Deep Learning-Based Structural Monitoring of Oil Palm Inflorescences for Early-Stage Pollination Assessment Using UAV Imagery

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Abstrak

Kajian ini dijalankan untuk suatu sistem pemantauan awal pendebungaan kelapa sawit berasaskan dron tanpa pemandu (UAV) dan deep learning bagi memantau keseimbangan bunga jantan dan bunga betina dalam kawasan mikro-plot terkawal berkeluasan 10 × 10 pokok. Sistem yang dicadangkan diintegrasikan dengan pengesanan imej bunga menggunakan model YOLO, pengiraan Pollination Ratio Index (PRI), dan beberapa analisis statistik bagi menilai perkembangan pendebungaan. Data dikumpulkan dari November 2025 hingga Januari 2026 dengan mengambil kira faktor altitud, halangan kanopi, dan keadaan angin. Keputusan menunjukkan bahawa variasi struktur bunga memberi kesan signifikan terhadap nilai PRI dan keseimbangan pengesanan, dengan perbezaan statistik yang signifikan diperoleh melalui analisis ANOVA ($p < 0.05$). Kajian ini membuktikan bahawa pemantauan struktur bunga menggunakan UAV berpotensi menjadi mekanisme sokongan keputusan yang lebih awal dan lebih sistematik berbanding kaedah pemerhatian manual yang konvensional.

Abstract

This study was conducted to develop an early-stage oil palm pollination monitoring system based on Unmanned Aerial Vehicle (UAV) technology and deep learning to monitor the balance between male and female flowers within a controlled 10 × 10 tree micro-plot area. The proposed system integrates floral image detection using a YOLO model, Pollination Ratio Index (PRI) computation, and several statistical analyses to evaluate pollination development. Data were collected from November 2025 to January 2026, taking into account altitude, canopy occlusion, and wind-condition factors. The findings indicate that variations in floral structure significantly affect PRI values and detection balance, with statistically significant differences identified through ANOVA analysis ($p < 0.05$). This study demonstrates that UAV-based floral structure monitoring has strong potential to serve as an earlier and more systematic decision-support mechanism compared to conventional manual observation methods.

Keywords **:** *Oil palm inflorescence, Deep learning, Object detection, Pollination monitoring, Precision agriculture, Elaeidobius kamerunicus, UAV-based imaging*