Enhancing health monitoring of energy harvesting systems through edge analytics in off-grid smart irrigation systems

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Abstract

Energy harvesting offers a sustainable solution by utilising ambient energy to efficiently capture, convert, and store power, particularly vital for off-grid devices that rely on limited battery power, susceptible to rapid depletion from computationally intensive applications demanding low latency and real-time responses. Ensuring the operational health of energy harvesting systems is critical; thus, this study evaluates an edge-computing architecture logic that leverages real-time sensor data for fault detection, early fault identification, and predictive maintenance to reduce downtime and enhance system reliability. The framework employs algorithms to optimise energy consumption, prolong operational lifespan, and ensure sustainability. Continuous analysis of energy input/output, environmental factors such as temperature and solar intensity, and energy trends at the edge enables detection of shading, faults, and failures. Results indicate that 90.5 % of the energy harvested reflected stable operation, with shading accounting for 7 %, faults 1 %, and failures 1 %. Additionally, the study identifies critical energy management points such as charge depletion and peak consumption hours, facilitating adaptive responses to changing energy patterns. A comparative analysis between standard edge analysis and integrated edge-predictive methods shows that the integrated system achieves an accuracy of 91.6 %, compared to the edge analytics model with an accuracy of 86.2 % effectively stabilising short-term fluctuations, generating fewer and more stable alerts, with a coefficient of determination R^2 of 0.98. Overall, this approach enhances the scalability and sustainability of solar energy harvesting, particularly in off-grid scenarios, by providing timely fault detection, improving operational efficiency, and promoting sustainable energy practices that minimise waste and maximise energy use.

Keywords: Edge analytics, IoT-based monitoring, off-grid renewable energy systems, predictive maintenance, real-time analytics

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