COMPUTER-IMPLEMENTED METHOD AND NON-TRANSITORY COMPUTER-READABLE MEMORY FOR AIR TRAFFIC CONTROL PERFORMANCE MONITORING

Field of the Invention

The present invention relates to the field of air traffic control and more particularly to a computer-implemented method and a non-transitory computer-readable memory for air traffic control performance monitoring.

Background of the Invention

Air traffic controllers tactically monitor via display screens air traffic within an airspace. Current approaches to address issues related to tactical monitoring activity of an air traffic controller both operationally and in training are limited due to a lack of knowledge extraction and representation of such an activity. For example, there is a lack of exploitation of shared information between physical heterogeneous data capture systems with human operated functions, an inadequate representation of tactical air traffic complexity, and a shortage of methods to extract and represent monitoring behaviour of an air traffic controller during an air traffic situation. Accordingly, it would be desirable to provide a computer-implemented method and a non-transitory computer-readable memory for air traffic control performance monitoring that addresses one or more of these limitations.

Summary of the Invention

Accordingly, in a first aspect, the present invention provides a computer-implemented method for air traffic control performance monitoring. The method includes executing on one or more processors the steps of: receiving traffic data; receiving human data; integrating the traffic data and the human data spatially and over time; calculating tactical air traffic complexity; identifying an eye signature associated with a tactical monitoring activity; and integrating the calculated tactical air traffic complexity and the eye signature to deduce a monitoring strategy being applied.

In a second aspect, the present invention provides a non-transitory computer-readable memory storing computer program instructions executable by a computer processor to perform operations for air traffic control performance monitoring. The

operations include: receiving traffic data; receiving human data; integrating the traffic data and the human data spatially and over time; calculating tactical air traffic complexity; identifying an eye signature associated with a tactical monitoring activity; and integrating the calculated tactical air traffic complexity and the eye signature to deduce a monitoring strategy being applied.

Other aspects and advantages of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

Brief Description of the Drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIG. 1 is a schematic flow diagram illustrating a computer-implemented method for air traffic control performance monitoring in accordance with an embodiment of the present invention;

FIG. 2 is a partial screenshot of a radar display screen illustrating track and label of an aircraft on the radar display screen in accordance with an embodiment of the present invention;

FIG. 3 is a schematic flow diagram illustrating a computer-implemented method for integrating traffic data and human data spatially and over time in accordance with an embodiment of the present invention;

FIG. 4 is a schematic flow diagram illustrating a computer-implemented data fusion process in accordance with an embodiment of the present invention;

FIG. 5 is a schematic diagram illustrating three-dimensional (3D) aircraft shape movements with different overlaps in accordance with an embodiment of the present invention;

FIG. 6 is a graph of a Conflict Activity Level (CAL) time profile curve in accordance with an embodiment of the present invention;

FIG. 7 is a schematic flow diagram illustrating a computer-implemented method for identifying an eye signature associated with a tactical monitoring activity for aircraft crossing with potential conflict in accordance with an embodiment of the present invention;

FIGS. 8A through 8D are graphs of fixation count and duration plots of Aircraft A and Aircraft B across an elapsed time frame till crossing in accordance with an embodiment of the present invention;

FIG. 9 is a schematic diagram illustrating aligned fixation peak definition and tolerance in accordance with an embodiment of the present invention;

FIGS. 10A through 10C are graphs of cumulative plots of aligned peaks, fixation count and fixation duration for Aircraft A and B in accordance with an embodiment of the present invention;

FIG. 11 is a schematic flow diagram illustrating a computer-implemented method for identifying an eye signature associated with a tactical monitoring activity for aircraft frequency switching in accordance with an embodiment of the present invention;

FIG. 12 is a schematic flow diagram illustrating a computer-implemented method for identifying an eye signature associated with a tactical monitoring activity of generic flight path monitoring in accordance with an embodiment of the present invention;

FIG. 13 is a graph of time series plots of eye and hand movements of an air traffic controller for an Aircraft C in accordance with an embodiment of the present invention;

FIG. 14 are graphs illustrating a Radar Command Group (RCG) time profile for an Aircraft C of an air traffic controller in accordance with an embodiment of the present invention;

FIG. 15 are graphs illustrating different RCG time profile cases with their respective information entropy values in accordance with an embodiment of the present invention;

FIG. 16 is a schematic block diagram illustrating a computer system suitable for implementing the method for air traffic control performance monitoring disclosed herein;

FIGS. 17A through 17D are graphs of fixation count and duration plots across time for aircraft pair AXM540 and TGW971 in accordance with an embodiment of the present invention;

FIGS. 18A through 18C are graphs of cumulative aligned fixation peaks plots for AXM540 and TGW791 in accordance with an embodiment of the present invention;

FIG. 19 is a photograph of a standard Controller Working Position (CWP) with remote eye tracker used in an experimental setup;

FIG. 20 is a schematic diagram illustrating close and independent crossing points in an experimental scenario;

FIG. 21 is a schematic diagram illustrating different aircraft pair flight configuration in an experimental scenario;

FIG. 22 is a schematic map illustrating different aircraft and their respective positions in an experimental scenario;

FIGS. 23A through 23D are graphs of fixation count and duration plots of CSN387 and GIA275 across the elapsed time frame till crossing;

FIGS. 24A through 24D are graphs of fixation count and duration plots of SIA141 and CSN387 across the elapsed time frame till crossing;

FIGS. 25A through 25D are graphs of fixation count and duration plots of SIA371 and CSN387 across the elapsed time frame till crossing;

FIG. 26 is a schematic diagram illustrating analysis of crossing point instances; and

FIG. 27 is a graph comparing crossing characteristics for number of 0 aligned peaks.

Detailed Description of Exemplary Embodiments

The detailed description set forth below in connection with the appended drawings is intended as a description of presently preferred embodiments of the invention, and is not intended to represent the only forms in which the present invention may be practiced. It is to be understood that the same or equivalent functions may be accomplished by different embodiments that are intended to be encompassed within the scope of the invention.

Referring now to FIG. 1, a computer-implemented method 10 for air traffic control performance monitoring is shown. The method 10 for air traffic control performance monitoring may be executed on one or more processors.

The method 10 begins at step 12 by receiving traffic data. The traffic data may include radar data and traffic characteristics. Radar data may include standard radar information on an aircraft using radar surveillance and a radar display position of track and label of the aircraft represented on a radar display. The radar information on the aircraft may include latitude and longitude of the aircraft, flight parameters of the aircraft such as, for example, speed, heading and Flight Level (FL). The radar display position of the aircraft may include track and label of the aircraft on the radar display screen as shown in FIG. 2. The traffic data may be retrieved from surveillance equipment.

At step 14, human data is received. Human data may include human physiological data such as, for example, eye tracking data and heart rate data, and human machine interface (HMI) input data captured when an air traffic controller is interacting with a machine while performing surveillance activities.

The traffic data and the human data are integrated at step 16 spatially and over time. This may be by means of a module for real time asynchronous data fusion that allows dynamic movement and timestamp synchronization. This serves to align all the different data streams and sources arising from surveillance tasks of air traffic controllers to the same reference point in space and time. With real time data fusion, the traffic data and the human data are fused together in real time and this facilitates extraction and representation of knowledge of how traffic controllers look at different traffic objects on a display screen. Advantageously, by considering information from both human and air

traffic data, it ensures that both aspects of information relating to the radar surveillance task of an air traffic controller are considered.

Referring now to FIG. 3, a computer-implemented method 30 for integrating the traffic data and the human data spatially and over time is shown. The method 30 may begin at step 32 by synchronizing the traffic data and the human data based on timestamps. All different data streams may be synchronized and fused together using a dynamic data alignment and timestamp synchronization model.

At step 34, the synchronized traffic data and the synchronized human data are converted into a same unit of measurement.

The converted traffic data and the converted human data are aligned at step 36 to a spatial reference frame. Following conversion to the same unit of measurement, the converted data may be aligned to the same spatial reference frame taking into consideration air traffic controller interaction.

At step 38, the aligned traffic data and the aligned human data are fused.

As an example, a data fusion process 120 of matching a synchronised timestamp and spatially aligned positions between eye and radar data streams will now be described below with reference to FIG. 4. The data fusion process 120 may begin at step 122 by selecting eye data. At step 124, radar data is selected.

At step 126, a determination is made as to whether an eye data timestamp is greater than a radar data timestamp. If the eye data timestamp is less than the radar data timestamp, a next line of radar data is selected. If the eye data timestamp is greater than the radar data timestamp, the eye data is matched to the earlier radar data at step 128.

At step 130, a determination is made as to whether more eye data is available. If more eye data is available, a next line of eye data is selected. The data fusion process 120 is complete when no more eye data is available.

The data fusion process 120 integrates data of different streams together and then checks if eye data is on any flight object. Performing such a step allows the eye data to be labelled with a flight object that is being looked at.

Data fusion may be performed by using captured timestamps to synchronously integrate both sets of eye and dynamic radar data. As the series of events from both data streams randomly occur at different instances, these two data streams have to be matched to one another in order to determine if eye fixation is on a flight. To harmonise eye fixation with a flight object, both sets of data (eye fixation and flight object) have to be matched at the same instant. As a human eye is attracted to new visual stimulus, in the absence of a change in dynamic radar data, any new fixation data may be from looking at an original image and this corresponds to the same positional data of the flight object before an event update.

In this manner, the module for dynamic data alignment and timestamp synchronization model integrates two sets of activity data, namely radar and human data in air traffic control, in a highly dynamic changing and synchronous manner in real-time with respect to both spatial and time frames.

Subsequent to this, the data may then be matched accordingly for further analysis, as will be presented in later modules of the described algorithm framework.

Referring again to FIG. 1, tactical air traffic complexity is calculated at step 18. This may be by means of a module for quantifying tactical traffic complexity that uses traffic data to quantify tactical traffic complexity in tactical monitoring tasks of air traffic controllers and this facilitates a deeper understanding of the traffic situation through the different interactions of several traffic factors.

In this module, a tactical air traffic complexity model, Conflict Activity Level – Separation Axes Theorem (CAL-SAT) model – may be used for forecasting and planning of control strategies employed by air traffic controllers based on traffic flow and network characteristics. A CAL time profile feature ranging from two aircraft to an entire airspace sector may be generated based on instantaneous flight characteristics on the assumption that aircraft pairs maintain current trajectory.

Using the CAL-SAT model, the step of calculating tactical air traffic complexity may begin with forming three-dimensional (3D) aircraft movement shapes using aircraft flight parameters. The parameters of a current position of the aircraft, speed, heading, current and cleared Flight Level (FL) may be used to form the 3D aircraft shape movement. The 3D aircraft shape movement may be set at an angle of deviation $\beta = 5°$ laterally and vertically, with an extension factor of 2.

A level of conflict activity may then be determined based on a degree of overlap between the aircraft movement shapes. Conflict Activity Level (CAL) values may thus be derived and used to ascertain an extent of conflict between the 3D aircraft shape movement of an aircraft pair. A score of "1" may indicate low complexity with the presence of registered aircraft, a score of "2" may indicate high complexity with an overlap present in the 3D aircraft shape movement, and a score of "3" may indicate the highest complexity level as the 3D aircraft shape movement of one aircraft is wholly inside that of another. Examples of 3D aircraft shape movements with different overlaps forming different complexity levels are shown in FIG. 5.

Following determination of the level of conflict activity, a profile of the level of conflict activity over time may be generated. To generate a CAL time profile, Separation Axes Theorem (SAT) may be used. Pairwise computation of CAL vertically and laterally may be performed concurrently before obtaining the overall CAL value. After that, a CAL time profile curve as shown in FIG. 6 may be generated.

Using a combination of both instantaneous CAL values and the CAL time profile, hotspots in the airspace may then be determined accordingly. Airways in the airspace with high complexity and congestion may also be deduced. Advantageously, this allows easier planning and control by air traffic control shift managers.

Referring again to FIG. 1, an eye signature associated with a tactical monitoring activity is identified at step 20. This may be by means of a module that uses eye signatures created for specific tactical monitoring activities to measure perception and comprehension levels of air traffic controllers, thereby evaluating visual monitoring performance at the same time. The eye signatures may be created to identify and evaluate visual monitoring behaviour for different tactical control activities. Eye signature metrics were developed to identify and evaluate visual monitoring performance for each

scenario of aircraft crossing with potential conflict, aircraft frequency switch and generic flight path monitoring of aircraft. Using these three signatures, the perception and comprehension of air traffic controllers may be captured and evaluated for these three key tactical monitoring activities that need to be managed. It has been found that these signatures may be used to distinguish the monitoring behaviour of air traffic controllers across different expertise levels and also for assisting air traffic controllers in their tactical monitoring tasks under various circumstances. As a result, operational norms for individual air traffic controllers or groups of air traffic controllers may be established using these signature metrics. Alerts may be triggered operationally when the air traffic controllers fail to perform at a specified level and the training of prospective air traffic controllers may also thus be evaluated more objectively by instructors.

Referring now to FIG. 7, a computer-implemented method 40 for identifying the eye signature associated with the tactical monitoring activity for aircraft crossing with potential conflict is shown.

