

2025/26 Interdepartmental Final Year Project Interim Report

# **Intelligent UAV Systems for GNSS-Based Remote Sensing on Vegetation**

[AAE] ZHOU Jiayi (22099961D)

[AAE] MAHMUD Md Sahat (22097159D)

[EEE] GAMAGE Sashenka (22097129D)

[ME] TAN Qing Lin (22101126D)

**Chief Supervisor:** [AAE] Prof. Guohao ZHANG

**Co-Supervisor:** [AAE] Prof. Li-Ta HSU

**Date of Submission:** 2026 January 18

## Contents

<b>1</b>	<b>Abstract</b>	<b>1</b>
<b>2</b>	<b>Introduction</b>	<b>1</b>
<b>3</b>	<b>Literature Review</b>	<b>1</b>
3.1	Path Planning . . . . .	1
3.2	GNSS-R . . . . .	1
3.3	Machine Learning . . . . .	1
3.4	LiDAR SLAM . . . . .	1
<b>4</b>	<b>Methodology</b>	<b>1</b>
4.1	UAV Platform . . . . .	1
4.2	System Architecture . . . . .	2
4.3	Path Planning . . . . .	2
4.4	GNSS-R . . . . .	2
4.5	Machine Learning . . . . .	2
4.6	LiDAR SLAM . . . . .	2
<b>5</b>	<b>Experiments</b>	<b>2</b>
5.1	Experiment Workflow . . . . .	2
5.2	Summary of Experiments Conducted . . . . .	2
5.3	Key Experiment 1 . . . . .	2
5.4	Key Experiment 2 . . . . .	3
<b>6</b>	<b>Results and Discussion</b>	<b>3</b>
6.1	Path Planning . . . . .	3
6.2	GNSS-R . . . . .	3
6.3	Machine Learning . . . . .	3
6.4	LiDAR SLAM . . . . .	3
<b>7</b>	<b>Conclusion</b>	<b>3</b>

<b>8</b>	<b>Future Works</b>	<b>3</b>
8.1	Path Planning . . . . .	3
8.2	GNSS-R . . . . .	4
8.3	Machine Learning . . . . .	4
8.4	LiDAR SLAM . . . . .	4
<b>9</b>	<b>Project Management</b>	<b>4</b>
9.1	Gantt Chart . . . . .	4
9.2	Project Difficulties and Solutions . . . . .	4
9.2.1	Path Planning . . . . .	4
9.2.2	GNSS-R . . . . .	4
9.2.3	Machine Learning . . . . .	4
9.2.4	LiDAR SLAM . . . . .	5
	<b>Appendix</b>	<b>6</b>
	<b>References</b>	<b>7</b>

