ABSTRAK

IMPLEMENTASI PERANGKAT DAN ANALISIS DATA GAS ANALYZER PEMANTAUAN EMISI KARBON DI PERKEBUNAN KELAPA SAWIT LAHAN GAMBUT

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Perubahan iklim akibat peningkatan CO_2 dan CH_4 menjadikan ekosistem gambut, khususnya yang menjadi lahan perkebunan kelapa sawit, sebagai prioritas pemantauan emisi. Pemantauan yang kredibel untuk kebutuhan *monitoring-reporting-verification* (MRV) menuntut integrasi multi-sensor (gas dan mikroklimat) yang pada sebuah menara meteorologi statis. Namun, tata letak antar sensor di menara kerap berjauhan (puluhan meter) untuk pengukuran pada ketinggian yang berbeda, sementara antarmuka I^2C dan UART pada instrumen riset umumnya dibatasi jarak kabel pendek dan rentan degradasi sinyal. Keterbatasan jarak ini menghambat sinkronisasi data dan meningkatkan *downtime*. Penelitian ini menerapkan I^2C extender dan UART extender guna memperluas jangkauan komunikasi sensor, sekaligus menganalisis hubungan emisi CO_2 dengan variabel lingkungan menggunakan tiga pendekatan korelasi (Spearman, Kendall Tau, dan *distance correlation*). Uji lapangan dilakukan di PT Persada Dinamika Lestari, Kalimantan Selatan, menggunakan Gas Analyzer dan Microclimate Station. Ekstender berhasil memperluas jangkauan hingga 20 m dengan latensi rata-rata 74,33 ms, *jitter* 0,69 ms, dan keberhasilan akuisisi 99,90%. Secara operasional, latensi <100 ms dan *jitter* sub-ms memadai untuk akuisisi 1 Hz–10 Hz, sehingga kesinambungan data untuk MRV tetap terjaga. Analisis korelasi menunjukkan CO_2 berasosiasi negatif dengan suhu, tekanan, uap air, dan radiasi matahari, konsisten dengan penurunan konsentrasi siang hari akibat penyerapan fotosintetik dan pengenceran *boundary layer*, serta positif dengan kelembapan relatif, mencerminkan akumulasi malam hari saat lapisan permukaan stabil. Hubungan dengan CH_4, curah hujan, dan kecepatan angin lemah/tidak signifikan, menandakan perbedaan skala proses dan kontrol hidrologi yang berbeda. Di antara metode yang diuji, Spearman paling efektif mengungkap hubungan monotonic lintas rentang pengamatan, sementara *distance correlation* membantu menandai kemungkinan ketidaklinieran lemah. Temuan ini menunjukkan bahwa skema ekstender I^2C/UART yang rendah biaya, berlatensi rendah, dan andal dapat menskalakan jaringan sensor di lahan gambut, sekaligus memperkaya interpretasi proses melalui analisis korelasi multi-metode untuk mendukung strategi mitigasi emisi yang berkelanjutan.

Kata Kunci: Emisi karbon, Gas Analyzer, Microclimate, I2C Extender, UART extender, Korelasi data emisi

ABSTRACT

IMPLEMENTATION OF MONITORING EQUIPMENT AND DATA ANALYSIS OF GAS ANALYZERS FOR CARBON EMISSIONS IN PEATLAND OIL PALM PLANTATIONS

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Rising concentrations of CO_2 and CH_4 make peatland ecosystems, especially oil palm plantations, priorities for emission monitoring. Credible Monitoring–Reporting–Verification (MRV) requires integrated multi-sensor networks (gas and microclimate) on a fixed meteorological tower. In practice, sensors on such towers are separated by tens of meters to sample different heights, while I^2C and UART interfaces are limited to short cable runs and are susceptible to signal degradation, hindering synchronization and increasing downtime. This study implements I^2C and UART extenders to overcome distance constraints and analyzes relationships between CO_2 and environmental variables using three correlation approaches: Spearman, Kendall Tau, and distance correlation. Field tests were conducted at PT Persada Dinamika Lestari, South Kalimantan, employing a Gas Analyzer and a Microclimate Station. The extenders expanded communication range to 20 m with average latency of 74.33 ms, jitter of 0.69 ms, and a data-acquisition success rate of 99.90%. Operationally, latency under 100 ms and sub-millisecond jitter are adequate for 1–10 Hz acquisition, preserving MRV continuity. Correlation analysis shows that CO_2 is negatively associated with air temperature, pressure, water vapor, and solar radiation, consistent with daytime drawdown from photosynthetic uptake and boundary-layer dilution, and positively associated with relative humidity, reflecting nocturnal accumulation under stable surface layers. Relationships with CH_4, rainfall, and wind speed were weak or not significant, indicating different process scales and hydrological controls. Among the three methods, Spearman most effectively identified monotonic associations across the observation range, whereas distance correlation highlighted weak nonlinearity that rank-based metrics may understate. These results demonstrate that a low-cost, low-latency, and reliable I^2C/UART-extender scheme can scale sensor networks on peatland towers and strengthen the interpretability of multi-sensor carbon monitoring. The approach offers a practical pathway to precise and adaptive emissions surveillance in tropical peatlands and supports sustainable mitigation strategies within oil palm landscapes.

Keywords: Carbon emissions, Gas Analyzer, Microclimate, I2C extender, UART extender, Emission data correlation.