学 位 論 文 審 査 の 要 旨

博士（環境科学）　　氏　名　XIAO Juan

審査委員　主査　准教授　Ram Avtar
副査　教　授　露崎　史朗
副査　教　授　沖野　龍文
副査　准教授　石川　守
副査　准教授　早川　裕一
副査　准教授　Rage Uday Kiran
（会津大学　コンピュータ理工学科）

学 位 論 文 題 名

Enhancing crop monitoring using unmanned aerial vehicle (UAV) images and deep learning
（ドローン画像とディープラーニングを用いた作物モニタリングの強化）

Effective crop monitoring is crucial for maximizing crop yield, promoting sustainable agriculture, and ensuring food security. Unmanned Aerial Vehicles (UAVs) offer precise spatial and spectral information about crops, making them an important platform for precision agriculture. This study aimed to enhance crop monitoring by integrating UAV images and Deep Learning (DL) techniques. Firstly, the research used UAV, DL, and geographic information systems (GIS) technology to monitor corn growth performance across different management practices. A literature review was then conducted on the SpatioTemporal Fusion (STF) of remote sensing images to reveal the potential of UAV image prediction for crop monitoring. Finally, this research proposed a DL-based STF model for centimeter-scale UAV image prediction to provide multi-temporal UAV images for enhancing crop monitoring.

The research involved two experimental corn fields divided into four plots, evaluating various corn management practices. UAVs equipped with RGB and multispectral cameras were used to collect corn field images. The study mapped plant height, Normalized Difference Vegetation Index (NDVI), Normalized Difference Red-Edge Index (NDRE), plant density, and plant volume based on the UAV images. The YOLOv5 model and the Otsu thresholding method were used to automatically count corn plants and extract heights and Vegetation Indices (VIs) from UAV images. The results showed that these techniques were efficient and accurate.

The emergence rates of corn plants varied across plots, with fertilizer application close to seeds being the optimal practice for higher emergence rates. The study provided valuable insights into corn field practices to help optimize corn cultivation, with potential

applications in other crops. This study used UAV and DL techniques to provide precise information and valuable insights into corn field practices, which can help farmers to optimize corn cultivation. The techniques applied in this study could be extrapolated to improve cultivation processes for other crops.

The research also conducted a comprehensive review of SpatioTemporal Fusion (STF) models, focusing on DL-based models that use Convolutional Neural Networks (CNNs). A new end-to-end DL-based STF model named UAV-Net was proposed, capable of predicting centimeter-scale UAV images with high accuracy and precision. The model showed promising potential for various precision environmental monitoring applications. State-of-the-art STF models fuse images from various satellites, not satisfying the demand for precise crop monitoring. The review demonstrated that DL-based STF models have a high potential for higher-resolution image fusion. To this end, this research proposed an end-to-end DL-based STF model, named UAV-Net, that can predict centimeter-scale UAV images. UAV-Net exhibits an encoder-decoder architecture with Modified ResNet (MResNet), Feature Pyramid Network (FPN), and decoder modules. The encoder used MResNet modules to extract input features, while the FPN module performs a multiscale fusion of the features extracted by the encoder before reconstructing UAV images using transposed convolution in the decoder module. Through the comparison and ablation experiments, this study evaluated the efficacies of the MResNet modules with 18, 34, and 50 layers, along with the FPN module of UAV-Net. The experimental results on real-world datasets demonstrated that UAV-Net adequately predicted UAV images both visually and quantitatively.

Overall, this research demonstrated the significant potential of using UAV images and DL techniques for precise crop monitoring, contributing to precision agriculture. The proposed STF model opens possibilities for extending applications to other Earth observation monitoring, such as forest and ecological monitoring, to improve management practices and decision-making processes. This study develops various methods that can be useful to provide precise information and valuable insights into corn field practices, which can help farmers to optimize corn cultivation.

The examination committee recognized that this thesis presents important findings in the development of various methods to monitor corn crops using high-definition UAV data using advanced deep-learning techniques. In addition to the excellent academic knowledge in the research, her academic records throughout the Ph. D. course was good. She has already published 3 international peer-reviewed international journal papers. Based on this evidence, the committee reached the conclusion that Xiao Juan is eligible for the degree of Doctor of Philosophy (Environmental Science).