In the case of aircraft crossing with potential conflict, two aircraft are flying towards the same fixed crossing point at a certain distance away. As time passes, the distance between the aircraft reduces. While the vertical profile of the two aircraft still overlaps, there is a potential conflict at the crossing point. To ascertain if the two aircraft are in conflict, an air traffic controller would have done so by fixating on the aircraft pair-in-crossing more often and for a longer duration. With this understanding, a signature of aligned fixation peaks was developed to identify deliberate monitoring of a selected aircraft pair-in-crossing by an air traffic controller by comparing fixation peaks within a short span of time to determine if there is a potential conflict. The visual signature captures the monitoring behaviour of the air traffic controller for aircraft crossing with potential conflict. This signature involves the determination of an air traffic controller looking at both aircraft of the aircraft pair-in-crossing to handle their crossing, together with the time (instance) when the air traffic controller looks at both aircraft. This caters to understanding the intent of changes in monitoring behaviour by air traffic controllers. The acquisition and representation of their monitoring behaviour is achieved by first identifying the respective fixation count and duration peaks before aligning them. Metrics may also be derived to evaluate this signature. The signature may be formulated using three phases: identification of fixation peaks, establishing alignment of fixation peaks and

evaluation of aligned fixation peaks. The first and second phases seek to determine that an air traffic controller is looking at both aircraft of the aircraft pair-in-crossing to handle the crossing, while the third phase represents an instance when such behaviours are exhibited.

Accordingly, the method 40 for identifying the eye signature associated with the tactical monitoring activity for aircraft crossing with potential conflict may begin at step 42 by plotting a fixation count and a fixation duration against an elapsed frame number for aircraft pairs-in-crossing, and identifying at step 44 a plurality of fixation peaks where the fixation count or the fixation duration is greater than an average number of non-zero fixation counts or non-zero fixation durations over time. In this manner, the activity of an air traffic controller deliberately looking at an aircraft may be captured as any fixation exhibited by the air traffic controller is first matched to a corresponding flight object of an aircraft on a radar screen. The elapsed frame number refers to the number of frames elapsed since the start of the radar simulation with each frame being the duration of each revolution. In an exemplary embodiment, each frame may have a duration of 9.8 seconds (s). These plots on fixation by the air traffic controller on either aircraft from the aircraft pair-in-crossing may thus be made to identify the activity of the air traffic controller looking at them.

From the fixation count and duration plots across frame number, there exists frames with (non-zero frames) and without (zero frames) fixation exhibited on the aircraft pairs. Peaks in the fixation count and duration plot may also be observed at certain frame numbers among the non-zero frames. This indicates that the air traffic controller looked at the aircraft-of-interest more frequently than average. Fixation peaks may thus be defined as instances where fixation count or fixation duration on the aircraft pair-in-crossing is above an average number of non-zero fixation count or duration exhibited by an air traffic controller over time. Such behaviour may be modelled via equation (1) below which defines and identifies a fixation peak, while equation (2) below shows the calculation of the average non-zero fixation count.

$$\text{Fixation Peak} = (\text{Fixation Count})_{\text{per frame}} > \text{Average}(\text{Fixation Count})_{\text{non-zero frames}} \quad (1)$$

$$\text{Average}(\text{Fixation Count})_{\text{non-zero frames}} = \left(\frac{\sum(\text{Fixation Count})_{\text{per frame}}}{\text{Number of frames}}\right)_{\text{non-zero frames}} \quad (2)$$

where non-zero frames = frames with fixation count > 0

Equations (1) and (2) above may also be applied for the identification of fixation peaks based on fixation duration. By identifying a fixation peak on an aircraft, it highlights that the air traffic controller is focusing more on the aircraft exhibiting an activity of interest to him and is deliberately monitoring the aircraft.

As a form of illustration, fixation count and fixation duration plots of an aircraft pair-in-crossing (two arbitrary aircraft – Aircraft A and B) are shown in FIGS. 8A through 8D to illustrate the aligned fixation peaks signature. Both aircraft appear at frame 1 and fly across a crossing point at frame 42.

For both Aircraft A and B, the average non-zero fixation count and fixation duration are computed using equation (2) above and the fixation peaks, together with its corresponding frame number, are also computed respectively.

Table 1 below shows the average fixation count and fixation duration and frame number of fixation peaks among the non-zero frames for Aircraft A and B derived by fulfilling the fixation peak condition in equation (1) above for both fixation count and fixation duration.

Table 1: Fixation Peak Identification for Aircraft A and B

Callsign	**Average Non-Zero Fixation Count**	**Frame Number of Fixation Peaks (Fixation Count)**	**Average Non-Zero Fixation Duration (ms)**	**Frame Number of Fixation Peaks (Fixation Duration)**
Aircraft A	1.44	30, 36, 37, 38	649	30, 36, 37, 38, 39
Aircraft B	2.10	5, 9, 30, 36	1340	5, 7, 30, 36

Referring again to FIG. 7, the fixation peaks may be aligned at step 46 according to location to form a plurality of aligned fixation peak signatures. By aligning the different fixation peaks occurring near each other for the aircraft pairs-in-crossing, the deliberate

monitoring activity on both aircraft for an aircraft pair-in-crossing by an air traffic controller in order to handle the aircraft crossing may be captured.

From FIGS. 8A through 8D and Table 1 above, it may be observed that there are several frame instances when the fixation peaks for both aircraft in crossing are occurring near to each other in time. This may mean that apart from deliberately monitoring the aircraft at that particular frame, with fixation peaks of two aircraft occurring at the same frame or near each other, it may also indicate that the air traffic controller is comparing the aircraft pairs-in-crossing at around the same time to be aware of its possible crossing occurring later.

To determine if the air traffic controller is comparing between both aircraft, the fixation peaks of both aircraft should be occurring near to each other in time, indicating that the fixation peaks should be aligned. For these fixation peaks to be aligned, the fixation peaks would have occurred in the same frame or within one (1) frame of each other. Hence, when the fixation peaks on both aircraft have the same frame number, they are aligned. Furthermore, a tolerance of ±1 frame is set to determine the interval of an aligned fixation peak to take into consideration cases in which the series of fixation is exhibited across a frame transition. Using the aircraft pair-in-crossing A and B, FIG. 9 provides an illustration of different cases that may be used to quantify an aligned fixation peak.

Using this understanding of aligned fixation peaks from FIG. 9, the frame number of the aligned fixation peaks between the aircraft pair-in-crossing of Aircraft A and B may be computed for both fixation count and fixation duration on them. The overall aligned fixation peaks signature may then be derived by selecting the frame numbers where an aligned peak is present for both fixation count and fixation duration. Whenever an aligned peak is one derived from a frame transition, both the frame from the start to end of when the aligned peak is exhibited are used. Table 2 below shows the frame number of these aligned peaks.

Table 2: Frame number of Aligned Peaks for Fixation Count, Fixation Duration and a combination of both

Aligned Peaks	**Fixation Count**	**Fixation Duration (ms)**	**Combined**
Frame Number	30, 36, 37	30, 36, 37	30, 36, 37

Referring again to FIG. 7, the aligned fixation peak signatures may be evaluated at step 48 by determining a number of non-aligned fixation peaks (0 aligned peaks indicating a lack of signature), a total number of aligned fixation peaks, a total fixation count and a total fixation duration of the aligned fixation peaks.

For every set of aligned fixation peak signature on each aircraft pair-in-crossing, four metrics (3 continuous and 1 Boolean) were derived to describe each of these signatures. The four metrics were derived to represent the aligned fixation peaks characteristics quantitatively. These characteristics seek to provide an overall indication to depict the aligned fixation peaks signature. The three continuous metrics are namely the total number of aligned fixation peaks, total fixation count and total fixation duration, while the Boolean metric is the presence of 0 aligned peaks. The Boolean metric may be used to indicate whether the air traffic controller exhibited the aligned fixation peak for every aircraft pair-in-crossing. For aircraft A and B, the frames used to compute the aligned fixation peaks signature and their corresponding fixation count and duration in these peaks are shown in Table 3 below.

Table 3: Eye Tracking Metric of Aircraft A and B in the Aligned Frames

Frame Number	Eye Metric on Aircraft	Aircraft A	Aircraft B
30	Fixation Count	3	4
	Fixation Duration (ms)	1160	1937
36	Fixation Count	4	4
	Fixation Duration (ms)	2850	2850
37	Fixation Count	2	-
	Fixation Duration (ms)	775	-

Using these figures in Table 3 above, the metrics are computed and shown in Table 4 below.

Table 4: Aligned Fixation Peak Metrics for Aircraft A and B

Aligned Fixation Peaks Metric	Number of 0 Aligned Peaks	Total Number of Aligned Peaks	Total Fixation Count	Total Fixation Duration (ms)
Air Traffic Controller A	0	3	17	9572

From Table 4 above, it can be seen that the aligned fixation peaks signature, exhibited by the air traffic controller on aircraft A and B, may be depicted using the four

metrics. These figures indicate that of the three instances in which the air traffic controller deliberately monitors the aircraft pair-in-crossing, a total of 17 fixation counts and a fixation duration of 9572 (ms) were recorded. By computing these metrics for all the aircraft pairs-in-crossing monitored by the same air traffic controller, a comparison of crossing monitoring behaviours for different crossing configurations may be made. Furthermore, by computing these metrics across all air traffic controllers for the same aircraft pair-in-crossing, comparisons of crossing monitoring behaviour across different air traffic controllers may also be performed.

The aligned fixation peaks may be presented for easier understanding of the crossing monitoring behaviour of the air traffic controller. Such is performed in two ways including the representation of aligned peak instance together with their characteristics across time.

The four metrics are derived to evaluate the aligned fixation peaks signature quantitatively, together with a cumulative plot for a qualitative evaluation. Such are performed upon establishing the aligned fixation peaks signature for the crossing monitoring behaviour of air traffic controllers. Qualitatively, a cumulative plot is able to showcase the instances at which such aligned peaks occur for a deeper understanding and evaluation of the crossing monitoring behavior of an air traffic controller.

Accordingly, cumulative plots in respect of the total number of aligned fixation peaks, the total fixation count and the total fixation duration of the aligned fixation peaks against the elapsed frame number for aircraft pairs-in-crossing may be generated at step 50.

When representing the aligned fixation peaks as a cumulative time series plot, every ‘step up’ increase of the line signifies that the air traffic controller exhibited an aligned fixation peak. The length of this vertical increase represents the proportionate increase of the metric throughout the flight duration from the point of entry to the crossing point for the aircraft pair-in-crossing.

As a form of illustration, three (3) cumulative line plots of the number of aligned fixation peaks, total fixation count and total fixation duration against the elapsed frame number for an air traffic controller are shown in FIGS. 10A through 10C. As can be seen

from this example, at frame 30, a direct aligned peak within the same frame (case 1) is detected for the case of fixation count and fixation duration. At frame 36, a transitional aligned peak is detected together with frame 37 (case 2), as there may be a transition of fixation count and fixation duration. As the step increase in aligned fixation is the same for frames 30, 36 and 37 (1/3 for each frame), the gradient of the 'step up' is the same for the plot involving aligned fixation peaks in FIGS. 10A through 10C.

These frame numbers indicate when the air traffic controller monitors aircraft A and B by comparing between them within a short span of time, represented when the aligned peaks are being exhibited. By adopting this approach of fixation peaks for both count and duration, together with their alignment, the deliberate monitoring of the selected aircraft pair-in-crossing by the air traffic controller may be filtered. Hence, instances where air traffic controllers monitor to compare the two involved aircraft may also be captured.

Referring now to FIG. 11, a computer-implemented method 60 for identifying the eye signature associated with the tactical monitoring activity for aircraft frequency switch is shown.

The activity of managing aircraft frequency switch involves both incoming and outbound aircraft. For incoming aircraft, as it approaches the sector boundary, the pilot will call into the frequency of the air traffic controller so that the air traffic controller takes jurisdiction of it. Whereas for outbound aircraft, as it approaches the sector boundary, the air traffic controller hands the aircraft over to an adjacent sector. Therefore, whenever there is a need for a change in aircraft frequency, air traffic controllers would need to recognise them, which is evidenced from the clicking of the 'UCO' (taking jurisdiction of aircraft upon entry to sector) and 'TOC' (handing over jurisdiction of aircraft upon leaving sector) command on the label of an aircraft. To do so, the air traffic controller would need to be fixated on the track or label of the aircraft before clicking on respective commands within a specified duration based on operational requirements to perform this switch of frequency. As a result, a fixation-click count signature involving fixation of an air traffic controller on the track or label of incoming or outgoing aircraft before clicking on respective commands within a specified duration based on operational requirements has also been developed.

The method 60 for identifying the eye signature associated with the tactical monitoring activity for aircraft frequency switch is therefore premised on the fact that if an air traffic controller perceives and comprehends an aircraft during such a task, the air traffic controller would have at least fixated once on the aircraft (criteria 1) and clicked on the appropriate command (criteria 2) within a specific duration after the pilot's request.

Accordingly, the method 60 may begin at step 62 by receiving a request to switch frequency in respect of an aircraft.

At step 64, a determination is made as to whether there is at least one fixation count in respect of the aircraft.

If at least one fixation count is determined in respect of the aircraft, a determinarion may then be made at step 66 as to whether there has been activation of a switching command in respect of the aircraft within a predetermined period.

If this is also positive, then an aircraft frequency switch eye signature is generated at step 68.

Because the fixation-click count signature has been found to be a common action amongst air traffic controllers, the fixation-click count signature may be used as a suitable measure to identify if an air traffic controller has perceived and comprehended an aircraft during this activity.

Referring now to FIG. 12, a computer-implemented method 80 for identifying the eye signature associated with the tactical monitoring activity of generic flight path monitoring is shown.