## **1 Abstract**

Placeholder text

## **2 Introduction**

Placeholder text

## **3 Literature Review**

Placeholder text

### ***3.1 Path Planning***

Placeholder text

### ***3.2 GNSS-R***

Placeholder text

### ***3.3 Machine Learning***

Placeholder text

### ***3.4 LiDAR SLAM***

Placeholder text

## **4 Methodology**

Placeholder text

### ***4.1 UAV Platform***

Placeholder text

## ***4.2 System Architecture***

Placeholder text

## ***4.3 Path Planning***

Placeholder text

## ***4.4 GNSS-R***

Placeholder text

## ***4.5 Machine Learning***

Placeholder text

## ***4.6 LiDAR SLAM***

Placeholder text

# **5 Experiments**

Placeholder text

## ***5.1 Experiment Workflow***

Placeholder text

## ***5.2 Summary of Experiments Conducted***

Placeholder text

## ***5.3 Key Experiment 1***

Placeholder text

## **5.4    *Key Experiment 2***

Placeholder text

## **6    Results and Discussion**

Placeholder text

### **6.1    *Path Planning***

Placeholder text

### **6.2    *GNSS-R***

Placeholder text

### **6.3    *Machine Learning***

Placeholder text

### **6.4    *LiDAR SLAM***

Placeholder text

## **7    Conclusion**

Placeholder text

## **8    Future Works**

Placeholder text

### **8.1    *Path Planning***

Placeholder text

## **8.2 GNSS-R**

Placeholder text

## **8.3 Machine Learning**

Placeholder text

## **8.4 LiDAR SLAM**

Placeholder text

# **9 Project Management**

Placeholder text

## **9.1 Gantt Chart**

Placeholder text

## **9.2 Project Difficulties and Solutions**

Placeholder text

### **9.2.1 Path Planning**

Placeholder text

### **9.2.2 GNSS-R**

Placeholder text

### **9.2.3 Machine Learning**

Placeholder text

#### 9.2.4 *LiDAR SLAM*

Placeholder text



## **Appendix**

Placeholder text

## References

- [1] A. D. Richardson, T. F. Keenan, M. Migliavacca, Y. Ryu, O. Sonnentag, and M. Toomey, “Climate change, phenology, and phenological control of vegetation feedbacks to the climate system,” *Agricultural and Forest Meteorology*, vol. 169, p. 156–173, Feb. 2013. [Online]. Available: <http://dx.doi.org/10.1016/j.agrformet.2012.09.012>
- [2] J. Wallace, G. Behn, and S. Furby, “Vegetation condition assessment and monitoring from sequences of satellite imagery,” *Ecological Management & Restoration*, vol. 7, no. s1, May 2006. [Online]. Available: <http://dx.doi.org/10.1111/j.1442-8903.2006.00289.x>
- [3] Y. Zeng, D. Hao, A. Huete, B. Dechant, J. Berry, J. M. Chen, J. Joiner, C. Frankenberg, B. Bond-Lamberty, Y. Ryu, J. Xiao, G. R. Asrar, and M. Chen, “Optical vegetation indices for monitoring terrestrial ecosystems globally,” *Nature Reviews Earth & Environment*, vol. 3, no. 7, p. 477–493, May 2022. [Online]. Available: <http://dx.doi.org/10.1038/s43017-022-00298-5>
- [4] P. Gibbons and D. Freudenberger, “An overview of methods used to assess vegetation condition at the scale of the site,” *Ecological Management & Restoration*, vol. 7, no. s1, May 2006. [Online]. Available: <http://dx.doi.org/10.1111/j.1442-8903.2006.00286.x>
- [5] D. Parkes, G. Newell, and D. Cheal, “Assessing the quality of native vegetation: The ‘habitat hectares’ approach,” *Ecological Management & Restoration*, vol. 4, no. s1, Feb. 2003. [Online]. Available: <http://dx.doi.org/10.1046/j.1442-8903.4.s.4.x>
- [6] L. Li, X. Xin, J. Zhao, A. Yang, S. Wu, H. Zhang, and S. Yu, “Remote sensing monitoring and assessment of global vegetation status and changes during 2016–2020,” *Sensors*, vol. 23, no. 20, p. 8452, Oct. 2023. [Online]. Available: <http://dx.doi.org/10.3390/s23208452>
- [7] J. Campbell and R. Wynne, *Introduction to Remote Sensing, Fifth Edition*. Guilford Publications, 2011. [Online]. Available: <http://books.google.com.hk/books?id=NkLmDjSS8TsC>

- [8] S. Qian, “Overview of hyperspectral imaging remote sensing from satellites,” p. 41–66, Nov. 2022. [Online]. Available: <http://dx.doi.org/10.1002/9781119687788.ch2>
- [9] C. Hu, Y. Li, Z. Chen, F. Liu, Q. Zhang, A. V. Monti-Guarnieri, S. Hobbs, A. Anghel, and M. Datcu, “Distributed spaceborne sar: A review of systems, applications, and the road ahead,” *IEEE Geoscience and Remote Sensing Magazine*, vol. 13, no. 2, p. 329–361, Jun. 2025. [Online]. Available: <http://dx.doi.org/10.1109/MGRS.2025.3535412>
- [10] K. M. Bergen, S. J. Goetz, R. O. Dubayah, G. M. Henebry, C. T. Hunsaker, M. L. Imhoff, R. F. Nelson, G. G. Parker, and V. C. Radeloff, “Remote sensing of vegetation 3-d structure for biodiversity and habitat: Review and implications for lidar and radar spaceborne missions,” *Journal of Geophysical Research: Biogeosciences*, vol. 114, no. G2, Jun. 2009. [Online]. Available: <http://dx.doi.org/10.1029/2008JG000883>
- [11] M. N. Khan, Y. Tan, A. A. Gul, S. Abbas, and J. Wang, “Forest aboveground biomass estimation and inventory: Evaluating remote sensing-based approaches,” *Forests*, vol. 15, no. 6, p. 1055, Jun. 2024. [Online]. Available: <http://dx.doi.org/10.3390/f15061055>
- [12] M. A. Wulder, C. C. Dymond, J. C. White, D. G. Leckie, and A. L. Carroll, “Surveying mountain pine beetle damage of forests: A review of remote sensing opportunities,” *Forest Ecology and Management*, vol. 221, no. 1–3, p. 27–41, Jan. 2006. [Online]. Available: <http://dx.doi.org/10.1016/j.foreco.2005.09.021>
- [13] L. A. Arroyo, C. Pascual, and J. A. Manzanera, “Fire models and methods to map fuel types: The role of remote sensing,” *Forest Ecology and Management*, vol. 256, no. 6, p. 1239–1252, Sep. 2008. [Online]. Available: <http://dx.doi.org/10.1016/j.foreco.2008.06.048>
- [14] L. Tang and G. Shao, “Drone remote sensing for forestry research and practices,” *Journal of Forestry Research*, vol. 26, no. 4, p. 791–797, Jun. 2015. [Online]. Available: <http://dx.doi.org/10.1007/s11676-015-0088-y>

