Leveraging Synthetic Data and Unsupervised Domain Adaptation techniques for efficient building of Deep Learning Crop-Weed identification models

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1 Research Proposal

In recent years, machine learning (ML) and deep learning (DL) have achieved notable success in agriculture, with applications in weed control, plant disease diagnosis, agricultural robotics, and precision livestock management. However, these models rely heavily on large, high-quality labeled datasets, making performance closely tied to data quantity and quality. Labeling such datasets is both costly and time-consuming due to rising labor costs. This challenge has spurred substantial interest among researchers and practitioners in developing label-efficient ML/DL methods for agricultural applications.

Advances in video games and simulators have enabled the creation of synthetic data, providing diverse and customizable datasets. For instance, INRAE's TSCF unit recently released CropCraft, a procedural world generator for simulating agricultural environments (see Figure 1). With CropCraft, large, varied datasets of crop fields can be generated with automatic labeling for crop-weed detection. However, training ML models on synthetic data alone often leads to significant domain gaps with real-world data due to differences in visual and statistical properties.

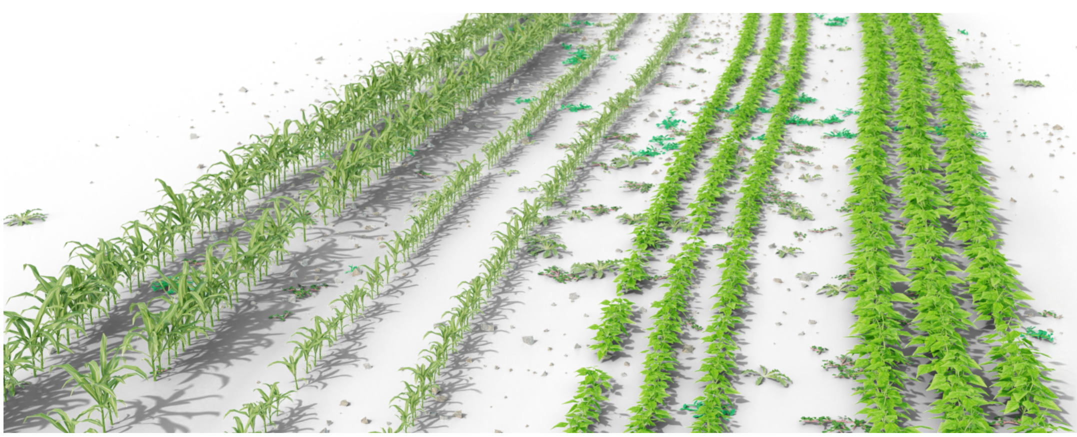

Figure 1: A simulated crop field created with the CropCraft tool.

To address this, Unsupervised Domain Adaptation (UDA) [1] and Style Transfer (ST) [2] techniques can bridge these gaps. UDA reduces the domain gap between a labeled source domain (e.g., synthetic crop-weed images) and an unlabeled target domain (e.g., real-world crop-weed images) by aligning their marginal distributions [3]. Style Transfer combines the content of one image with the style of another to create a new image, commonly used in digital art but also applicable in domain adaptation [2]. Together with UDA, ST can help reduce domain gaps between image sets captured in different conditions [4]. While Generative Adversarial Networks have been popular for ST tasks, they are computationally intensive and unstable. Recent advancements leverage novel architectures like Diffusion Models [5] and advanced State-Space Models [6] for improved style transfer.

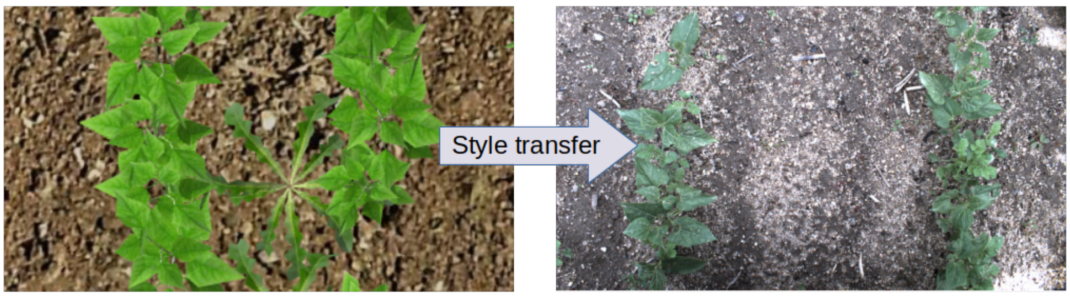

Figure 2: The aim of the project is to use Style Transfer to make synthetic images more realistic.

