Topic: Computer Vision
Project Title: Vision-Based Detection and Tracking of UAV Swarms
Description of the Project:
Unmanned Aerial Vehicle (UAV) swarms consist of multiple drones working together towards shared objectives, and they can be utilized across diverse sectors. They can assist in locating individuals during emergencies like natural disasters and play a role in military operations for target identification and tactical missions. Moreover, in areas lacking internet access, drone swarms can establish temporary communication networks, showcasing their diverse range of applications and ongoing innovation. However, the proliferation of hundreds of small-scale and low-cost UAVs forming swarms presents significant challenges to low-altitude airspace defense. Ensuring airspace security requires the detection and tracking of UAV swarms to enable them to operate within designated airspace and identify potential threats. While radar technology has traditionally been used for this purpose, its high cost and limited flexibility make it inefficient in certain scenarios, particularly in battlefield and disaster management contexts. Recently, the advancement of high-resolution cameras at low costs, with the flexibility to adapt to various situations, has drawn the attention of researchers. Utilizing vision data for UAV detection and tracking has shown promising performance and offers a more cost-effective and flexible solution compared to radar technology. This project aims to utilize vision data for the detection and tracking of UAV swarms. Our objective is to distinguish whether a drone is part of a swarm or not, and to determine the direction of movement of the drones within the swarms. Despite being a computer vision problem, this project presents several challenging issues. Primarily, UAVs appear smaller from a distance, posing difficulties for detection. While conventional computer vision typically addresses target objects that occupy around 20% of the entire frame, in this scenario, UAVs may only occupy approximately 0.07% of the frame. Additionally, the dynamic motion of UAVs and their ability to blend into the background further complicate the task. This project focuses on specific applications of UAV swarms, such as military combat operations and disaster management, where computational resources are limited. Our goal is to develop a model capable of efficiently detecting and tracking UAV swarms in real-time while operating with low computational power.

Task for the Project:

1. **Overview of Object Detection and Tracking Using Computer Vision:** Exploring contemporary algorithms and architectures.
2. **Requirement Analysis:** Assessing project objectives to determine model functional domain.
3. **Challenge Analysis:** Evaluating task difficulties and model limitations.
4. **Performance Metrics:** Establishing metrics to evaluate system suitability for identified requirements.
5. **Formulation of the pipeline:**
    - Capture video frames and conduct essential image preprocessing tasks like resizing and augmentations.
    - Utilize a detection backbone to extract image features from the chosen frame.
    - Extract motion features from successive frames and combine them with the image features during detection.
    - Detect drones and determine their swarm affiliation, fine-tuning the detection model for optimal performance.
    - Develop and implement an effective tracker, considering the challenge of tracking extremely small objects, to track the identified drones across consecutive frames.

6. **Validation:** Assess the soundness of the implemented system through the defined performance metrics and performing an ablation test of the system components.

Skills Needed:

1. Experience in Python programming, PyTorch framework, and Conda (anaconda or miniconda) environment.
2. Knowledge of deep learning and Convolution Neural Network
3. Experience on vision-based object detection algorithms such as YOLO is preferred.

Materials to be read:

[1] Rahman, M. H., & Madria, S. (2023, September). An Augmented Dataset for Vision-based Unmanned Aerial Vehicles Detection and Tracking. In *2023 IEEE Applied Imagery Pattern Recognition Workshop (AIPR)* (pp. 1-8). IEEE.

[2] Wang C, Su Y, Wang J, Wang T, Gao Q. UAVSwarm Dataset: An Unmanned Aerial Vehicle Swarm Dataset for Multiple Object Tracking. *Remote Sensing*. 2022; 14(11):2601. https://doi.org/10.3390/rs14112601

[3] Sangam, T., Dave, I. R., Sultani, W., & Shah, M. (2023, May). Transvisdrone: Spatio-temporal transformer for vision-based drone-to-drone detection in aerial videos. In *2023 IEEE International Conference on Robotics and Automation (ICRA)* (pp. 6006-6013). IEEE.

[4] Wang, C. Y., Yeh, I. H., & Liao, H. Y. M. (2024). YOLOv9: Learning What You Want to Learn Using Programmable Gradient Information. *arXiv preprint arXiv:2402.13616*.

[5] Zhang, Y., Sun, P., Jiang, Y., Yu, D., Weng, F., Yuan, Z., ... & Wang, X. (2022, October). Bytetrack: Multi-object tracking by associating every detection box. In *European conference on computer vision* (pp. 1-21). Cham: Springer Nature Switzerland.