For the activity of generic flight path monitoring, an aircraft is flying along the designated airway in a sector of control of an air traffic controller. The aircraft will fly along this airway from acceptance to handing over, which also involves either a changing Flight Level (FL) flight or cruising flight. To manage this tactical monitoring activity of the generic flight path monitoring of the aircraft, the air traffic controller would likely have deliberately fixated on the label of the aircraft, while performing a mouseover on several occasions throughout the course of its flight, to be aware of the flight state of the aircraft. This mouseover action is essential as it represents that the air traffic

controller is hovering over the label of the aircraft to look at the information on it intentionally, as well as executing radar commands (clearances) to the aircraft based on the situation.

A generic flight path monitoring signature, herein known as Radar Command Group (RCG) Time Entropy signature, is thus provided to capture the perception and comprehension level of an air traffic controller for a generic flight of an aircraft across an airspace. This signature involves a combination of both eye and hand movement data of the air traffic controller, together with the time (instance) when such an action is executed. Using this signature, the regularity of an air traffic controller monitoring an aircraft on its flight path may also be determined. Acquisition and representation of generic flight path monitoring may be achieved by first identifying the respective fixation count and mouseover label movement on the aircraft to establish an RCG. The regularity of the RCG exhibited on the aircraft may then be calculated using an information entropy formula. The signature may thus be formulated using three phases: identification of RCG, construction of RCG time profile and calculation of RCG time entropy value to quantify the regularity of the generic flight path monitoring activity.

Accordingly, the method 80 for identifying the eye signature associated with the tactical monitoring activity of generic flight path monitoring may begin at step 62 by identifying a plurality of time intervals in which one or more mouseovers of an aircraft label and at least one fixation on the aircraft label occur over an aircraft flight path.

In this first phase of the formulation of the RCG time entropy signature, the definition of the RCG is first ascertained. The RCG is a fixed time interval that consists of one or several mouseovers of aircraft labels with at least one fixation within it. To define the RCG, the activity of an air traffic controller deliberately looking at an aircraft and performing a mouseover is captured. Any fixation exhibited by the air traffic controller may first be matched to a corresponding flight object of an aircraft on a radar screen. The fixation and its corresponding duration exhibited may then be matched to a frame number. In the present context, the frame number refers to the number of frames elapsed since the start of the radar simulation with each frame being the duration of each revolution. Similarly, the mouseover action exhibited by the air traffic controller for the purpose of looking intentionally or issuing radar commands may also be captured and matched to the respective frame numbers.

An arbitrary aircraft, Aircraft C, may be used to illustrate different fixation and mouseover actions exhibited by an air traffic controller. Different possible radar command actions may include mouseover of aircraft label for the purpose of selecting an aircraft label (SAA), issuing clearances like, for example, taking jurisdiction of aircraft upon entry to sector (UCO), handing over jurisdiction of aircraft upon leaving sector (TOC), clearing an aircraft to climb or descend to a specific FL (EFL), clearing the aircraft to fly on a specified heading (HDG) and changing the exit FL (XFL), by clicking on fields in an aircraft label on the radar display and also to move the label of the aircraft. Accordingly, a time series of fixation and mouseover action by an air traffic controller on the label of Aircraft A may be superimposed and plotted for a better visualisation of the eye and hand physiological signals of the air traffic controller for aircraft A across time as shown in FIG. 13.

In FIG. 13, each dot represents a fixation with its value corresponding to the elapsed time in seconds and also its fixation duration in milliseconds (ms). Subsequently, each vertical line drawn represents a corresponding radar command as indicated in the legend shown in FIG. 13. From FIG. 13, it may be observed that there are several instances where an air traffic controller exhibits fixation and mouseover of aircraft label very close to each other in time, while there are also instances where fixations occur with no mouseover of label nearby and vice versa. This demonstrates that whenever fixations and mouseover occur very close in time, the air traffic controller is active in deliberately fixating on the aircraft during the course of its flight to maintain awareness of it or to issue appropriate commands for its flight path monitoring. Observations of the different mouseover of label with fixations occurring shows it occurs intermittently.

Based on these observations, the RCG may thus be identified as a fixed time interval that consists of one or several mouseover of an aircraft label with at least one fixation within it. The time interval of this group may then be set using the timestamp of the first and last of such mouseover labels within the group, together with the consideration of a half frame tolerance of 4.9 seconds, as fixations on the aircraft could happen slightly before and after a mouseover label event. Other radar commands occurring in the same frame may be grouped together in the same RCG.

Referring again to FIG. 12, total fixation count and total fixation duration of the identified time intervals may be plotted at step 84 against elapsed time to generate a time profile of the identified time intervals.

In the second phase upon identifying an RCG, the different RCGs present in the generic flight path of the aircraft may then be plotted across time, together with its corresponding sum of fixation count and fixation duration, as the aircraft flies across its flight path in the sector to construct an RCG time profile. Using the constructed RCG time profile, the regularity of the generic flight path monitoring of the air traffic controller may then be evaluated.

Referring now to FIG. 14, an example of an RCG time profile of an air traffic controller for aircraft C is shown. Different RCG types are indicated in the legend shown in FIG. 14. Three (3) key tasks are crossing monitoring, taking jurisdiction of aircraft upon entry to sector (UCO) and handing over jurisdiction of aircraft upon leaving sector (TOC). The other RCG that do not belong to these three (3) key tasks are labelled as 'Generic'. If there are two (2) out of the three (3) key tasks occurring at the same RCG, a separate pattern is assigned to the RCG. Hence, a total of six (6) different RCG types were derived accordingly.

From FIG. 14, it may be observed that the air traffic controller has exhibited all three (3) key tasks in the RCG time profile. By comparing the fixation count and fixation duration of each RCG, the RCG at frame 52 (crossing) has more fixation duration than fixation count. Deeper investigation revealed that at this RCG, the air traffic controller was issuing a clearance for aircraft C to climb, thereby giving rise to more information processing required.

Based on the RCG time profile shown in FIG. 14, it may be observed that an air traffic controller would exhibit RCGs across the entire sector occupancy of an aircraft. As a result, it may be postulated that for an air traffic controller to be perceiving and comprehending an aircraft regularly for a generic flight path monitoring task, there should be a minimum number of RCGs spread out regularly across the time profile.

Referring again to FIG. 12, aircraft sector duration may be calculated at step 86 and time difference between respective ones of the identified time intervals may be calculated at step 88.

At step 90, a probability of each of the identified time intervals occurring based on the time difference between the respective ones of the identified time intervals and the aircraft sector duration may be calculated, and at step 92, an information entropy may be calculated based on the probability of each of the identified time intervals occurring.

In this third phase, the RCG time profile may be evaluated by assessing the number of RCGs and the consistency (regularity) of the RCG time profile to determine if an air traffic controller has fixated on the label of the aircraft deliberately throughout the course of its flight across the airspace sector.

Information entropy, as defined by equations (3) and (4) below, may be used to evaluate the RCG time profile.

$$I_i = \frac{1}{p_i} \tag{3}$$

$$H(p) = \sum_{i=1}^{n} p_i \log I_i = -\sum_{i=1}^{n} p_i \log p_i \tag{4}$$

Using information entropy to compute the regularity of the RCG time profile, the duration of the aircraft in the sector is first computed. Subsequently, the time difference between individual RCG across time is calculated by taking the difference in the frame number between the end of current RCG and the start of the next RCG. A reference RCG is positioned intentionally at the start and end of every flight path profile for the information entropy computation to denote the instant where the aircraft enters and leaves the airspace respectively. From the list of time differences, the probability of each time difference occurring is calculated using equation (5) below before applying it to equation (4) above.

$$Probability = \frac{Time\ Difference}{Flight\ Duration} \tag{5}$$

A higher information entropy means a higher information gained by the air traffic controller of the aircraft during its generic flight monitoring activity.

Using this calculation and understanding of information entropy in quantifying the regularity of the RCG time profile, a set of information entropy values for different RCG time profiles may be calculated to determine the RCG time entropy value so as to ascertain a proper interpretation of them for the air traffic controller.

Referring now to FIG. 15, an illustration of different RCG time profile cases and corresponding RCG time entropy values for Aircraft C with the same start and end reference frames is shown. By comparing cases 1 and 2 and cases 3 and 6, it may be observed that one extra RCG results in a higher information entropy value, despite the same time interval between each individual RCG. This means that every new RCG results in more information gain by the air traffic controller, which is reflective of a regular generic flight path monitoring. Comparing cases 2 and 3, a larger duration between RCG, 18 frames for case 2 and 4 frames for case 3 also results in a larger information entropy. This shows that if an air traffic controller tends to monitor the aircraft closely in time and not monitor again, information gained by the air traffic controller is lesser, which is also reflective of the need to monitor the aircraft during its flight duration more regularly. Furthermore, by comparing cases 3, 4 and 5, where all cases have 4 RCGs that are spaced 4 frames apart individually, a first RCG occurring 39 frames after an aircraft enters the sector results in a higher information entropy value as opposed to the first RCG occurring 1 frame and 77 frames after an aircraft enters the sector. Such an observation is also reflective of the regularity in the generic flight path monitoring of air traffic controllers as the information gained by an air traffic controller only when he monitors early or late is lesser as compared to one who monitors in the middle. Lastly, case 7 shows an RCG time profile with 6 RCGs that are randomly spaced. It has the highest information entropy value amongst all the cases and this is reflective of a regular generic flight path monitoring of air traffic controllers where monitoring is performed throughout the flight path profile regularly, with the intervals randomly spaced.

As a result, for Aircraft C, a higher RCG time entropy value signifies that an air traffic controller has deliberately fixated on the track or label of the aircraft more regularly by either exhibiting the RCG more often or more consistently throughout the course of its flight. Hence, a higher RCG time entropy value would mean a more regular generic

flight path monitoring behaviour from an air traffic controller for that aircraft. The RCG time entropy value for Aircraft C was calculated and this was found to be 1.79.

Referring again to FIG. 1, the calculated tactical air traffic complexity and the eye signature are integrated at step 22 to deduce a monitoring strategy being applied. The monitoring strategy of air traffic controllers may be defined as the way in which the air traffic controllers execute a task after considering the tactical traffic complexity together with their eye signatures. For example, in the tactical monitoring activity of aircraft crossing with potential conflict, one possible monitoring strategy deduced may be the use of aligned fixation peaks for the purpose of maintaining vertical separation early. As another example, in the activity of generic flight path monitoring, one possible monitoring strategy used may be to monitor the aircraft more often when a command needs to be issued.

Deduction of the monitoring strategy being applied may be by means of a module for data integration and contextualisation. This module may integrate the tactical air traffic complexity of the tactical monitoring activity and corresponding eye signatures of the air traffic controllers in real time, synchronously, for traffic complexity evaluation and monitoring enhancement of air traffic controllers. Advantageously, this contextualizes the eye signatures to the various tactical traffic complexities, allowing the monitoring strategies of the air traffic controllers to be deduced.

The step 22 of integrating the calculated tactical air traffic complexity and the eye signature to deduce the monitoring strategy being applied may include identifying one or more instances of change in the calculated tactical air traffic complexity and the eye signature, and contextualising the one or more instances of change to deduce the monitoring strategy being applied. The one or more instances of change may be traced to understand monitoring behaviour.

It follows from the foregoing that the method 10 for air traffic control performance monitoring can thus combine human and traffic data in real time to enable monitoring performance assessment holistically through its tactical complexity and eye signatures. For complexity, it can pinpoint the spatial and temporal sequence of tactical complexity and human physiological data (for example, through eye signatures) and correlate them in real time, synchronously. Therefore, the monitoring strategies of the air traffic

controllers can also be deduced, enabling a curated real time feedback for them. In doing so, alert triggers and measures like adaptive automation may be triggered in real time, allowing timely real-time intervention. With the method 10 for air traffic control performance monitoring, the monitoring strategies and desired monitoring behaviour of an air traffic controller may be appropriately deduced, thus enhancing their monitoring performance. This may pave the way for operational aids and alerts to be created both operationally and in training for the visual monitoring activities of air traffic controllers.

Computer program instructions executable by a computer processor to perform operations for air traffic control performance monitoring described above may be stored in non-transitory computer-readable memory.

Referring now to FIG. 16, a computer system 100 suitable for implementing the method 10 for air traffic control performance monitoring is shown. The computer system 100 includes a processor 102 (which may be referred to as a central processor unit or CPU) that is in communication with memory devices including secondary storage 104, read only memory (ROM) 106, random access memory (RAM) 108, input/output (I/O) devices 110, and network connectivity devices 112. The processor 102 may be implemented as one or more CPU chips.

It is understood that by programming and/or loading executable instructions onto the computer system 100, at least one of the CPU 102, the RAM 108, and the ROM 106 are changed, transforming the computer system 100 in part into a particular machine or apparatus having the novel functionality taught by the present disclosure. It is fundamental to the electrical engineering and software engineering arts that functionality that can be implemented by loading executable software into a computer can be converted to a hardware implementation by well-known design rules. Decisions between implementing a concept in software versus hardware typically hinge on considerations of stability of the design and numbers of units to be produced rather than any issues involved in translating from the software domain to the hardware domain. Generally, a design that is still subject to frequent change may be preferred to be implemented in software, because re-spinning a hardware implementation is more expensive than re-spinning a software design. Generally, a design that is stable that will be produced in large volume may be preferred to be implemented in hardware, for example in an application specific integrated circuit (ASIC), because for large production runs the

hardware implementation may be less expensive than the software implementation. Often a design may be developed and tested in a software form and later transformed, by well-known design rules, to an equivalent hardware implementation in an application specific integrated circuit that hardwires the instructions of the software. In the same manner as a machine controlled by a new ASIC is a particular machine or apparatus, likewise a computer that has been programmed and/or loaded with executable instructions may be viewed as a particular machine or apparatus.

