ABSTRAK

Transformasi Industri 4.0 menuntut arsitektur komputasi yang efisien dan responsif untuk mendukung analitik data *real-time*, termasuk *predictive maintenance*. *Edge*, *Cloud*, dan *Hybrid Computing* banyak dibahas, namun masih sedikit studi eksperimental yang membandingkan performanya secara sistematis di konteks manufaktur. Penelitian ini mengisi gap tersebut dengan mengevaluasi tiga arsitektur berdasarkan kekuatan komputasi (*CPU* & *RAM*), penyimpanan (*Write IOPS* & *disk usage*), dan latensi *end-to-end*. Eksperimen dilakukan selama tiga jam per skenario dengan laju 20 pesan/detik menggunakan protokol MQTT dan model *predictive maintenance*. Hasil menunjukkan bahwa *Edge* unggul dalam latensi rendah (17,5 ms) namun terbatas dalam hal skalabilitas. *Cloud* lebih efisien dalam penyimpanan (*disk usage* 12% lebih rendah) dan komputasi, tetapi memiliki latensi lebih tinggi (116 ms). *Hybrid* mendistribusikan beban secara seimbang, namun latensinya tertinggi karena proses dua tahap. Penelitian ini juga mengidentifikasi tiga faktor pemilihan arsitektur: kebutuhan latensi rendah (*Edge*), komputasi-penyimpanan besar (*Cloud*), dan keseimbangan efisiensi-latensi (*Hybrid*). Temuan ini memberikan dasar empiris untuk pemilihan arsitektur komputasi optimal di ekosistem Industri 4.0.

Kata Kunci: *Cloud Computing* , *Edge Computing*, *Hybrid*, Industri 4.0, *Predictive Maintenance*

ABSTRACT

The Industry 4.0 transformation demands efficient and responsive computing architectures to support real-time data analytics, including predictive maintenance. Edge, Cloud, and Hybrid Computing have been widely discussed, but there are few experimental studies that systematically compare their performance in a manufacturing context. This study fills the gap by evaluating three architectures based on computing power (CPU & RAM), storage (Write IOPS & disk usage), and end-to-end latency. The experiments were conducted for three hours per scenario at a rate of 20 messages/second using the MQTT protocol and a trained predictive maintenance model. The results show that Edge excels in low latency (17.5 ms) but is limited in scalability. Cloud is more efficient in storage (12% lower disk usage) and computing, but has higher latency (116 ms). Hybrid distributes the load evenly, but has the highest latency due to the two-stage process. This study also identifies three factors for architecture selection: low latency Requirement (Edge), large compute-storage (Cloud), and efficiency-latency trade-offs (Hybrid). These findings provide an empirical basis for selecting optimal computing architectures in Industry 4.0 ecosystems.

***Keywords**: Edge Computing, Cloud Computing, Hybrid, Predictive Maintenance, Industry 4.0*