Proceedings of the 2024 Winter Simulation Conference
H. Lam, E. Azar, D. Batur, S. Gao, W. Xie, S. R. Hunter, and M. D. Rossetti, eds.

AUTONOMOUS POP-UP ATTACK MANEUVER USING IMITATION LEARNING

Joao P. A. Dantas[1]

[1] Computer Science Division, Aeronautics Institute of Technology, Sao Jose dos Campos, SP, BRAZIL

ABSTRACT

This study presents a methodology for developing models that replicate the complex pop-up attack maneuver in air combat, using flight data from a Brazilian Air Force pilot in a 6-degree-of-freedom flight simulator. By applying imitation learning techniques and employing a Long Short-Term Memory (LSTM) network, the research trained models to predict aircraft control inputs through sequences of state-action pairs. The model's performance, evaluated using Root Mean Squared Error (RMSE) and the coefficient of determination (R^2), demonstrated its effectiveness in accurately replicating the maneuver. These findings highlight the potential of deploying such models in fully autonomous aircraft, enhancing autonomous combat systems' reliability and operational capabilities in real-world scenarios.

1 INTRODUCTION

Autonomous systems are now essential in modern warfare, assuming roles that once required human intervention. These systems are used in various military applications, from surveillance to combat, and offer significant strategic advantages (Ryan and Mittal 2019). A key challenge is enabling them to perform complex tasks like air combat maneuvers with the proficiency of human pilots (McGrew 2008).

The pop-up attack, involving a rapid ascent to engage a target followed by a quick descent to avoid counterattacks, is challenging to replicate autonomously due to the need for fast decision-making (Wang et al. 2009). Imitation learning, where autonomous systems learn by observing human experts, offers a promising solution (Hussein et al. 2017). Using simulated flight data, these models can replicate complex maneuvers like the pop-up attack, mimicking the execution of human pilots (Wang et al. 2022).

The main contribution of this research is to develop models for autonomous pop-up attack maneuvers using simulated flight data. The goal is to create systems that accurately replicate human decision-making, enhancing the reliability and effectiveness of autonomous combat systems in real-world scenarios.

2 METHODOLOGY

The dataset for this research comprises 30 flight recordings of pop-up attack maneuvers executed by a Brazilian Air Force fighter pilot. Each flight was standardized by trimming frames to the shortest sequence length across all samples, ensuring uniformity during model training.

For model development, the flight data was segmented into state-action pairs. State vectors included key variables like latitude, longitude, altitude, pitch, roll, yaw angles and velocities, accelerations, radial angle, target distance, and altitude difference. Action vectors consisted of the pilot's inputs: pitch (JX), roll (JY), and throttle settings.

We used a Long Short-Term Memory (LSTM) network, a type of recurrent neural network (RNN) well-suited for sequential data. Training involved 5-fold cross-validation with early stopping to prevent overfitting, and the Adam optimizer, with a tuned learning rate, ensured efficient learning. Model performance was evaluated using Root Mean Squared Error (RMSE) and the coefficient of determination (R^2), with the best model selected for further analysis. This model generated flight trajectories using a sliding window approach, ensuring continuous and accurate predictions. These predictions were compared to actual maneuvers, focusing on the mean and standard deviation of actions, providing insights into the model's precision and identifying areas for refinement.

3 RESULTS AND DISCUSSION

Cross-validation results showed a mean R^2 of 0.72 with a standard deviation of 0.02, indicating a strong correlation between predicted and actual trajectories with minimal variance across folds. The best model achieved an R^2 of 0.73 and an RMSE of 1.55 on the test group, confirming the model's generalizability. Figure 1 reinforces these findings by comparing actual and predicted actions for pitch (JX), roll (JY), and throttle. Solid blue lines represent actual actions, while dashed red lines show predictions, with shaded regions indicating the standard deviation, visually capturing the variability in the maneuvers.

