Sensor-driven control of UAS using AI in simulation

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Abstract: The development of control algorithms and behaviours for autonomous Uncrewed Aerial Systems (UAS) presents many challenges. In progressing from concept to demonstrated flight capability, there are significant overheads, costs, and risks in conducting flight trials of new capabilities. Hence, testing and developing capabilities in simulation is an important step. As autonomy capabilities in UAS are rapidly improving, the introduction of Artificial Intelligence (AI) has enhanced dynamic sensor-driven decision-making algorithms and autonomous behaviours. The ArduPilot autopilot firmware is a common open-source industry tool through which these algorithms can control the UAS. However, ArduPilot's associated Software in the Loop (SITL) simulation capability does not provide the ability to simulate visual sensor feeds and does not contain accurate flight dynamic models. Therefore, there is a need to simulate the sensors to test these sensor-driven control algorithms.

Our Aerial Autonomy Algorithm Test and Evaluation Software Suite (A3TESS) provides an end-to-end simulation environment for the validation of sensor-driven algorithms. It comprises of three components: SITL, Aircraft Modelling Integration Environment Library (AMIEL) and Unreal Engine. SITL is used to model the UAS autopilot without hardware. AMIEL, a custom software library, models representative flight dynamics of our UAS of interest. Finally, a proprietary Unreal Engine plugin uses state data produced by AMIEL to display the UAS in a high fidelity, 3D graphical world. Unreal Engine was chosen due to its extensive use in Computer Vision (CV) applications; from dataset generation, algorithm diagnosis, reinforcement learning as shown by Qiu W et al (2017).

A3TESS enables AI-based CV algorithms to be tested with a motion-video virtual camera feed from a UAS flying in simulation generated through Unreal Engine. This simulates the output from an electro-optic sensor on-board a real UAS. CV algorithms integrated with A3TESS are able to process this camera feed to classify objects of interest within the image frame, producing object labels and pixel coordinates. Using the camera rotation, displacement, the UAS position, and attitude data retrieved from the simulated autopilot, the object can then be geolocated within the simulated world. With an estimated position of the object of interest, dynamic decision-making algorithms can then trigger sensor-driven behaviours for the UAS. Examples include controlling the UAS to circle the detected object to ensure it remains inside the camera's field of view at all times. The CV algorithms currently implemented in A3TESS include You Only Look Once (YOLOv8) and Vision-Language models (Florence-2). A3TESS allows sensor-driven control of UAS to be evaluated in a high-fidelity simulation environment, and provides a rapid pathway from ideation to experimental flight trials. A similar solution proposed by Shah et al (2018) utilised Microsoft AirSim, which has ArduPilot SITL integration but lacks AMIEL's fixed-wing flight dynamics, which A3TESS provides.

In conclusion, a simulation environment is key to an efficient workflow that spans from concept and algorithm development through to autonomous UAS behaviours proven in real world test flights. Within A3TESS, ArduPilot SITL and AMIEL accurately simulates the dynamic response of the aircraft to representative control inputs. The camera feed from Unreal Engine is of sufficient fidelity for CV algorithms, when using real-world trained models to detect objects and validate the sensor-driven behaviours. Therefore, through combining these components in A3TESS, we have demonstrated AI-enhanced sensor-driven control algorithms and autonomous behaviours for closed-loop control of UAS when executing flights within simulation.

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