Additionally, after the system 100 is turned on or booted, the CPU 102 may execute a computer program or application. For example, the CPU 102 may execute software or firmware stored in the ROM 106 or stored in the RAM 108. In some cases, on boot and/or when the application is initiated, the CPU 102 may copy the application or portions of the application from the secondary storage 104 to the RAM 108 or to memory space within the CPU 102 itself, and the CPU 102 may then execute instructions that the application is comprised of. In some cases, the CPU 102 may copy the application or portions of the application from memory accessed via the network connectivity devices 112 or via the I/O devices 110 to the RAM 108 or to memory space within the CPU 102, and the CPU 102 may then execute instructions that the application is comprised of. During execution, an application may load instructions into the CPU 102, for example load some of the instructions of the application into a cache of the CPU 102. In some contexts, an application that is executed may be said to configure the CPU 102 to do something, for example, to configure the CPU 102 to perform the function or functions promoted by the subject application. When the CPU 102 is configured in this way by the application, the CPU 102 becomes a specific purpose computer or a specific purpose machine.

The secondary storage 104 is typically comprised of one or more disk drives or tape drives and is used for non-volatile storage of data and as an over-flow data storage device if RAM 108 is not large enough to hold all working data. Secondary storage 104 may be used to store programs which are loaded into RAM 108 when such programs are selected for execution. The ROM 106 is used to store instructions and perhaps data which are read during program execution. ROM 106 is a non-volatile memory device which typically has a small memory capacity relative to the larger memory capacity of secondary storage 104. The RAM 108 is used to store volatile data and perhaps to store

instructions. Access to both ROM 106 and RAM 108 is typically faster than to secondary storage 104. The secondary storage 104, the RAM 108, and/or the ROM 106 may be referred to in some contexts as computer readable storage media and/or non-transitory computer readable media.

I/O devices 110 may include cameras, printers, video monitors, liquid crystal displays (LCDs), plasma displays, touch screen displays, keyboards, keypads, switches, dials, mice, track balls, voice recognizers, card readers, paper tape readers, or other well-known input devices. The network connectivity devices 112 may take the form of modems, modem banks, Ethernet cards, universal serial bus (USB) interface cards, serial interfaces, token ring cards, fiber distributed data interface (FDDI) cards, wireless local area network (WLAN) cards, radio transceiver cards that promote radio communications using protocols such as code division multiple access (CDMA), global system for mobile communications (GSM), long-term evolution (LTE), worldwide interoperability for microwave access (WiMAX), near field communications (NFC), radio frequency identity (RFID), and/or other air interface protocol radio transceiver cards, and other well-known network devices. These network connectivity devices 112 may enable the processor 102 to communicate with the Internet or one or more intranets. With such a network connection, it is contemplated that the processor 102 might receive information from the network, or might output information to the network in the course of performing the above-described method steps. Such information, which is often represented as a sequence of instructions to be executed using processor 102, may be received from and outputted to the network, for example, in the form of a computer data signal embodied in a carrier wave. Such information, which may include data or instructions to be executed using processor 102 for example, may be received from and outputted to the network, for example, in the form of a computer data baseband signal or signal embodied in a carrier wave. The baseband signal or signal embedded in the carrier wave, or other types of signals currently used or hereafter developed, may be generated according to several methods well-known to one skilled in the art. The baseband signal and/or signal embedded in the carrier wave may be referred to in some contexts as a transitory signal.

The processor 102 executes instructions, codes, computer programs, scripts which it accesses from hard disk, floppy disk, optical disk (these various disk based

systems may all be considered secondary storage 104), flash drive, ROM 106, RAM 108, or the network connectivity devices 112. While only one processor 102 is shown, multiple processors may be present. Thus, while instructions may be discussed as executed by a processor, the instructions may be executed simultaneously, serially, or otherwise executed by one or multiple processors. Instructions, codes, computer programs, scripts, and/or data that may be accessed from the secondary storage 104, for example, hard drives, floppy disks, optical disks, and/or other device, the ROM 106, and/or the RAM 108 may be referred to in some contexts as non-transitory instructions and/or non-transitory information.

In an embodiment, the computer system 100 may comprise two or more computers in communication with each other that collaborate to perform a task. For example, but not by way of limitation, an application may be partitioned in such a way as to permit concurrent and/or parallel processing of the instructions of the application. Alternatively, the data processed by the application may be partitioned in such a way as to permit concurrent and/or parallel processing of different portions of a data set by the two or more computers. In an embodiment, virtualization software may be employed by the computer system 100 to provide the functionality of a number of servers that is not directly bound to the number of computers in the computer system 100. For example, virtualization software may provide twenty virtual servers on four physical computers. In an embodiment, the functionality disclosed above may be provided by executing the application and/or applications in a cloud computing environment. Cloud computing may comprise providing computing services via a network connection using dynamically scalable computing resources. Cloud computing may be supported, at least in part, by virtualization software. A cloud computing environment may be established by an enterprise and/or may be hired on an as-needed basis from a third party provider. Some cloud computing environments may comprise cloud computing resources owned and operated by the enterprise as well as cloud computing resources hired and/or leased from a third party provider.

In an embodiment, some or all of the functionality disclosed above may be provided as a computer program product. The computer program product may comprise one or more computer readable storage medium having computer usable program code embodied therein to implement the functionality disclosed above. The computer program

product may comprise data structures, executable instructions, and other computer usable program code. The computer program product may be embodied in removable computer storage media and/or non-removable computer storage media. The removable computer readable storage medium may comprise, without limitation, a paper tape, a magnetic tape, magnetic disk, an optical disk, a solid state memory chip, for example analog magnetic tape, compact disk read only memory (CD-ROM) disks, floppy disks, jump drives, digital cards, multimedia cards, and others. The computer program product may be suitable for loading, by the computer system 100, at least portions of the contents of the computer program product to the secondary storage 104, to the ROM 106, to the RAM 108, and/or to other non-volatile memory and volatile memory of the computer system 100. The processor 102 may process the executable instructions and/or data structures in part by directly accessing the computer program product, for example by reading from a CD-ROM disk inserted into a disk drive peripheral of the computer system 100. Alternatively, the processor 102 may process the executable instructions and/or data structures by remotely accessing the computer program product, for example by downloading the executable instructions and/or data structures from a remote server through the network connectivity devices 112. The computer program product may comprise instructions that promote the loading and/or copying of data, data structures, files, and/or executable instructions to the secondary storage 104, to the ROM 106, to the RAM 108, and/or to other non-volatile memory and volatile memory of the computer system 100.

In some contexts, the secondary storage 104, the ROM 106, and the RAM 108 may be referred to as a non-transitory computer readable medium or a computer readable storage media. A dynamic RAM embodiment of the RAM 108, likewise, may be referred to as a non-transitory computer readable medium in that while the dynamic RAM receives electrical power and is operated in accordance with its design, for example during a period of time during which the computer system 100 is turned on and operational, the dynamic RAM stores information that is written to it. Similarly, the processor 102 may comprise an internal RAM, an internal ROM, a cache memory, and/or other internal non-transitory storage blocks, sections, or components that may be referred to in some contexts as non-transitory computer readable media or computer readable storage media.

Examples

Experiment 1

To illustrate the aligned fixation peaks signature, an aircraft pair-in-crossing of AXM540 and TGW971 was used. In the first phase, the fixation count and duration against frame number was plotted as shown in FIGS. 17A through 17D. FIGS. 17A through 17D show the plot for one expert, one intermediate and one novice participant for AXM540 and TGW971.

From FIGS. 17A through 17D, it can be observed that fixation peaks are observed for both fixation count and fixation duration plots. After aligning the appropriate fixation peaks to form the aligned fixation peak signatures, it is being evaluated for a group of five participants. The number of 0 aligned peaks, total number of aligned peaks, total fixation count and total fixation duration of the aligned fixation peaks signature is computed, together with the cumulative plot, as shown in FIGS. 18A through 18C.

As can be seen from FIGS. 18A through 18C, three cumulative line plots of the number of aligned fixation peaks, total fixation count and total fixation duration against the elapsed frame number were made for all five participants. Every 'step up' increase of the line signifies that the participant exhibited an aligned fixation peak. The length of vertical increase of this line represents the proportion of the metric throughout the flight duration from the point of entry to the crossing point for the aircraft pair-in-crossing AXM540 and TGW791. From FIGS. 18A through 18C, it can be observed that different participants have different crossing monitoring behaviour as the aligned fixation peaks were not executed at the same frame. This highlights that different individuals exhibit a different crossing monitoring behaviour when performing this task. Despite the differences in crossing monitoring behaviour, all participants began the crossing monitoring of AXM540 and TGW791 earlier and have more than one aligned fixation peak up till 0.5 min before the crossing. Two periods of crossing monitoring behaviour, frames 0 to 6 and frames 20 to 35, were found to be exhibited by all participants. This indicates that for AXM540 and TGW791, participants exhibited crossing monitoring behaviour at the start of the scenario and 3.6 minutes before the aircraft pair crosses.

Experimental Setup for Experiments 2 and 3

For the experiment, a real-time simulator, the NLR ATM Research SIMulator (NARSIM), was used to generate and simulate air traffic scenarios in real time, with every radar update at 9.8 seconds. Pseudo-pilots were used to facilitate the flying of aircraft, by following the same scenario script, so that events in the same scenario occurred at the same instant. A standard Controller Working Position (CWP), consisting of a 2K radar screen (50cm by 50cm, equivalent to 20 inches by 20 inches) was used to display air traffic data in a given airspace sector, as seen in FIG. 19.

A remote eye tracker, Tobii X2-30, was used to capture the eye data of the participants in a non-intrusive manner. Under ideal conditions, its accuracy and precision are 0.4° and 0.26° respectively (Tobii 2013). In this setup, the eye tracker is positioned 18 cm in front of the screen and 55 cm from a participant's eye to extend the eye tracker's field of view so that gaze data on any regions of the 2K screen can be captured. This meant that the eye tracker was deployed in a non-ideal condition that closely mimics an air traffic controller's working environment. A study was conducted to determine the accuracy and precision of the eye tracker without a chinrest, prior to this study, for this non-ideal condition. For a total of 3128 gaze data samples, the accuracy and precision of the Tobii X2-30 was found to be 3.5° and 1.1°, respectively, with good validity of 93.7%.

Raw eyeball movement and radar data are extracted from the Tobii eye tracker and NARSIM, respectively, via an intelligent real-time post processing server using a Dynamic Data Alignment and Timestamp Model. This ensures that the two data streams are synchronous in time and space. The two sets of extracted data are then computed to determine the various eye tracking metrics. Using these accuracy and precision values, the velocity threshold in the I-VT algorithm for fixation determination is 105°/s and the new boundaries of the aircraft's track and label for the mapping of a fixation would be a 70 pixel diameter and 230 pixel diameter circle, respectively. These eye metrics which were mapped to a flight object on the radar screen were then relayed to the Thales TopSky-HF software to record the data of the different test participants.

Experimental Sessions for Experiments 2 and 3

88 one-hour experimental sessions of data were collected among male participants whose ages varied between 24 and 41 (M = 29, SD = 5.34). These sessions comprised 24 novice sessions (zero air traffic control (ATC) experience, only ATC knowledge), 20 intermediate sessions (more than 50 hours of simulator ATC training and ATC knowledge, yet to handle live traffic) and 44 expert sessions (licensed ATCOs with more than three months of live traffic experience).

Experiment 2

Prior to the experiment, each participant involved in a session underwent an initial 9-point eyetracker calibration exercise. Calibration was repeated until a satisfactory calibration was obtained that refers to Tobii Studio's qualitative calibration report.

Real time simulations were conducted for 88 one-hour experimental sessions, with different scenarios consisting of 60 aircraft each that mimic operational air traffic, which is approximately to 1.2 times of that of the regular traffic volume. In each scenario, there is a mixture of climbing and cruising flight along the different airways (flight path), and also different crossing characteristics like the angle crossing point (wide and medium) and proximity of crossing point (close and independent). FIG. 20 provides a depiction of the close and independent crossing points. The airspace of interest in this real time study was based on an existing airspace sector with information referenced from the publicly available SkyVector website.

For the crossing characteristic of angle of crossing, a wide-angle crossing point is defined as a crossing point with an angular difference of 45 to 180 degrees between the two intersecting airways, whereas a medium angle crossing point is one with an angular difference of 16 to 44 degrees between the two intersecting airways.

For the crossing characteristic of proximity of crossing, close proximity crossing is defined as a crossing point with another one within 10 to 20 Nautical Miles (NM) from it and independent proximity crossing is defined as a crossing point with another crossing point more than 20 NM away from it. The value of 10 NM was selected as it is the

Required Navigation Performance (RNP) standard which all of the aircraft are to observe in which an aircraft should not deviate left and right by more than 10 NM.

The aligned fixation peaks signature was tested to determine its ability to identify a participant's monitoring behaviour on various aircraft pair flight configuration for different expertise levels. An aircraft pair flight configuration refers to how two aircraft will interact with each other as they fly in an airspace. In this study, three aircraft pair flight configurations, namely, 1) two aircraft flying past a crossing point simultaneously, 2) two aircraft flying past a crossing point with 1 min difference, and 3) two aircraft that do not fly past the same crossing point, were used. It is believed that the greatest number of aligned fixation peaks signature would be exhibited for the case of two aircraft flying past a crossing point simultaneously. FIG. 21 illustrates the different aircraft pair flight configurations with the callsign and position of these aircraft for each of the test scenarios. Furthermore, the aligned fixation peaks signature is also tested on the different expertise levels (expert, intermediate and novice), where it is believed that participants of all expertise levels will exhibit aligned fixation peaks signature for the case of two aircraft flying past a crossing point simultaneously.