This project aims to use ST and UDA techniques to modify synthetic crop-weed images to resemble real-world visuals, enabling models trained on synthetic data to perform well in real-world applications. Few studies in the literature have explored this area; some experiments have adapted simulated images for tasks like depth and odometry estimation in autonomous driving [7]. No studies have focused on agricultural environments or object detection/semantic segmentation tasks. This project presents a unique opportunity to engage with cutting-edge technologies, gain hands-on experience with advanced ML models, and make impactful contributions to real-world problems.

1.1 Objectives

The aim of this internship is to assess the crop-weed identification performance of ML models trained on synthetic data and subsequently close the gap between synthetic and real-world domains by using Style Transfer and Unsupervised Domain Adaptation techniques.

In particular, the objectives are:

- Using the Gazebo ROS simulator and the CropCraft tool, collect RGB images of crop and weeds and get their automatic annotation (bounding boxes and/or semantic segmentation masks)
- Train object detection and/or semantic segmentation models to identify crop and weeds on the synthetic images, test the performance of the model on real-world data and assess the domain gap

- Do a literature investigation on Style Transfer and Unsupervised Domain Adaptation techniques
- Exploit the most promising literature techniques to make the synthetic images more realistic and close the domain gap
- Write a report

References

[1] M. Toldo, A. Maracani, U. Michieli, and P. Zanuttigh, "Unsupervised domain adaptation in semantic segmentation: A review," *Technologies*, vol. 8, no. 2, p. 35, 2020.

[2] A. Singh, V. Jaiswal, G. Joshi, A. Sanjeeve, S. Gite, and K. Kotecha, "Neural style transfer: A critical review," *IEEE Access*, vol. 9, pp. 131 583–131 613, 2021.

[3] S. Srivastava and K. Ansari, "Stft: Style loss and fourier transformation for domain gap reduction," 2022.

[4] R. Bertoglio, A. Mazzucchelli, N. Catalano, and M. Matteucci, "A comparative study of fourier transform and cyclegan as domain adaptation techniques for weed segmentation," *Smart Agricultural Technology*, vol. 4, p. 100 188, 2023.

[5] J. Chung, S. Hyun, and J.-P. Heo, "Style injection in diffusion: A training-free approach for adapting large-scale diffusion models for style transfer," in *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2024, pp. 8795–8805.

[6] F. Botti, A. Ergasti, L. Rossi, *et al.*, "Mamba-st: State space model for efficient style transfer," *arXiv preprint arXiv:2409.10385*, 2024.

[7] X. Bai, Y. Luo, L. Jiang, *et al.*, "Bridging the domain gap between synthetic and real-world data for autonomous driving," *Journal on Autonomous Transportation Systems*, vol. 1, no. 2, pp. 1–15, 2024.

2 Research Environment

The National Research Institute for Agriculture, Food, and the Environment (INRAE) is a public research institution under the French ministries of agriculture and research. The institute ranks among the world's leading institutions in agricultural and food sciences, plant and animal sciences, with 12,000 staff and 268 units across France. INRAE addresses global challenges such as population growth, climate change, resource scarcity, and biodiversity loss, advancing sustainable agricultural practices, quality food systems, and resource management.

The Technologies and Information Systems for Agro-Systems (TSCF) research unit at INRAE's Clermont-Ferrand center focuses on agro-equipment for ecological agricultural transitions. With

60 researchers, TSCF develops robots capable of precise, safe, and repeatable tasks in natural settings. Their work in perception and control algorithms enables these robots to perform agricultural tasks, advancing agroecology principles. TSCF's collaborative projects have led to innovations in trajectory tracking, tool coordination, and safety, applicable across various robotic platforms.

3 Required and Preferred Qualifications

Required Qualifications:

- Master's level engineering student / university student (Élève ingénieur / université de niveau master 2)
- Proficiency in Python
- Foundational knowledge in Machine Learning
- Knowledge of spoken and written English

Preferred Qualifications:

- Experience with ML frameworks such as PyTorch or TensorFlow
- Familiarity with robotics tools like ROS and Gazebo

4 Internship Conditions

- Location: INRAE/Unité TSCF, 9 avenue Blaise Pascal, 63170 Aubière
- Duration and Desired Period: 6 months (start date flexible, as soon as possible)
- Compensation: Hourly stipend of 4.35€/h in accordance with current regulations
- Meals: Subsidized meals at the affiliated canteens
- Transportation: Partial reimbursement of public transport subscriptions

5 Applications

Please submit your application by filling out this form https://forms.gle/QcoXJYoP5sTA2mFz8 by May 31, 2025. Links to online repositories showcasing previous Python or ML projects will be highly valued. Interviews may be conducted before the deadline, and the position may be filled in advance.