Codifying Simulation Performance Using Data

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Abstract - In 2020 VRAI and Dstl undertook a study to understand how subjective pilot performance metrics (situational awareness and lookout) could be understood using data capture. This paper will discuss the methodology for how to capture simulation data and what results are expected from the 975m data points captured to date. The paper will provide an insight into the value of capturing human performance data when conducting simulation-based training.

1 Introduction and Approach

Training and education data can potentially be exploited in a number of areas including: educational research to study student learning and identify patterns; personalized learning by tailoring instruction and resources to meet their individual needs and learning styles; adaptive learning that uses data to adjust the level of the instruction to match the student's level of understanding; predictive modelling to predict student success and identify at-risk students who may need extra support; and through Learning Management Systems (LMS) informing decisions on curriculum development, hiring, resource allocation and so forth.

With technologies such as AI and biometric sensors improving at pace, the potential of transforming training and education through quantitative data exploitation is being actively pursued. As one example, the USAF Pilot Training Next (PTN) programme was launched in 2018 against a backdrop of pilot shortages and the need to dramatically reduce the time in training. As part of a student-centred learning approach, PTN explored wearable biometric devices to collect and monitor physiological data, such as changes in heart rate. Further, instruction was assisted by data collection software and artificial intelligence-based applications designed to assist students in identifying training tasks for self-guided learning.

Although PTN was formally ended in FY2021, some of these training innovations have been carried forward under the enduring Pilot Training Transformation (PTT) initiative [1]. In terms of other armed services, the British Army's Collective Training Transformation Programme (CTTP) has also placed emphasis on training data exploitation and "data will be captured and exploited to drive change and efficiency … creating the ability to dynamically control the training environment to set an appropriate level of complexity and challenge … and bring data to a single place for analysis, with common data standards enabling an ambitious use of data analytics pan-Army" [2].

In this paper we will discuss in more detail another training data-based initiative called Project iDAS (immersive Data driven Airmanship Simulator) which is aimed at helping the UK Royal Air Force (RAF) explore the benefits of data analysis to assess pilot behaviour and identify characteristics of good airmanship.

2 Project iDAS - Domain Concepts

One of the key objectives of Project iDAS is to deliver a system capable of capturing and storing pilot data as the pilots complete simulated flying tasks, and to build up a rich dataset related to the performance of pilots, in particular with respect to airmanship. Predictive analytics is used on this data to identify patterns in 'good' pilot behaviour. This will enable the RAF to train airmanship in future military aviators to a higher standard, faster, in a more cost-effective way. To capture and store relevant data to this end, a data analysis framework for simulator performance data was developed. In data analysis a domain concept is a high-level abstraction that describes some characteristic of the environment and scenario about which data will be captured, from which we derive concrete measurements that will be included in an analysis dataset. By focusing on domain concepts, we can take a high-level overview of the type of data that will be included in a dataset without getting overwhelmed by the detail of a large number of actual measurements (often in the hundreds).

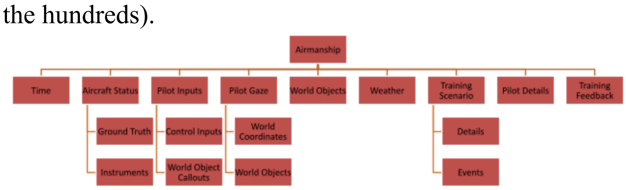

Fig. 1. A set of domain concepts identified for the iDAS project.

The domain concepts that have been identified in this project are shown in Figure 1 and can be briefly described as follows:

- **Background Data** - Understanding who the pilot is, what their experience is like and attempting to control for mitigating factors such as prior VR experience or lack thereof.
- **Time** - A common timestamp that can be used to combine data from multiple sources and identify those that take place in the simulator (e.g., movements of simulated aircraft) and in the real world (e.g., a pilot moving their head in the VR system). This is essential for aligning data generated by different systems.
- **Aircraft Status** - High frequency recording of the aircraft status including airspeed, position, attitude, altitude, etc. This will be recorded both in terms of the actual ground truth values and those displayed on the aircraft's instruments. In some cases, small discrepancies between these are normal, and in some scenarios malfunctioning instruments may be simulated.
- **Pilot Inputs** - Detailed records of the control actions that the pilot has taken (e.g., joystick movements, switch changes etc.). Callout of identified world objects (e.g. other aircraft) has been identified as a key interaction and these inputs are key to measuring this.
- **Pilot Gaze** - High frequency recording of the gaze direction of the pilot with details of the world objects (e.g. instruments, aircraft, etc.) within the pilot's field of view, based on these gaze directions.
- **World Objects** - Details of positions, velocities, and orientations of other aircraft and other important objects within the simulated environment.
- **Weather** - Details of the weather status in the area surrounding the aircraft.
- **Training Scenario** - Details of the training scenario the pilot is flying (e.g. the objectives of the scenario, the key objects involved in the scenario, etc.). Scenarios also include key events (e.g. the introduction of a malfunctioning instrument) and it is important to record the occurrence of these events.
- **Pilot Details** - A unique identifier for the pilot that flew the recorded session that allows access to details about their flight experience and other relevant demographics.
- **Training Feedback** - Sometimes when the simulated system is used, feedback from trainers is given following the completion of the training scenario. Where possible it is important to connect this feedback to the other data so that insights based on this feedback can be extracted.

3 Project iDAS - Detailed Data Definitions

This section expands on each of the domain concepts identified above and describes specific details of how data for each of these will be captured.

3.1 Background

As part of the HEAT (VRAI's VR training platform Hazardous Environment Awareness Trainer System) and iDAS data capture framework, onboarding data was collected on the participants. At a basic level, this data allows for comparative analysis between inexperienced and experienced pilots. This information is crucial in how airmanship characteristics differ between different categories of pilot and is a fundamental part of the data set.

1. How long have you served in the RAF? (0-2 yrs, 2-5 yrs, 5-10 yrs 10+ yrs.)
2. What is your primary discipline? (rotary/Fixed - fast jet/ Fixed multi engine)
3. With what Squadron are you currently stationed? (options based on above answer)
4. Have you ever served operationally overseas?
5. If so, how many terms?
6. Are you currently an instructor?
7. Have you ever served as an instructor?
8. If so, for how long? (0-2 yrs, 2-5 yrs, 5-10 yrs, 10+ yrs)
9. How would you currently assess your airmanship ability? (1-10)
10. Have you ever flown the T6 Texan II?
11. If so, what is your level of experience? (0-10 hrs, 10-50 hrs, 50-100hrs, 100+ hrs)
12. Have you read the briefing documents supplied?
13. Do you feel confident in your ability to complete the task as described?
14. Have you previously used a Virtual Reality Headset?
15. Have you previously completed any flight simulation using virtual reality?

3.2 Time

To achieve a complete picture of what takes place during a training scenario data from multiple sources must be combined. It is important that this data can be accurately temporally aligned so that interactions between these data sources can be captured – for example, the head movements a pilot makes within the VR system with the appearance of aircraft in the simulated environment. The main data sources will typically be either a recording of the state of the simulation at regular intervals, or the recording of a piece of data triggered by an event. For complete reproducibility, every piece of data recorded will include as many of the following timestamps as possible:

- **Zulu Time**: All data sources uses a common reference time of GMT and, wherever appropriate, data is accompanied by a timestamp (to millisecond precision) aligned to a common GMT reference.
- **Session Time**: This records the elapsed time within the simulation to millisecond precision.
- **Frame ID**: Within the main data stream coming from the Prepare3D (P3D) [3] flight simulation environment each record is given a consecutive frame number starting from zero.
- **Simulation time**: Part of the simulation setup in P3D sets a date and time for the flight session to be simulated to allow different scenarios to be simulated

(for example Winter flights, Summer flights, night-time flights or day-time flights).

Wherever possible data was recorded at a frequency of 30 frames per second, but this may differ for certain data sources. Table 1 shows a small data sample illustrating these different time stamps.

Table 1. A sample of data illustrating the different timestamps recorded.