With reference to FIG. 22, using a time duration between frame number 80 to 160, all three of aircraft crossing pairs case activities are observed and compared. In a first case where two aircraft fly past a crossing point simultaneously, aircraft CSN387 and GIA275 are used. CSN387 is flying on airway M771 and GIA275 is flying on airway L629. These two aircraft cross simultaneously across DUBSA at frame 156. In a second case, aircraft SIA141 and GIA275 are used as the two aircraft flying past a crossing point. Similarly, the crossing point, DUBSA, is used and SIA141 flies across DUBSA at frame 150, while GIA275 flies across DUBSA at frame 156. This means that both aircraft fly across DUBSA with a 1 min difference. For the last case of two aircraft that do not fly past the same crossing point, aircraft CSN387 and SIA371 were used. SIA371 started flying at frame 47 on N891 and does not cross with CSN387.

A total of three (3) crossing point instances comprising one crossing point instance per expertise group were chosen in each of these comparisons. The total number of aligned peaks for every participant in each case was tabulated and its fixation count and fixation duration plot across the elapsed time frame are seen. A comparison of the results between the three different cases was also made, where the aligned

fixation peaks signature is applied on the aircraft pair flight configuration for all three cases. FIGS. 23A through 25D show one of the fixation count and duration plots across the elapsed time frame for one participant from each expertise group, while Table 5 below illustrates the frame number of the exhibited aligned fixation peaks, as well as the sum of these peaks, for all three cases.

Table 5: Aligned Fixation Peaks for all 4 cases

Case ID & Aircraft pair-in-crossing comparison	**Expertise Level**	**Frame number of Aligned Fixation Peaks**	**Sum of Aligned Fixation peaks**
Case 1 CSN387 & GIA275	Expert	127,128,134,135,142,148,149,150,154	9
	Intermediate	110,111,114,115,144,145,148,149,154,155	10
	Novice	139,140,144,145,146,147,148,151,154,155	10
Case 2 SIA141 & GIA275	Expert	140,141,144	3
	Intermediate	139	1
	Novice	146,147	2
Case 3 SIA371 & CSN387	Expert	-	0
	Intermediate	-	0
	Novice	94	1

Results from Table 5 and FIGS. 23A through 25D show that aligned fixation peaks are observed in all three cases. In Case 1, two aircraft flying past a crossing point simultaneously, highlights the greatest number of aligned fixation peaks exhibited out of all three cases. This indicates that the aligned fixation peaks signature is most evident when there are two aircraft flying past a crossing point simultaneously. This could likely occur as the participants have correctly identified that the two aircraft are in crossing and are monitoring to ensure that they cross safely. In cases 2 and 3, only 0 to 3 aligned fixation peaks were exhibited for all participants. The significantly fewer number of aligned fixation peaks exhibited indicates that participants could have identified the crossings of these two aircraft. Upon determining that these two aircraft do not cross based on their respective trajectories, these participants have likely stopped monitoring for crossing with potential conflict, resulting in the low number of aligned fixation peaks. Therefore, these results showcase the suitability of the aligned fixation peaks signature applied on aircraft crossing with potential conflict.

Furthermore, in all three cases, the aligned fixation peaks were exhibited by participants across all expertise levels. In case 1, the case where aligned fixation peaks signature is most suitably applied, expert, intermediate and novice participants exhibited approximately the same number of aligned peaks. These results suggest that the aligned fixation peaks signature can be exhibited by participants of all expertise levels. The execution of the aligned fixation peaks signature by participants of various expertise levels is thus demonstrated.

These results validate the use of aligned fixation peaks as a visual signature capture for crossing monitoring behaviour across participants of all expertise levels. Hence, the aligned fixation peaks signature is a suitable measure to represent the crossing monitoring behaviour of participants.

With the establishment of the aligned fixation peaks signature as a viable measure of a participant's crossing monitoring behaviour across all expertise levels, the effect of the different crossing characteristics and the difference in crossing monitoring behaviour across the different expertise level is then investigated.

With reference to FIG. 26, the different crossing point instances were split into two different cases: instances where the aligned fixation peaks signature is not exhibited and instances where the signature is exhibited. In both cases, analysis was performed at three different layers to understand the difference in monitoring behaviour between the three expertise levels. The three layers represent the different crossing characteristics: crossing points in general, angle of crossing points (wide vs medium) and proximity of crossing points (close vs independent). Furthermore, within each layer, the differences in crossing characteristics were also analysed whenever two levels exist. For the case of crossing instances with no aligned fixation peaks, the Boolean metric, number of 0 aligned peaks, was used. On the other hand, for the case of crossing instance with aligned fixation peaks, the continuous metrics, total number of aligned peaks, total fixation count and total fixation duration, together with the cumulative plot of crossing instances between the participants, were used.

In the analysis, a total of 264, 220 and 484 crossing point instances were examined for novice, intermediate and expert participants, respectively. For the analysis on the angle of crossing for these crossing point instances, there were 198, 165 and 363

wide angle and 66, 55 and 121 medium angle crossing point instances for novice, intermediate and expert participants, respectively. On the other hand, for the analysis on the proximity of crossing for these crossing point instances, there were 126, 105 and 231 close crossing point instances and 72, 60 and 132 independent crossing point instances were used for novice, intermediate and expert participants, respectively.

For the crossing point instances with no aligned fixation peaks, the Boolean metric, number of 0 aligned peaks, was first counted for all aircraft pairs-in-crossing. This metric represents the lack of crossing monitoring behaviour of participants for a crossing point instance. The total number of 0 aligned peak instances for the three different layers of analysis, across all three expertise groups, was tabulated in Table 6 and presented as a fraction of the total number of crossing point instance.

Table 6: Number of 0 Aligned Fixation Peaks for aircraft pairs-in-crossing across all 3 expertise groups

Metric 1: Number of 0 Aligned Fixation Peaks [Total 0 aligned peaks / total instances]		**Novice**	**Intermediate**	**Expert**
Layer 1: Generic Crossing Points	All crossing points	76/264 (0.29)	44/220 (0.2)	73/484 (0.15)
Layer 2: Angle of Crossing	Wide Angle	67/198 (0.34)	38/165 (0.23)	62/363 (0.17)
	Medium Angle	9/66 (0.14)	6/55 (0.11)	11/121 (0.09)
Layer 3: Proximity of Crossing	Close	40/126 (0.32)	21/105 (0.2)	34/231 (0.15)
	Independent	36/72 (0.5)	23/60 (0.38)	39/132 (0.3)

Results from Table 6 show that only 15% of expert crossing instances have no aligned fixation peaks signature detected when looking at the crossing point instance in general. Furthermore, by considering the crossing point instances in general, novice participants are most likely to not exhibit an aligned fixation peaks signature, as seen in 29% of the crossing instances. For intermediate participants, no aligned fixation peaks signature was detected in 20% of the crossing point instances. This meant that the intermediate and novice participants are 1.33 and 1.93 times more likely to miss the monitoring of aircraft pairs-in-crossing, as opposed to the experts. This is reasonable as the task of identifying aircraft pairs-in-crossing, which is to fixate more often and longer

for the aircraft pairs within a short duration, should be the most obvious to experts, followed by intermediates, then novices, owing to their experience and training.

At the second layer, differentiating the crossing points by wide and medium angle, a similar observation can also be made, that the expert participants are least likely to miss an aircraft pair-in-crossing, followed by intermediate and novice. For wide angle crossings, 17%, 23% and 34% of these crossing instances were missed by experts, intermediates and novices respectively. For medium angle crossings, it is also found that 9%, 11% and 14% of these crossing instances were missed by experts, intermediates and novices respectively. This meant that at wide angle crossings, intermediate and novice participants are 1.35 and 2 times more likely to miss the monitoring of aircraft pairs-in-crossing, as opposed to expert participants, while intermediates and novices are 1.22 and 1.55 times more likely to miss the monitoring of aircraft pairs-in-crossing for medium angle crossings. These results are consistent with that from the analysis of crossing points in general, where novices are unlikely to identify and recognise the aircraft pairs-in-crossing by fixating on them more often for a longer duration within a short time span. This points out that experts can execute the task of monitoring for aircraft pairs-in-crossing more easily, for both wide and medium angle crossing points.

At the third layer, the crossing points are differentiated by their proximity, which are close and which are independent crossing points. It is found that for close crossing instances, 15%, 20% and 32% of them were missed by experts, intermediates and novices respectively, while 30%, 38% and 50% of the independent crossing instances were missed by experts, intermediates and novices respectively. This indicates that intermediate and novice participants are 1.33 and 2.13 times more likely to miss the monitoring of aircraft flying at close crossings, compared to experts, while intermediates and novices are 1.27 and 1.67 times more likely to miss the monitoring of aircraft pairs-in-crossing for independent crossings. Similarly, these findings by varying the proximity of crossings are agreeable to the findings of both crossing points in general and different angles of crossings, whereby experts can better perform the task of monitoring for aircraft pairs-in-crossing and novices are most likely to miss that. This also means that experts, being better trained and having more experience, can better handle the task of monitoring aircraft pairs-in-crossing for various proximities of crossing points.

Subsequently, to analyse the differences in crossing characteristics within the second and third layer, percentage figures of the number of 0 aligned peaks from Table 6 were used and divided to obtain a ratio value. This was conducted for the three expertise levels, before plotting the values as shown in FIG. 27.

From FIG. 27, it can be observed that participants across all expertise levels monitored differently for wide and medium crossing point instances. Expert, intermediate and novice participants are 1.89, 2.09 and 2.43 times more unlikely to exhibit the aligned fixation peaks signature on wide angle crossings as compared to medium angle ones. This suggests that it is easier for participants across all expertise groups to exhibit aligned fixation peaks on medium angle crossing points. One possible explanation is that aircraft in medium angle crossings are spatially closer to each other as compared to wide angle crossings, thereby making it easier for consecutive monitoring between the aircraft pair-in-crossing (aligned fixation peaks) to be executed. Additionally, it is also noted that the ratio of the number of 0 aligned peaks of wide angle over medium angle crossing points is the least for experts, followed by intermediates and novices. This likely means that experts are better trained and more familiar in monitoring aircraft pairs-in-crossings as more aligned peaks are exhibited for the more difficult wide angle crossing points.

By comparing close and independent crossing points in FIG. 27, participants of all three expertise levels were also found to monitor differently for close and independent crossing point instances. Expert, intermediate and novice participants are 2, 1.9 and 1.56 times more unlikely to exhibit the aligned fixation peaks signature on independent crossings as compared to close ones. This means that it is easier for participants of all expertise groups to exhibit aligned fixation peaks in the crossing monitoring of aircraft flying across close crossings. One possible explanation is that areas with close crossings tend to be more crowded as there will be a group of aircraft near to each other spatially on the radar screen. This makes it easier to exhibit aligned fixation peaks to ascertain if the aircraft pair will fly into crossing. This is supported by the Gestalt Law of Proximity, where “objects that are near to each other tend to be grouped together” by human beings for their perceptual organisation. Furthermore, the ratio of the number of 0 aligned peaks of independent over close crossing points is the most for experts,

followed by intermediates and novices. This likely means that the expert participants are not as familiar with identifying independent crossings as compared to close crossings.

Results from the analysis of crossing instances with no aligned fixation peaks showed that regardless of the different crossing point characteristics, expert participants missed the monitoring of aircraft pairs-in-crossing the least, followed by intermediate participants, then novice participants. This highlights that with more experience and higher expertise, participants tended to perform better in identifying and recognising aircraft pairs-in-crossing. Comparing the different crossing point characteristics, it was found that medium angle and close crossings are easier to monitor, as participants of all three expertise levels missed the monitoring of these aircraft pairs-in-crossing the least. For the angle of crossing, this can likely be attributed to the geometry of the crossing point as medium angle crossings are spatially closer to each other as compared to wide angle crossings, making it easier for aligned fixation peaks to be exhibited. For the proximity of crossing, one likely reason is that objects that are nearer together tend to be perceived as a group by human beings, thereby making it easier for aligned fixation peaks to be exhibited on close crossings. In addition, experts were also found to less likely miss aircraft pairs-in-crossing for wide angle crossings, as compared to other participants. However, experts were found to miss the most aircraft pairs-in-crossing for independent crossings, as compared to other participants. This can likely mean that the expert participants are as familiar in identifying and recognising independent crossings.

Using the remaining 188 novice, 176 intermediate and 411 expert instances of aligned fixation peaks for the different aircraft pairs-in-crossing, the three continuous metrics, total number of aligned peaks, total fixation count and total fixation duration were computed. Differences in the monitoring of aircraft pairs-in-crossing due to various expertise levels and crossing characteristics, like the angle and proximity of crossing, were then analysed.

To compare the differences in monitoring of aircraft pairs-in-crossing due to various expertise levels on the different crossing characteristics, the descriptive statistics (sample size = N, mean = M, standard deviation = SD) of the crossing point instances were first listed in Table 7 below.

