Real-time applications mostly involve dynamically changing variables; this often leads to the appearance of non-convex problems and mixed integer nonlinear programs that require much computation. Future work involves developing new optimization algorithms and heuristic approaches that will be able to efficiently address energy consumption, computational complexity, and real time decision making by the UAV in a construction environment. This review, based on a structured methodology involving keyword-based searches, citation analysis, and relevance filtering across IEEE Xplore, Scopus, Web of Science, and Google Scholar, underscores the growing importance of AI-powered UAVs in enhancing automation, optimizing resource management, and improving safety in construction. These challenges are going to consistently make AI-powered UAVs more important in order to enhance automation, optimized resource management, and safety features for the construction industry, leading toward more sustainable and efficient infrastructural development.

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