ZULU Time	Session Time	Frame ID	Sim. Time	Lat.	Long.
2020-11-09 14:32:11. 77734	6.8261849	154	2018-06-02 07:13:08.77734	29.5153862	-98.280317
2020-11-09 14:32:11.83203	6.8936849	155	2018-06-02 07:13:08.83203	29.5153876	-98.280317
2020-11-09 14:32:11.89063	6.9281239	156	2018-06-02 07:13:08.89063	29.5153883	-98.280317
2020-11-09 14:32:11.94531	6.9620065	157	2018-06-02 07:13:08.94531	29.5153890	-98.280317
2020-11-09 14:32:12.00412	6.995332	158	2018-06-02 07:13:09.00412	29.5153899	-98.280317

3.3 Aircraft Status

A detailed data stream of the status of the simulated aircraft throughout the simulation is recorded. This will include the ground truth details of the aircraft's position, orientation, and velocity within the world as well as the status of all key aircraft systems. Table 2 shows a small sample of what this data, the majority of which comes directly from P3D, will look like (note only the Frame Number time reference is shown, although all time recordings discussed above will be recorded).

Table 2. A sample of data illustrating the different timestamps.

Frame ID	Lat.	Long.	Alt.	Pitch	Roll	Landing Gear	Left Flap	Right Flap
271	29.515704	-98.280	764.90810	-1.3495	-0.1399	True	0	0
272	29.515708	-98.280	764.90835	-1.3494	-0.1344	True	0	0
273	29.515713	-98.280	764.90859	-1.3492	-0.1316	True	0	0
274	29.515717	-98.280	764.90884	-1.3490	-0.1259	True	0	0
275	29.51572	-98.280	764.90908	-1.3488	-0.1185	True	0	0

As well as recording the ground truth data describing the aircraft status the values displayed on the aircraft's instruments is recorded. Under normal circumstances there are expected small differences between these values. In our initial testing for example there appears to be a slight variance (±2 degrees) in certain circumstances on attitude gauge. In addition, in some training scenarios it might be useful to simulate malfunctioning instruments. Therefore, it is important to record what was displayed to a pilot through their instruments as well as the ground truth.

3.3 Pilot Inputs

Every action that the pilot takes through their controls (flight stick, rudder pedals, throttle control, etc.) is recorded. This data is useful to determine whether or not pilots are taking appropriate actions at appropriate times (for example, correct control of flaps during landing), but also forms the basis of high-level indicators of a pilot's airmanship (for example, the frequency of adjustments made or the smoothness of control inputs).

3.4 Pilot Gaze

One of the advantages of VR training is that exactly what a pilot is focusing on during training can be recorded and analysed. Using the VR hardware deployed as part of the iDAS system detailed data on the orientation of the pilot's head and, through eye tracking, the focus of their gaze can be recorded at high frequency. As well as recording the orientation of the pilot's head and the direction of their gaze, a process known as picking is used to identify the simulated world objects that the pilot is looking at. These might be other aircraft or other world objects, or specific instruments or controls within the pilot's cockpit.

3.5 World Objects

In order to measure the performance of a pilot against scenario objectives and their general airmanship capabilities, it is important to record the status of other objects within the environment. For example, in order to measure the pilot's ability to successfully perform lookout, their ability to callout aircraft when they enter their field of view will be measured. This requires details of the positions of other aircraft to be captured. For every training scenario, a set of relevant important world objects is defined and detailed records of these objects throughout the situation recorded. These include position, orientation, and velocity (and other relevant information) of objects. This is most likely be recorded at a much lower frequency than other data recorded. Table 3 shows a sample of the kind of data that is recorded about important world objects.

Table 3. A sample of the data that will be recorded about important world objects within a training flight.

Frame ID	Object ID	Lat.	Long.	Alt.	Heading
371	OBJ-12-A	29.5359762	-98.293099	765.07941	337.240199
371	OBJ-13-B	29.5339266	-98.292063	765.11808	337.110265
381	OBJ-12-A	29.5359922	-98.293107	765.078569	337.244035
381	OBJ-13-B	29.5339443	-98.292072	765.112009	337.102246
391	OBJ-12-A	29.5360081	-98.293115	765.075361	337.247908
391	OBJ-13-B	29.5339621	-98.292081	765.106369	337.094411

3.6 Weather

Weather has an important impact on how different flight training scenarios are approached, and the ability to control and change weather at will is one of the advantages of simulated VR training. Throughout a simulated flight details of the weather conditions are recorded. The P3D simulator includes detailed weather simulation and allows recording of detailed information of the weather conditions surrounding the simulated aircraft.