- [15] J. Wu, Y. Zhang, P. Hu, and Y. Wu, “A review of the application of hyperspectral imaging technology in agricultural crop economics,” *Coatings*, vol. 14, no. 10, p. 1285, Oct. 2024. [Online]. Available: <http://dx.doi.org/10.3390/coatings14101285>
- [16] J. G. Su and E. W. Bork, “Characterization of diverse plant communities in aspen parkland rangeland using lidar data,” *Applied Vegetation Science*, vol. 10, no. 3, p. 407–416, Jul. 2007. [Online]. Available: <http://dx.doi.org/10.1111/j.1654-109X.2007.tb00440.x>
- [17] S. Jin, A. Camps, Y. Jia, F. Wang, M. Martín-Neira, F. Huang, Q. Yan, S. Zhang, Z. Li, K. Edokossi, D. Yang, Z. Xiao, Z. Ma, and W. Bai, “Remote sensing and its applications using gnss reflected signals: advances and prospects,” *Satellite Navigation*, vol. 5, no. 1, May 2024. [Online]. Available: <http://dx.doi.org/10.1186/s43020-024-00139-4>
- [18] S. Jin and A. Komjathy, “Gnss reflectometry and remote sensing: New objectives and results,” *Advances in Space Research*, vol. 46, no. 2, p. 111–117, Jul. 2010. [Online]. Available: <http://dx.doi.org/10.1016/j.asr.2010.01.014>
- [19] M. Martín-Neira, “A pasive reflectometry and interferometry system (paris) application to ocean altimetry,” 1993. [Online]. Available: <https://api.semanticscholar.org/CorpusID:210311905>
- [20] N. Rodríguez-Alvarez, A. Camps, M. Vall-llossera, X. Bosch-Lluis, A. Monerris, I. Ramos-Perez, E. Valencia, J. F. Marchan-Hernandez, J. Martinez-Fernandez, G. Baroncini-Turricchia, C. Perez-Gutierrez, and N. Sanchez, “Land geophysical parameters retrieval using the interference pattern gnss-r technique,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 49, no. 1, p. 71–84, Jan. 2011. [Online]. Available: <http://dx.doi.org/10.1109/TGRS.2010.2049023>
- [21] P. Ferrazzoli, L. Guerriero, N. Pierdicca, and R. Rahmoune, “Forest biomass monitoring with gnss-r: Theoretical simulations,” *Advances in Space Research*, vol. 47, no. 10, p. 1823–1832, May 2011. [Online]. Available: <http://dx.doi.org/10.1016/j.asr.2010.04.025>
- [22] Y. Jia and Y. Pei, *Remote Sensing in Land Applications by Using GNSS-Reflectometry*. InTech, Jul. 2018. [Online]. Available: <http://dx.doi.org/10.5772/intechopen.72901>

- [23] X. Wu and S. Jin, “Gnss-reflectometry: Forest canopies polarization scattering properties and modeling,” *Advances in Space Research*, vol. 54, no. 5, p. 863–870, Sep. 2014. [Online]. Available: <http://dx.doi.org/10.1016/j.asr.2014.02.007>
- [24] S. H. Yueh, R. Shah, M. J. Chaubell, A. Hayashi, X. Xu, and A. Colliander, “A semiempirical modeling of soil moisture, vegetation, and surface roughness impact on cygnss reflectometry data,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 60, p. 1–17, 2022. [Online]. Available: <http://dx.doi.org/10.1109/TGRS.2020.3035989>
- [25] A. Camps, H. Park, M. Pablos, G. Foti, C. P. Gommenginger, P.-W. Liu, and J. Judge, “Sensitivity of gnss-r spaceborne observations to soil moisture and vegetation,” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 9, no. 10, p. 4730–4742, Oct. 2016. [Online]. Available: <http://dx.doi.org/10.1109/JSTARS.2016.2588467>
- [26] D. O. Silva, L. S. Pereira, E. R. Schlosser, M. V. Heckler, and F. Antreich, “On the characterization of reflective surfaces using dual-polarization gnss-r,” *Signal Processing*, vol. 227, p. 109692, Feb. 2025. [Online]. Available: <http://dx.doi.org/10.1016/j.sigpro.2024.109692>