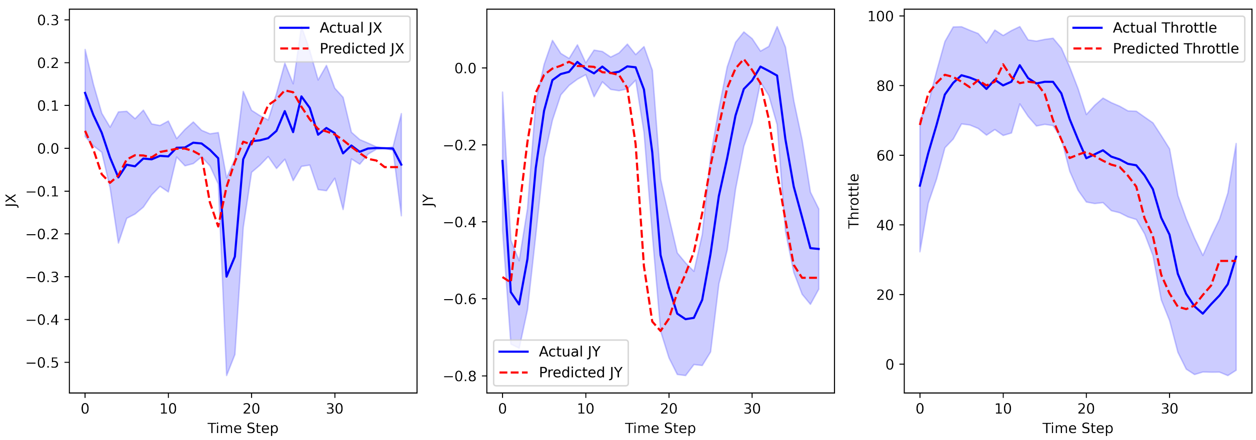

Figure 1: Trajectory comparison – Actual vs Predicted with mean and standard deviation.

The overall performance metrics, particularly the R^2 and RMSE values, align with the visual analysis, which shows that the predicted trajectories closely follow the actual trajectories. This confirms the effectiveness of the LSTM-based model in predicting the aircraft's control inputs during pop-up attack maneuvers. The source code for this research is available at https://github.com/jpadantas/pop-up_attack.

4 CONCLUSION AND FUTURE WORK

This study developed models to replicate the pop-up attack maneuver in air combat using simulated flight data from a Brazilian Air Force pilot. Based on imitation learning and LSTM networks, the models demonstrated the potential to predict aircraft control inputs and reproduce pilot decision-making. Future work will expand the dataset with more recordings from different pilots and use generative learning to create additional synthetic data, aiming to further improve accuracy in autonomous combat scenarios.

REFERENCES

Hussein, A., M. M. Gaber, E. Elyan, and C. Jayne. 2017, apr. "Imitation Learning: A Survey of Learning Methods". *ACM Comput. Surv.* 50(2):1–35 https://doi.org/10.1145/3054912.

McGrew, J. S. 2008. *Real-time maneuvering decisions for autonomous air combat*. PhD, Massachusetts Institute of Technology.

Ryan, T. R. and V. Mittal. 2019. "Potential for Army Integration of Autonomous Systems by Warfighting Function". *Military Review* 99(5):122.

Wang, H., X. Liu, and X. Zhou. 2022. "Autonomous UAV Interception via Augmented Adversarial Inverse Reinforcement Learning". In *Proceedings of 2021 International Conference on Autonomous Unmanned Systems (ICAUS 2021)*, edited by M. Wu, Y. Niu, M. Gu, and J. Cheng, 2073–2084. Singapore: Springer https://doi.org/10.1007/978-981-16-9492-9_205.

Wang, N., L. Wang, Y. Bu, G. Zhang and L. Shen. 2009. "Tactical Aircraft Pop-Up Attack Planning Using Collaborative Optimization". In *Proceedings of the Intelligent Computing 5th International Conference on Emerging Intelligent Computing Technology and Applications*, ICIC'09, 361–370. Berlin, Heidelberg, Germany: Springer: Springer-Verlag.