Table 7: Descriptive Statistics for Aircraft pairs-in-crossing with Aligned Fixation Peaks

		Aligned Fixation Peaks Metric	Novice	Intermediate	Expert
Layer 1	All crossing points	Total Number of Aligned Peaks	N = 188, M = 5.62, SD = 4.192	N = 176, M = 5.37, SD = 3.87	N = 411, M = 5.48, SD = 3.976
		Total Fixation Count	N = 188, M = 26.05, SD = 22.877	N = 176, M = 22.02, SD = 16.829	N = 411, M = 24.13, SD = 19.207
		Total Fixation Duration (ms)	N = 188, M = 23589.78, SD = 21211.24	N = 176, M = 25109.11, SD = 20765.97	N = 411, M = 22640.87, SD = 19649.25
Layer 2	Wide Angle	Total Number of Aligned Peaks	N = 131, M = 5.25, SD = 3.893	N = 127, M = 4.43, SD = 2.841	N = 301, M = 4.88, SD = 3.460
		Total Fixation Count	N = 131, M = 24.22, SD = 20.981	N = 127, M = 18.48, SD = 13.572	N = 301, M = 20.96, SD = 16.983
		Total Fixation Duration (ms)	N = 131, M = 21273.42, SD = 18792.86	N = 127, M = 19866.76, SD = 15076.60	N = 301, M = 19706.19, SD = 18100.50
	Medium Angle	Total Number of Aligned Peaks	N = 57, M = 6.46, SD = 4.74	N = 49, M = 7.80, SD = 5.00	N = 110, M = 7.12, SD = 4.775
		Total Fixation Count	N = 57, M = 30.25, SD = 26.456	N = 49, M = 31.18, SD = 20.741	N = 110, M = 32.80, SD = 22.139
		Total Fixation Duration (ms)	N = 57, M = 28913.33, SD = 25320.72	N = 49, M = 38696.45, SD = 26726.91	N = 110, M = 30671.20, SD = 21486.91
Layer 3	Close	Total Number of Aligned Peaks	N = 86, M = 5.64, SD = 4.099	N = 84, M = 4.60, SD = 2.875	N = 197, M = 5.08, SD = 3.726

		Total Fixation Count	N = 86, M = 27.05, SD = 22.506	N = 84, M = 19.06, SD = 14.496	N = 197, M = 22.47, SD = 18.699
		Total Fixation Duration (ms)	N = 86, M = 23406.83, SD = 19134.39	N = 84, M = 20968.36, SD = 15702.30	N = 197, M = 21433.34, SD = 20541.39
	Independent	Total Number of Aligned Peaks	N = 102, M = 5.60, SD = 4.290	N = 92, M = 6.08, SD = 4.495	N = 214, M = 5.84, SD = 4.168
		Total Fixation Count	N = 102, M = 25.21, SD = 23.262	N = 92, M = 24.72, SD = 18.372	N = 214, M = 25.65, SD = 19.582
		Total Fixation Duration (ms)	N = 102, M = 23744.03, SD = 22909.30	N = 92, M = 28889.80, SD = 23960.71	N = 214, M = 23752.47, SD = 18770.24

From Table 7 above, it can be observed that the sample sizes for each group are different. Hence, to examine if expertise level has a significant effect on the different metrics at different crossing characteristics, a Levene's F test, a statistical test to determine if different samples have equal variances, was then performed to determine if the homogeneity of variance assumption was met. The homogeneity of variance meant that the level of variance of a variable is constant across the sample. This is required to choose the type of statistical test to perform in order to determine whether there are any statistically significant differences between three or more means of an independent variable. In ANOVA (an established statistical test), when homogeneity of variance is violated, there is a greater probability of falsely indicating that there are at least two group means that are statistically significantly different from each other. Results of the Levene's F test are shown in Table 8 below and the homogeneity of variance is not met when the corresponding p-value is lesser than 0.05, at the 95% confidence level.

Table 8: Levene's F test result for homogeneity of variance on expertise level

Comparison of all Expertise Levels		**Aligned Fixation Peaks Metric**	**Levene's F test output**
Layer 1	All crossing points	Total Number of Aligned Peaks	$F_{2,772} = 0.756$, $p = 0.470$
		Total Fixation Count	$F_{2,772} = 8.671$, $p = 1 * 10^{-4} \approx 0$ *

		Total Fixation Duration	$F_{2,772} = 0.756$, $p = 0.095$
Layer 2	Wide Angle	Total Number of Aligned Peaks	$F_{2,556} = 3.643$, $p = 0.027$ *
		Total Fixation Count	$F_{2,556} = 10.617$, $p = 1 * 10^{-5} \approx 0$ *
		Total Fixation Duration	$F_{2,556} = 2.155$, $p = 0.117$
	Medium Angle	Total Number of Aligned Peaks	$F_{2,213} = 0.160$, $p = 0.853$
		Total Fixation Count	$F_{2,213} = 1.548$, $p = 0.215$
		Total Fixation Duration	$F_{2,213} = 1.547$, $p = 0.215$
Layer 3	Close	Total Number of Aligned Peaks	$F_{2,364} = 2.554$, $p = 0.079$
		Total Fixation Count	$F_{2,364} = 7.907$, $p = 1 * 10^{-4} \approx 0$ *
		Total Fixation Duration	$F_{2,364} = 0.592$, $p = 0.554$
	Independent	Total Number of Aligned Peaks	$F_{2,405} = 0.453$, $p = 0.636$
		Total Fixation Count	$F_{2,405} = 2.487$, $p = 0.084$
		Total Fixation Duration	$F_{2,405} = 4.156$, $p = 0.016$ *

* indicates significance at 95% level

It is revealed that the metrics on total fixation count for all crossing points, wide angle and close crossings, together with total fixation duration on independent crossing did not meet the homogeneity of variance assumption. Hence, a Welch's F test was used for these metrics, instead of a one-way ANOVA test, to compare if the expertise levels are statistically significantly different on the different aligned fixation peaks metric, for crossing points in general, wide and medium angle crossing points, as well as close and independent crossing points (characteristics of crossing points at all three layers). The results of this one-way ANOVA and Welch F test are shown in Table 9 below. Therefore, if the effect of expertise level is significant, at 95% confidence level, the corresponding p-value of the one-way ANOVA or Welch F test should be less than 0.05.

Table 9: One way ANOVA or Welch F test results to compare the effect of expertise level on the different aligned fixation peaks metric

		Aligned Fixation Peaks Metric	**One way ANOVA / Welch F Test Result**
Layer 1: Generic Crossing Points	All crossing points	Total Number of Aligned Peaks	$F_{2,772} = 0.176$, $p = 0.838$
		Total Fixation Count	$F_{2,379.21} = 1.950$, $p = 0.144$ (Welch)
		Total Fixation Duration	$F_{2,772} = 0.919$, $p = 0.399$

Layer 2: Angle of Crossing	Wide Angle	Total Number of Aligned Peaks	$F_{2,273.66} = 2.011$, $p = 0.136$ (Welch)
		Total Fixation Count	$F_{2,270.66} = 3.583$, $p = 0.030$ * (Welch)
		Total Fixation Duration	$F_{2,556} = 0.376$, $p = 0.687$
	Medium Angle	Total Number of Aligned Peaks	$F_{2,213} = 1.020$, $p = 0.362$
		Total Fixation Count	$F_{2,213} = 0.250$, $p = 0.779$
		Total Fixation Duration	$F_{2,213} = 2.593$, $p = 0.077$
Layer 3: Proximity of Crossing	Close	Total Number of Aligned Peaks	$F_{2,364} = 1.751$, $p = 0.175$
		Total Fixation Count	$F_{2,179.72} = 3.936$, $p = 0.021$ * (Welch)
		Total Fixation Duration	$F_{2,364} = 0.416$, $p = 0.660$
	Independent	Total Number of Aligned Peaks	$F_{2,405} = 0.303$, $p = 0.739$
		Total Fixation Count	$F_{2,405} = 0.071$, $p = 0.931$
		Total Fixation Duration	$F_{2,182.96} = 1.757$, $p = 0.175$ (Welch)

* indicates significance at 95% level

Results from Table 9 above show that there was a significant difference of expertise level on total fixation count for wide angle crossings [F(2, 556) = 3.583, p = 0.028] and close crossings [F(2, 364) = 3.875, p = 0.022]. Respective post-hoc analysis was performed to determine where the differences occurred between the expertise levels when there are three or more groups. Hence, Tukey's honestly significant difference (HSD) post-hoc test was used if homogeneity of variance was met, while the Games Howell post-hoc test was used when the homogeneity of variance was not met. Therefore, if two of the expertise groups were different, the adjusted p-value is lesser than 0.05 at 95% confidence level. Results of the post-hoc analysis are shown in Table 10 below.

Table 10: Post hoc analysis on statistically significant metrics

Crossing Characteristic	**Aligned Fixation Peak Metric**	**Difference of Levels**	**Difference of means**	**Adjusted p-value**
Wide Angle	Total Fixation Count (GamesHowell)	Expert – Intermediate	2.476	0.249
		Expert – Novice	-3.265	0.261
		Intermediate – Novice	-5.741	0.026 *
Close	Total Fixation Count	Expert – Intermediate	3.407	0.228

	(GamesHowell)	Expert – Novice	-4.580	0.227
		Intermediate – Novice	-7.987	0.018 *

Results in Table 10 above show that intermediate participants have a significantly lower total fixation count as compared to novice participants for both wide angle and close crossings. Additionally, no significant differences were found for other parameters using the results from Table 9. This indicates that expertise levels do not have an effect on the monitoring of aircraft pairs-in-crossing, as seen in most of the aligned fixation peaks metrics on different crossing characteristics.

This could likely mean that participants of all expertise levels can maintain their awareness on the aircraft pairs-in-crossing after successfully identifying and recognising them in various crossing characteristics, regardless of how these aircraft pairs-in-crossing were guided. For the metrics with significant differences, it shows that intermediate participants tend to fixate lesser on aircraft pairs-in-crossing for wide angle and close crossings. One possible reason could be that intermediate participants were working on other tasks at hand that they are more familiar with and better trained at, thereby resulting in a lesser fixation count on aircraft pairs-in-crossing for wide angle and close crossings. This could also highlight the difficulty in handling wide angle and close crossing points for intermediates.

To compare the differences in monitoring of aircraft pairs-in-crossing due to crossing characteristics (wide vs medium angle, close vs independent) for all expertise levels, the same descriptive statistics (sample size = N, mean = M, standard deviation = SD) of the crossing point instances in Table 7 was used.

Similarly, as the sample sizes for each group varies, to examine if crossing characteristic has a significant effect on the different metrics for all expertise levels, a Levene's F test was performed to determine if the homogeneity of variance assumption was met. Results of this Levene's F test are shown below in Table 11.

Table 11: Levene's F test result for homogeneity of variance on Crossing Characteristics

Comparison of Crossing Characteristics	**Expertise Level**	**Aligned Fixation Peaks Metric**	**Levene's F test output**

Layer 2 (Wide vs Medium)	Novice	Total Number of Aligned Peaks	$F_{1,186} = 2.618$, $p = 0.107$
		Total Fixation Count	$F_{1,186} = 4.263$, $p = 0.040$ *
		Total Fixation Duration	$F_{1,186} = 7.095$, $p = 0.008$ *
	Intermediate	Total Number of Aligned Peaks	$F_{1,174} = 23.8$, $p = 1 * 10^{-6} \approx 0$ *
		Total Fixation Count	$F_{1,174} = 15.128$, $p = 1 * 10^{-4} \approx 0$ *
		Total Fixation Duration	$F_{1,174} = 22.317$, $p = 1 * 10^{-6} \approx 0$ *
	Expert	Total Number of Aligned Peaks	$F_{1,409} = 21.710$, $p = 1 * 10^{-6} \approx 0$ *
		Total Fixation Count	$F_{1,409} = 18.530$, $p = 1 * 10^{-5} \approx 0$ *
		Total Fixation Duration	$F_{1,409} = 11.838$, $p = 1 * 10^{-4} \approx 0$ *
Layer 3 (Close vs Independent)	Novice	Total Number of Aligned Peaks	$F_{1,186} = 0.252$, $p = 0.616$
		Total Fixation Count	$F_{1,186} = 0.002$, $p = 0.969$
		Total Fixation Duration	$F_{1,186} = 2.768$, $p = 0.098$
	Intermediate	Total Number of Aligned Peaks	$F_{1,174} = 11.350$, $p = 0.001$ *
		Total Fixation Count	$F_{1,174} = 5.445$, $p = 0.021$ *
		Total Fixation Duration	$F_{1,174} = 8.836$, $p = 0.003$ *
	Expert	Total Number of Aligned Peaks	$F_{1,409} = 3.591$, $p = 0.059$
		Total Fixation Count	$F_{1,409} = 2.574$, $p = 0.109$
		Total Fixation Duration	$F_{1,409} = 0.291$, $p = 0.590$

* indicates significance at 95% level

From Table 11, metrics with p-value lesser than 0.05 did not meet the homogeneity of variance assumption, and a Welch's F test was used for these metrics, instead of a one-way ANOVA test, to compare if the crossing characteristics are statistically significantly different on the different aligned fixation peaks metric for all expertise levels. The results of this one-way ANOVA and Welch F test are shown in Table 12 below. If the effect of crossing characteristic is significant, at 95% confidence level, the corresponding p-value of the one-way ANOVA or Welch F test should be less than 0.05.

