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FACULTY OF ENGINEERING
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WHERE CONCEPTS BECOME REALITY

2025/26 Interdepartmental Final Year Project Interim Report

Intelligent UAV Systems for GNSS-Based Remote Sensing on Vegetation

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1 Abstract

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2 Introduction

Vegetation is a critical asset to the environment and the human civilization. Not only does vegetation produce essential societal resources, but its distribution and productivity also greatly impacts the terrestrial ecosystems and the global climate [1]. Therefore, the continuous and accurate monitoring of vegetation is essential for sustainable resource management [2], ecosystem preservation [3], and climate change modeling [1].

Traditionally, methods of vegetation monitoring involved manual field assessments of site characteristics, extracting vegetation condition indicators such as species composition, geometrical structure, and biochemical activities [4]. However, the accuracy and efficiency of such monitoring methods are highly dependent on the available expertise and resources, as the site assessments often required the assessor to possess reasonable levels of field knowledge prior to surveying [5]. To address the limitations of manual assessments and to accommodate for the increasing large-scale monitoring demands, remote sensing systems emerged as an essential tool for ecological monitoring [6].

Remote sensing refers to the acquisition of an object's information through measurements obtained without coming into direct contact with said object, effectively minimizing the need for manual involvement on-site [7]. Specifically, remote sensing relies on information derived from different measurements of energy reflected from the object of interest [7]. In the context of surveying terrestrial vegetation, the remote sensing methods could be classified into two categories based on the distance between the target object and the measurement sensor: 1) space-borne and 2) airborne remote sensing. Space-borne remote sensing involves the use of instruments onboard orbiting satellites, including spectral and hyperspectral cameras [8], synthetic aperture radar (SAR) [9], and space-borne Light Detection And Ranging (LiDAR) sensors [10]. Due to the wide coverage and availability of space-borne data, large-scale terrestrial changes over time could be captured, enabling the continuous monitoring of macro-scale ecosystems [11]. Compared to space-borne systems, airborne remote sensing can provide significantly improved spatial resolution and assessment flexibility through the integration of sensors onboard manned aircraft or unmanned aerial vehicles (UAVs) [11]. Although limited by coverage area, airborne remote sensing can provide timely information for addressing regional emergencies such as pest [12] or wildfire [13] outspreads since the systems could be deployed on-demand. In UAV-based remote sensing particularly, this temporal flexibility is further complemented with the benefit of low operational cost, rendering it an ideal platform for monitoring regional and urban vegetation [14].

Conventionally, UAV remote sensing platforms carry similar instruments to that of other remote sensing systems, including radar, LiDAR, and multi-spectral or hyperspectral imagery sensors [14]. However, while imaging instruments are susceptible to the influence of lighting and weather [15], LiDAR devices tend to face difficulties penetrating through dense canopy [16]. Therefore, it is critical to explore a robust sensing technique that is suitable for UAVs in terms of payload and power consumption to complement the existing instruments. Recently, the technique of Global Navigation Satellite System Reflectometry (GNSS-R) is receiving increasing interest in the field of remote sensing. GNSS-R exploits the L-band signals transmitted from Global Navigation Satellite Systems (GNSS) that are then scattered on different terrain surfaces of the Earth [17]. Then, the reception of reflected GNSS signals can provide information regarding the properties of the signal reflector on land [17]. As signals of opportunity conventionally dedicated to Positioning, Navigation, and Timing (PNT) applications, GNSS is capable of providing real-time measurements regardless of time, location, and weather [17]. Additionally, as a bi-static system where signal transmitters are separated from receivers, GNSS-R is exempt from the need of dedicated transmitter-receiver instruments that are crucial to mono-static radar systems [18]. Instead, any consumer-grade receivers capable of receiving reflected GNSS signals could be used for GNSS-R remote sensing, further demonstrating GNSS-R's applicability onboard low-cost remote sensing systems such as an UAV.

May need some intro for path planning and lidar here. The above is from Louise's project proposal, so need further editing.

In this project, the technique of GNSS-R will be integrated onto an UAV platform to achieve an intelligent and structured remote sensing system for vegetation monitoring. The main objectives of this project are as follows:

1. To introduce an autonomous path planning framework onboard the UAV platform for optimized GNSS-R remote sensing.
2. To analyze and model the correlations between signal propagation parameters retrieved through GNSS-R and ground vegetation conditions.
3. To classify signals reflected by vegetation and predict vegetation parameters based on raw GNSS data using machine learning-based approach.
4. To establish a detailed 3D canopy map using LiDAR-based SLAM, providing a spatial validation reference for the 2D vegetation features detected by GNSS-R.

This report is structured as follows: Section 3 reviews contemporary research in UAV path planning, GNSS-R, machine learning, and LiDAR SLAM, while Section 4 outlines the project's methodologies. The subsequent sections cover the experiments conducted (Section 5), a discussion of current results (Section 6), and the project conclusions (Section 7). Finally, Section 8 explores future work, and Section 9 summarizes project management details.

3 Literature Review

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4 Methodology

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Appendix

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