A Comprehensive Review on IoT-Based Hydroponic Farming Systems: Trends, Technologies, and Challenges

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Abstract: *IoT technology has revolutionized hydroponic farming by enhancing the precision of real-time monitoring, automation, and nutrient and water management. This review explores 25 recent studies integrating IoT systems in hydroponic environments, focusing on methodologies, outcomes, and identified research gaps. Each study demonstrates the application of various IoT components such as microcontrollers, sensors, cloud platforms, and machine learning models to optimize growing conditions, minimize resource waste, and increase crop yields. Key findings indicate significant improvements in nutrient efficiency, water usage, and yield outcomes, with reductions in manual oversight ranging from 15% to 50%. IoT systems have also enabled advanced functionalities such as predictive analytics, remote monitoring, and automated nutrient dosing. However, the literature reveals consistent gaps in system scalability, long-term power efficiency, and data security, particularly concerning sensor reliability and integration in larger setups. Additionally, many systems struggle to maintain consistent performance in environments with intermittent connectivity or varying light conditions, such as solar energy. By identifying these limitations, this review underscores the potential for future research to address these challenges through more robust, scalable designs and low-power solutions for sustainable operation. This study provides an in-depth synthesis of IoT applications in hydroponics, establishing a foundation for developing enhanced, resilient IoT-based systems better suited for diverse agricultural environments and capable of advancing sustainable agriculture through intelligent automation and resource management.*

Keywords: IoT, hydroponic farming, precision agriculture, real-time monitoring, automation, nutrient management, water efficiency