Table 12: One way ANOVA or Welch F test results to compare the effect of crossing characteristics on the different aligned fixation peaks metric

Comparison of Crossing Characteristics	**Expertise Level**	**Aligned Fixation Peaks Metric**	**One way ANOVA / Welch F Test Result**
Layer 2 (Wide vs Medium)	Novice	Total Number of Aligned Peaks	$F_{1,186} = 3.318$, $p = 0.07$
		Total Fixation Count	$F_{1,88.00} = 2.320$, $p = 0.131$
		Total Fixation Duration	$F_{1,83.98} = 4.186$, $p = 0.044$ *
	Intermediate	Total Number of Aligned Peaks	$F_{1,60.307} = 19.652$, $p = 1 * 10^{-5} \approx 0$ * (Welch)
		Total Fixation Count	$F_{1,64.498} = 15.775$, $p = 1 * 10^{-5} \approx 0$ * (Welch)
		Total Fixation Duration	$F_{1,60.164} = 21.662$, $p = 1 * 10^{-5} \approx 0$ * (Welch)
	Expert	Total Number of Aligned Peaks	$F_{1,152.783} = 20.330$, $p = 1 * 10^{-5} \approx 0$ * (Welch)
		Total Fixation Count	$F_{1,158.265} = 25.908$, $p = 1 * 10^{-6} \approx 0$ * (Welch)
		Total Fixation Duration	$F_{1,168.742} = 22.747$, $p = 1 * 10^{-6} \approx 0$ * (Welch)
Layer 3 (Close vs Independent)	Novice	Total Number of Aligned Peaks	$F_{1,186} = 0.05$, $p = 0.946$
		Total Fixation Count	$F_{1,186} = 0.301$, $p = 0.584$
		Total Fixation Duration	$F_{1,186} = 0.012$, $p = 0.914$
	Intermediate	Total Number of Aligned Peaks	$F_{1,156.410} = 6.895$, $p = 0.01$ * (Welch)
		Total Fixation Count	$F_{1,170.495} = 5.188$, $p = 0.024$ * (Welch)
		Total Fixation Duration	$F_{1,158.333} = 6.839$, $p = 0.01$ * (Welch)
	Expert	Total Number of Aligned Peaks	$F_{1,409} = 3.773$, $p = 0.053$
		Total Fixation Count	$F_{1,409} = 2.837$, $p = 0.093$
		Total Fixation Duration	$F_{1,409} = 1.430$, $p = 0.232$

* indicates significance at 95% level

Results from Table 12 show that there was no significant difference on both angle and proximity of crossing of all aligned fixation peaks metric for novice participants. A significant difference on angle of crossing of all aligned fixation peaks metric for intermediate and expert participants was not noted. Furthermore, a significant difference on the proximity of crossing of all aligned fixation peaks metric for intermediate participants was also not noted. As there are only two groups in both angle and proximity of crossings, no further post-hoc analysis is required. By comparing the means of the aligned fixation peaks metrics with significant differences, it was found that intermediate participants exhibited 0.57, 0.59 and 0.51 times lesser aligned fixation peaks, fixation count and fixation duration, respectively, on wide angle crossings as compared to medium angle crossings. A similar observation was also seen in expert participants, where experts exhibited 0.69, 0.64 and 0.64 times aligned fixation peaks, fixation count and fixation duration, respectively. Additionally, intermediate participants were also found to exhibit 0.76, 0.77 and 0.73 times lesser aligned fixation peaks, fixation count and fixation duration, respectively, on close crossings as compared to independent crossings.

Therefore, being more familiar and well-trained in guiding aircraft pairs-in-crossing, intermediate and expert participants exhibited lesser aligned fixation peaks, fixation count and fixation duration on wide angle crossings as compared to medium angle crossings, suggesting differences in monitoring behaviour. This is consistent with the findings in other studies, where licensed air traffic controllers were found to monitor differently as a result of the geometry and location of the crossing points. Hence, these results suggest that novice participants possibly do not know how to guide the aircraft pairs-in-crossing, as different crossing characteristics result in a similar monitoring behaviour. Furthermore, with lesser aligned fixation peaks, fixation count and fixation duration exhibited by only intermediate participants when comparing between close and independent crossings, it shows that they are also less familiar and lesser trained at handling close crossings as compared to experts. As a result, more training on close crossings can be focused on intermediate participants, while training on guiding aircraft pairs-in-crossing at various angles and proximities can be given for novice participants. This can aid them in achieving the same expertise level as the expert participants.

It can be concluded from this experiment that a novel eye signature for air traffic controllers, known as the aligned fixation peaks signature, has been presented. This signature seeks to model the monitoring behaviour of air traffic controllers for the activity of managing aircraft crossing with potential conflict using eye tracking technique. Information is acquired by identifying an air traffic controller's deliberate monitoring of the selected aircraft pair-in-crossing and comparing it within a short span of time to determine if there is a potential conflict.

Subsequent to this, the monitoring behaviour is represented using the aligned fixation peaks signature. As a result, this signature can indicate the instance and represent how an air traffic controller perceives and comprehends the aircraft pair-in-crossing accordingly.

This acquisition and representation of how an ATCO perceives and comprehends an aircraft pairs-in-crossing is achieved by first identifying the respective fixation count and duration peaks before aligning them. Metrics such as the number of 0 aligned peaks (lack of signature), total number of aligned fixation peaks, total fixation count and total fixation duration of these aligned fixation peaks were derived to evaluate the aligned fixation peaks signature.

Test validation conducted on the aligned fixation peaks signature also shows a strong relationship between the number of aligned fixation peaks and aircraft pair flying across the same crossing point, as well as the presence of this signature among participants of all expertise levels. Therefore, this signature represents instances when air traffic controllers are either attempting to determine the right aircraft pair-in-crossing or continuing to manage the activity of aircraft crossing with potential conflict.

Test results from the analyses highlight that participants with more experience and higher expertise tend to miss the monitoring of aircraft pairs-in-crossing to a lesser extent. This is seen in the least number of 0 aligned fixation peaks for expert participants. Furthermore, it was also found that medium angle and close crossings are easier to monitor as compared to wide angle and independent crossings, respectively. This is so as participants of all three expertise levels missed the monitoring of these aircraft pairs-in-crossing the least.

For crossing instances when participants exhibited aligned fixation peaks, there is a lesser effect on the expertise level as no significant difference was found for most of the aligned fixation peaks metrics when comparing individual crossing characteristics. Moreover, it is found that intermediate and expert participants tend to have more aligned peaks, fixation count and fixation duration on medium angle crossings, but not for novices. Additionally, intermediate participants were found to exhibit more aligned peaks, fixation count and fixation duration on independent crossing points. As a result, this suggests that novice participants do not have the right expertise and experience in guiding aircraft for different angles and proximities of crossings, while the same can be said of intermediate participants on the proximity of crossings.

Therefore, these results show that aligned fixation peaks signature can be used as a measure to understand the variation in a participant's monitoring behaviour due to angle and proximity of crossings, as well as expertise level. In addition, it can be used as a measure to differentiate the expertise level of the participants and understand the differences in their crossing monitoring behaviour when managing aircraft crossing with potential conflict. In the training of prospective air traffic controllers, the aligned fixation peaks signature can also be used so that the trainees would be better able to identify the different aircraft pairs-in-crossing and monitor them based on their crossing characteristics.

Efforts can thus be made to aid air traffic controllers in the monitoring of wide angle crossing and with more time dedicated to training prospective air traffic controllers in the handling of wide angle crossing. Similar efforts in training can also be dedicated to the monitoring of both close and independent crossing points. A performance scorecard can also be created, using the metrics of the aligned fixation peaks, to determine and benchmark an air traffic controller's expertise level. Lastly, this signature may also pave the way for the representation of an operator's visual monitoring behaviour in other surveillance domains, like vehicular operation.

Experiment 3

Prior to the experiment, each participant involved in a session underwent an initial 9-point eye-tracker calibration exercise. Calibration was repeated until a satisfactory calibration was obtained that refers to Tobii Studio's qualitative calibration report.

Real time simulations were conducted for 88 one-hour experimental sessions, with different scenarios consisting of 60 aircraft each that mimic operational air traffic, which is approximately to 1.2 times that of the regular traffic volume. In each scenario, there was a mixture of climbing and cruising flight along the different airways (flight path) of various distances. Each aircraft would enter and exit the airspace of interest (sector) at different random timings, while facing a crossing traffic at random instances, depending on the airway configuration and other traffic.

The airspace of interest in this real time study was based on an existing airspace sector with information referenced from the publicly available SkyVector website.

To illustrate an RCG time entropy signature, the construction of RCG time profile and calculation of the RCG time entropy value was applied to 12 selected aircraft of different flight path configurations comprising a total of 72 novice, 60 intermediate and 121 expert instances.

Differences in the generic flight path monitoring of aircraft due to various expertise levels and flight path configurations were then analysed. These comprised of four different flight path configurations, which is described in Table 13 below.

Table 13: Description of different flight path configuration

Flight path configuration	Flight Distance (NM)	Change in FL	Number of Crossing	Flight Segment
1	228	0	1	Entry > Airway > Crossing > Airway > Exit
2	108	-40	1	Entry > Crossing > Exit
3	123	70	1	Entry > Crossing > Airway > Exit
4	110	100	1	Entry > Airway > Crossing > Exit

To compare these differences, descriptive statistics (sample size = N, mean = M, standard deviation = SD) of the RCG time entropy values were first listed in Table 14 below.

Table 14: Descriptive statistics of the RCG time entropy value for the different flight path configuration across expertise level

Flight path configuration	Novice	Intermediate	Expert

1	N = 18, M = 2.10, SD = 0.629	N = 15, M = 2.40, SD = 0.384	N = 33, M = 2.12, SD = 0.336
2	N = 18, M = 1.56, SD = 0.597	N = 15, M = 1.82, SD = 0.469	N = 33, M = 1.63, SD = 0.467
3	N = 18, M = 1.17, SD = 0.926	N = 15, M = 1.70, SD = 0.647	N = 33, M = 1.83, SD = 0.504
4	N = 18, M = 1.53, SD = 0.568	N = 15, M = 1.71, SD = 0.493	N = 33, M = 1.83, SD = 0.388

From Table 14 above, it can be observed that the sample sizes for each expertise group are different. Hence, a Levene's F test, a statistical test to determine if different samples have equal variances, was then performed to determine if the homogeneity of variance assumption was met prior to examining if expertise level has a significant effect on the different metrics at different crossing characteristics. The homogeneity of variance assumption is a requirement to choose the type of statistical test to perform in order to determine whether there are any statistically significant differences between three or more means of an independent variable. Hence, ANOVA (an established statistical test) is used when the homogeneity of variance is met, otherwise the Welch's F Test is used. Thus, the results of the Levene's F test are seen in Table 15 below and the homogeneity of variance is not met when the corresponding p-value is lesser than 0.05, at the 95% confidence level.

Table 15: Levene's F test result for homogeneity of variance on expertise level

Flight path configuration	**Levene's F test output**
1	$F_{2,63} = 3.264$, $p = 0.045$ *
2	$F_{2,63} = 1.282$, $p = 0.285$
3	$F_{2,63} = 5.250$, $p = 0.08$ *
4	$F_{2,63} = 1.609$, $p = 0.208$

From Table 15, it is revealed that the metrics on total fixation count for all crossing points, wide angle and close crossings, together with total fixation duration on independent crossing, did not meet the homogeneity of variance assumption. Hence, the respective ANOVA and Welch F tests were performed to compare if the expertise levels are statistically significantly different on the different flight path configurations, as seen in Table 16 below. Therefore, if the effect of expertise level is significant, at 95% confidence

level, the corresponding p-value of the one-way ANOVA or Welch F test should be less than 0.05.

Table 16: One way ANOVA aornd Welch F test results to compare the effect of expertise level on the different flight path configuration

Flight path configuration	One way ANOVA / Welch F Test Result
1	$F_{2,28.67} = 3.145$, $p = 0.058$ (Welch)
2	$F_{2,63} = 1.107$, $p = 0.337$
3	$F_{2,27.828} = 3.878$, $p = 0.033$ (Welch) *
4	$F_{2,63} = 2.264$, $p = 0.112$

Results from Table 16 show that there was a significant difference of expertise level at flight path configuration 3. Respective post-hoc analysis was then performed to determine where the differences occurred between the expertise levels when there are three or more groups. Hence, the Tukey's honestly significant difference (HSD) post hoc test and Games Howell post hoc test was used when homogeneity of variance was met and not met, respectively. If two of the expertise groups are different, the adjusted p-value is lesser than 0.05 at 95% confidence level. Results of these post-hoc analyses are shown in Table 17 below.

Table 17: Post hoc analysis on statistically significant metrics

Flight path configuration	Difference of Levels	Difference of means	Adjusted p-value
3 (Games-Howell)	Expert – Intermediate	0.139	0.746
	Expert – Novice	0.660	0.026 *
	Intermediate – Novice	0.521	0.157

Results in Table 17 above indicate that novice participants have a significantly lower RCG time entropy value as compared to expert participants for flight path configuration 3. Additionally, no significant differences were found for other parameters using the results from Table 16. This indicates that expertise levels do not influence the generic flight path monitoring of aircraft on flight path configuration 1, 2 and 4, whereas only novices were found to monitor less regularly as compared to expert participants on flight path configuration 3. This could likely mean that participants of all expertise levels are able to maintain their awareness on an aircraft flying through the airspace in general for all flight path configuration, except for novice participants on flight path configuration 3. This suggests that it is more difficult for novice participants to maintain regular

awareness on the aircraft, by perceiving and comprehending on its general flight on flight path configuration 3. Hence, more training on flight path configuration 3 could be catered for novice participants.

Additionally, these results also suggest that intermediate participants are able to maintain their awareness on aircraft on the same level as experts based on the different flight path configuration. This could also possibly mean that intermediate participants are already trained well enough to maintain awareness on an aircraft's generic flight path monitoring.