Table 4. A sample of the data that will be recorded about weather within a training flight.

Frame ID	Ambient Temp.	Ambient Wind Dir.	Ambient Wind Vel.	Ambient Pressure	Outside Air Temp.	Ambient Density
1	14.639	357.790	0.554	979.112	14.852	0.0023
2	14.642	357.811	0.549	979.112	14.852	0.0023
3	14.642	357.821	0.549	979.112	14.863	0.0023
4	14.649	357.852	0.540	979.234	14.863	0.0023
5	14.649	357.863	0.539	979.234	14.879	0.0023

3.7 Training Scenario

So that performance against the scenario being flown during training can be measured it is important that details of the goals of the scenario are recorded. This data includes static details of the objectives of the scenario - for example, any important waypoints that must be reached, or the expected flight path. Dynamic data about important events within scenarios is also be recorded - for example, the appearance of other aircraft, changes in weather conditions, or the onset of instrument malfunctions.

3.8 Pilot Details

VRAI's HEAT system is a data capture and analytics platform designed for virtual reality training. The system allows users to track performance across a virtual training experience. To facilitate that it contains 3 main modules: Onboarding; virtual training data capture; and storage and analytics.

As part of the onboarding process, users set up a user profile. This can contain basic data such as age and years of experience, or more detailed information if necessary. This data is captured alongside the user's performance and is used to identify individual users within the system.

Individual data security and protection is of paramount importance. The aim is to collect the minimal amount of personal data required to complete the analysis task. There is a fully auditable system in place for data access and the system synonomises all data captured. The HEAT system is GDPR compliant and actual cloud storage is on servers within the UK and access to the data is controlled on an individual user basis.

On completion of training, pilots were asked to complete short questionnaires to capture additional data about the usability of the VR system, about the usability of the specific aircraft controllers and about their physical wellbeing. These questionnaires will be utilised during analysis to identify potential issues with user experience that could impact performance and data analysis.

3.9 Training Feedback

During the system validation phase a random selection of simulated flight training is accompanied by feedback from experienced flight trainers. These trainers are currently members of the iDAS team. This information will provide useful indicators of how data should be analyzed and target features for future machine learning systems.

4 Data Capture Mechanism

Although multiple systems are involved within a simulated flight training session, wherever possible data is captured through P3D. This alleviates some of the challenges that can arise when aligning high-frequency data from different sources. A bespoke piece of software has been commissioned to extract relevant data from P3D and store it in a format suitable for transmission, storage, and analysis. This software polls the P3D environment at high frequency and extracts a detailed record of all relevant details of the simulation. Data extracted from other sources uses a consistent Zulu time timestamp so that data can be aligned.

5 Conclusions and way ahead

Can we say anything about the results of this research and what the next steps are?

Eg.
Lessons from this approach and what one might do differently next time?
What has been discovered? Are there clear trends in linking experience with airmanship or are there other factors?
How might this approach be extended to other training?
As technology in this area develops what might the new opportunities and challenges be?

References

[1] US Congressional Research Service Report - U.S. Air Force Pilot Training Transformation (PTT) - 18 Jan 23
[2] Future Collective Training System Blueprint Iteration 1.5 (Releasable to Industry) 23 Jan 19
[3] Prepar3D or P3D is a simulator created by Lockheed Martin in 2009 as a commercial simulator branched from the Microsoft Flight Simulator X codebase

Author/Speaker Biography

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Andy Fawkes is an independent consultant and engineer working in the field of training and simulation. He previously presented at IT2EC 2022 "Visualisation – Challenges & Opportunities" and "My Digital Sibling". Formerly he was head of simulation policy for the UK MoD and Chair of the NATO M&S Group. He is a Fellow of the Institution of Mechanical Engineers (FIMechE).