Calculated Moves: Generating Air Combat Behaviour

Toubman, A.

Author: Toubman, A.
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Qapla’

“success!” in Klingon

Preface

Fighter jets are incredible machines. Equally incredible is the skill required to operate them. The pilots of these jets have to excel at observing, communicating, calculating, and making life-or-death decisions while zooming through the sky at inhuman speeds. Excelling at these tasks is only possible by rigorous training. However, defence budget cuts have resulted in fewer aircraft for air forces, and thus fewer aircraft available for real-world training. For instance, the Royal Netherlands Air Force had 213 F-16s available in 1992. Today, in 2019, there are 68 F-16s left. These are planned to be replaced by 37 F-35s in 2023, followed by additional F-35s at a later time. Innovative training methods are thus required to keep fighter pilots ready for future operations.

Another type of incredible machines are modern computers. Over the last decades, computers have become so powerful that they are able to simulate complex virtual worlds, in which humans can interact with life-like virtual entities. The computing power that is available today has also enabled the computers to reinvent their own programming, by means of machine learning algorithms. Since I started my PhD candidacy in 2013, the interest in machine learning has grown exponentially. From credit card fraud detection to self-driving cars, machine learning is now *everywhere*; so much so, that even the latest smartphones have separate processors dedicated solely to machine learning calculations.

One of the most important training tools in the arsenals of air forces is the flight simulator. A simulator relies on virtual entities called *computer generated forces* to create interesting situations that resemble the situations that fighter pilots may encounter in the real world. However, modelling and programming the behaviour of these entities remains challenging. As a result, only few behaviour models are created for the entities, and thus the simulators are left underused. In our research, we put one and one together by applying machine learning to fighter pilot training.

Personally, combining fighter jets and machine learning has felt like turning a piece of science fiction into reality. I hope that the research in this thesis will lead to safer skies. To all fighter pilots training in simulators I extend the greeting used by the Klingon warriors in the *Star Trek* television shows: *Qapla'!*

Armon Toubman
Almere, November 24, 2019

Contents

Nomenclature

AA-REWARD The reward function based on the probability-of-kill of missiles.

BIN-REWARD The binary reward function.

CENT The centralised coordination method with communication.

DECENT The decentralised coordination method with communication.

DOMAIN-REWARD The reward function based on domain knowledge.

$\mathbf{P}_K$ The probability-of-kill of a missile.

TACIT The decentralised coordination method without communication.

List of Acronyms

AI artificial intelligence.

ANOVA analysis of variance.

API application programming interface.

ATACC Assessment Tool for Air Combat CGFs.

BARS behaviourally anchored rating scale.

BOS behaviour observation scale.

BVR beyond-visual-range.

CAP combat air patrol.

CGF computer generated force.

CI confidence interval.

CLI command-line interface.

DIS distributed interactive simulation.

FSM finite-state machine.

GUI graphical user interface.

HSD honest significant difference.

HUD head-up display.

ICC intraclass correlation.

ICP integrated control panel.

IOS instructor operating station.

LCS learning classifier system.

LWACS Lightweight Air Combat Simulator.

MEC mission essential competency.

MFD multi-functional display.

NLR Netherlands Aerospace Centre.

PCDS Personal Computer Debriefing System.

PS problem statement.

RNLAF Royal Netherlands Air Force.

RQ research question.

RWR radar warning receiver.

SB Smart Bandits.

TOST two one-sided t-tests.

WVR within-visual-range.

XCS accuracy-based learning classifier system.

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