To compare the differences in generic flight path monitoring behaviour due to flight path configuration for all expertise levels, the same descriptive statistics (sample size = N, mean = M, standard deviation = SD) of the crossing point instances in Table 14 above was used.

In this comparison, the sample sizes for each flight path configuration is the same. This meant that the homogeneity of variance assumption was met and there is no need to perform a Levene's F test. ANOVA can then be performed to determine if the flight path configurations are statistically significantly different on the different expertise level as shown in Table 18 below.

Table 18: One way ANOVA test result to compare the effect of flight path configuration on different expertise level

Expertise Level	One way ANOVA Test Result
Novice	$F_{3,68} = 5.392$, $p = 0.002$ *
Intermediate	$F_{3,56} = 6.463$, $p = 0.001$ *
Expert	$F_{3,128} = 7.118$, $p = 1 * 10^{-4} \approx 0$ *

* indicates significance at 95% level

Results from Table 18 show that there is a significant difference of flight path configuration for all expertise levels.

A Tukey's HSD post hoc test was then performed to determine where the differences occurred between the flight path configurations when there are three or more groups. Similarly, if two flight path configurations are different, the adjusted p-value is

lesser than 0.05 at 95% confidence level Results of this post hoc analysis as shown in Table 19 below.

Table 19: post hoc analysis on statistically significant metrics

Flight path configuration	Difference of Levels	Difference of means	Adjusted p-value
Novice (Tukey's HSD)	1 – 2	0.533	0.108
	1 – 3	0.923	0.001 *
	1 – 4	0.563	0.081
	2 – 3	0.390	0.340
	2 – 4	0.297	0.999
	3 – 4	-0.360	0.411
Intermediate (Tukey's HSD)	1 – 2	0.582	0.014 *
	1 – 3	0.705	0.002 *
	1 – 4	0.685	0.003 *
	2 – 3	0.123	0.910
	2 – 4	0.103	0.944
	3 – 4	-0.020	1.000
Expert (Tukey's HSD)	1 – 2	0.484	$1 * 10^{-5} \approx 0$ *
	1 – 3	0.282	0.042 *
	1 – 4	0.291	0.033 *
	2 – 3	-0.202	0.229
	2 – 4	-0.192	0.268
	3 – 4	0.009	1.000

Results in Table 19 indicate that flight path configuration 1 has significantly higher RCG time entropy value as compared to other flight path configurations for intermediate and expert participants. Additionally, no significant differences were found between flight path configurations 2, 3 and 4 for both intermediate and expert participants. For novice participants, only flight path configuration 1 is significantly higher than flight path configuration 3. This indicates that flight path configuration influences the generic flight path monitoring of aircraft more for intermediate and expert participants.

These results suggest that a longer flight distance likely results in a more regular generic flight path monitoring of aircraft as seen in the higher RCG time entropy value for flight path configuration 1. Additionally, this behaviour is more distinct for both intermediate and expert participants, indicating that they are more aware of aircraft on a longer flight duration as compared to novice participants. This could likely mean that the novice participants are less able to maintain regular awareness on aircraft flying a longer

distance with no change of FL in the airspace, thereby indicating a lack of training or familiarity with such flights.

It is also noted that participants of all expertise could maintain their awareness on aircraft flying a shorter distance with changing FL, as seen in flight path configurations 2, 3 and 4. This could mean that a shorter distance and changing FL is easier for all participants as participants are actively seeking to issue a command in a short time. This makes it easier for participants to maintain regular awareness on these aircraft, depending lesser on their training and familiarity.

As a result, more training aids could be directed on an aircraft's flight path configuration with lesser need for commands to be issued for novice participants. These differences could also be used to differentiate the novice participants from intermediate and expert participants.

It can be concluded from the above experiment that another novel eye signature for air traffic controllers, known as the RCG time entropy signature, has been presented. This signature seeks to model the monitoring behaviour of air traffic controllers for the activity of generic flight path monitoring by using RCG, which comprises of fixations and mouseover label actions occurring on an aircraft closely in time. The regularity of an air traffic controller's generic flight path monitoring behaviour may be determined by first constructing an RCG time profile before evaluating it using the information entropy value of it. As a result, this signature could indicate how frequently and regularly an air traffic controller has perceived and comprehended the aircraft on its generic flight path, where a larger RCG time entropy value represents a higher level of regularity and consistency of the RCG time profile.

Experiments conducted on 12 selected aircraft of different flight path configurations using a real time, high-fidelity simulation showed a difference in the generic flight path monitoring behaviour based on expertise and flight path configuration.

Test results showed that novice participants lack training and are less familiar in maintaining regular awareness on an aircraft's generic flight path. This is due to novices monitoring less regularly both on flight path configuration 3 and for aircraft flying on a longer flight distance, as compared to other expertise levels.

For intermediate and expert participants, test results showed that intermediate participants are trained to the level of experts as they could exhibit a similar level of regular awareness on an aircraft's generic flight path monitoring. This is seen in both comparisons of expertise level and flight path configuration, where no significant difference in RCG time entropy value was found between intermediate and experts at various flight path configurations, as well as both participant groups exhibiting more regular awareness on aircraft with a longer flight distance.

Therefore, these results demonstrated that the RCG time entropy signature is a suitable measure for understanding differences in an air traffic controller's generic flight path monitoring of aircraft due to flight path configuration and expertise levels. Hence, it can also be used to differentiate the expertise level of air traffic controllers and also in the training of prospective air traffic controllers, where trainees can better monitor the generic flight path of aircraft, based on their flight path configurations.

Efforts can thus be catered to the monitoring of aircraft flying on a longer flight distance, while alerts can also be set whenever the RCG time entropy of the air traffic controller falls below a fixed number for different flight path configurations. Lastly, this signature could also pave the way for the representation of an operator's visual monitoring behaviour in other surveillance domains, like vehicular operation.

As is evident from the foregoing discussion, the present invention provides a computer-implemented method and non-transitory computer-readable memory storing computer program instructions for air traffic control performance monitoring that resolves asynchronous data fusion from different data sources arising from surveillance task of traffic controllers, pinpoints the spatial region of the screen together with its underlying complexity and complexity time profile and provides a quantification of various tactical monitoring activity visually, allowing them to be evaluated. The present invention also provides a holistic quantitative assessment of traffic controller performance by deducing its monitoring strategies.

The present invention is able to account for dynamic data changes spatially and in time as part of a real time eye tracking system as the present invention is able to fuse dynamic radar display data while having an overall spatial resolution of less than the size

of the flight object (ranging from 12 to 230 pixel diameter), and a time resolution less than the duration of radar update (ranging from 300ms to 9.8 seconds) at the same time.

Further advantageously, the present invention provides a better representation of tactical air traffic complexity. This is achieved by performing instantaneous aircraft data capture for real-time computation, projecting an aircraft's flight intent, evaluating across a broad spectrum of air traffic situations, determining various complexity scores at different regions on the radar screen, while computing complexity changes across time. Furthermore, the present invention considers the dynamic air traffic flow and its network characteristics in real-time, and is thus able to project complexity ahead, in terms of time, for tactical measures to be taken appropriately beforehand.

The present invention further provides new methods to extract and represent knowledge of an air traffic controller's perception and comprehension such that any changes are detected and identified accurately for multiple tasks across the air traffic controller's tactical monitoring activity.

A synchronous, high resolution data fusion is thus achieved for both human and radar data by integrating the calculated tactical traffic complexity and eye signature, allowing the performance of air traffic controllers to be assessed.

The present invention concerns the field of real time intelligent agents for assessing an operator's level of performance in the context of transportation traffic control. This agent may be used for the purpose of assessing the visual monitoring performance of traffic controllers, who perform surveillance activities on a visual display. It is an algorithm that integrates information from both dynamic traffic and human data streams in real time, while being synchronous. In doing so, the strategies that the traffic controllers deploy in managing these tactical monitoring activities may be deduced, by combining new knowledge on the tactical traffic complexity and eye signatures.

For this invention, the field of air transportation and Air Traffic Control (ATC) is selected to be used for illustration. Hence, this invention may be used for the purpose of assessing the visual monitoring performance of Air Traffic Controllers (ATCOs), who perform radar surveillance on the radar screen

The present invention may have real time operational application such as, for example, a real time individual performance alert trigger and also training application such as, for example, quantitative performance assessment and training feedback.

While preferred embodiments of the invention have been illustrated and described, it will be clear that the invention is not limited to the described embodiments only. Numerous modifications, changes, variations, substitutions and equivalents will be apparent to those skilled in the art without departing from the scope of the invention as described in the claims.

Further, unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising" and the like are to be construed in an inclusive as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to".

CLAIMS

1. A computer-implemented method for air traffic control performance monitoring, comprising executing on one or more processors the steps of:

receiving traffic data;

receiving human data;

integrating the traffic data and the human data spatially and over time;

calculating tactical air traffic complexity;

identifying an eye signature associated with a tactical monitoring activity; and

integrating the calculated tactical air traffic complexity and the eye signature to deduce a monitoring strategy being applied.

2. The computer-implemented method for air traffic control performance monitoring according to claim 1, wherein the step of integrating the traffic data and the human data spatially and over time comprises:

synchronizing the traffic data and the human data based on timestamps.

3. The computer-implemented method for air traffic control performance monitoring according to claim 2, wherein the step of integrating the traffic data and the human data spatially and over time further comprises:

converting the synchronized traffic data and the synchronized human data into a same unit of measurement.

4. The computer-implemented method for air traffic control performance monitoring according to claim 3, wherein the step of integrating the traffic data and the human data spatially and over time further comprises:

aligning the converted traffic data and the converted human data to a spatial reference frame.

5. The computer-implemented method for air traffic control performance monitoring according to claim 4, wherein the step of integrating the traffic data and the human data spatially and over time further comprises:

fusing the aligned traffic data and the aligned human data.

6. The computer-implemented method for air traffic control performance monitoring according to any one of the preceding claims, wherein the step of calculating tactical air traffic complexity comprises:

forming three-dimensional (3D) aircraft movement shapes using aircraft flight parameters; and

determining a level of conflict activity based on a degree of overlap between the aircraft movement shapes.

7. The computer-implemented method for air traffic control performance monitoring according to claim 6, wherein the step of calculating tactical air traffic complexity further comprises:

generating a profile of the level of conflict activity over time.

8. The computer-implemented method for air traffic control performance monitoring according to any one of the preceding claims, wherein the step of identifying the eye signature associated with the tactical monitoring activity comprises:

plotting a fixation count and a fixation duration against an elapsed frame number for aircraft pairs-in-crossing; and

identifying a plurality of fixation peaks where the fixation count or the fixation duration is greater than an average number of non-zero fixation counts or non-zero fixation durations over time.

9. The computer-implemented method for air traffic control performance monitoring according to claim 8, wherein the step of identifying the eye signature associated with the tactical monitoring activity further comprises:

aligning the fixation peaks according to location to form a plurality of aligned fixation peak signatures.

10. The computer-implemented method for air traffic control performance monitoring according to claim 9, wherein the step of identifying the eye signature associated with the tactical monitoring activity further comprises:

evaluating the aligned fixation peak signatures by determining a number of non-aligned fixation peaks, a total number of aligned fixation peaks, a total fixation count and a total fixation duration of the aligned fixation peaks.

11. The computer-implemented method for air traffic control performance monitoring according to claim 10, wherein the step of identifying the eye signature associated with the tactical monitoring activity further comprises:

generating cumulative plots in respect of the total number of aligned fixation peaks, the total fixation count and the total fixation duration of the aligned fixation peaks against the elapsed frame number for aircraft pairs-in-crossing.

12. The computer-implemented method for air traffic control performance monitoring according to any one of the preceding claims, wherein the step of identifying the eye signature associated with the tactical monitoring activity comprises:

receiving a request to switch frequency in respect of an aircraft;

determining at least one fixation count in respect of the aircraft;

determining activation of a switching command in respect of the aircraft within a predetermined period; and

generating an aircraft frequency switch eye signature.

13. The computer-implemented method for air traffic control performance monitoring according to any one of the preceding claims, wherein the step of identifying the eye signature associated with the tactical monitoring activity comprises:

identifying a plurality of time intervals in which one or more mouseovers of an aircraft label and at least one fixation on the aircraft label occur over an aircraft flight path.

14. The computer-implemented method for air traffic control performance monitoring according to claim 13, wherein the step of identifying the eye signature associated with the tactical monitoring activity further comprises:

plotting total fixation count and total fixation duration of the identified time intervals against elapsed time to generate a time profile of the identified time intervals.

15. The computer-implemented method for air traffic control performance monitoring according to claim 14, wherein the step of identifying the eye signature associated with the tactical monitoring activity further comprises:

calculating aircraft sector duration;

calculating time difference between respective ones of the identified time intervals;

calculating a probability of each of the identified time intervals occurring based on the time difference between the respective ones of the identified time intervals and the aircraft sector duration; and

calculating an information entropy based on the probability of each of the identified time intervals occurring.

16. The computer-implemented method for air traffic control performance monitoring according to any one of the preceding claims, wherein the step of integrating the calculated tactical air traffic complexity and the eye signature to deduce the monitoring strategy being applied comprises:

identifying one or more instances of change in the calculated tactical air traffic complexity and the eye signature; and

contextualising the one or more instances of change to deduce the monitoring strategy being applied.

17. A non-transitory computer-readable memory storing computer program instructions executable by a computer processor to perform operations for air traffic control performance monitoring, the operations comprising:

receiving traffic data;

receiving human data;

integrating the traffic data and the human data spatially and over time;

calculating tactical air traffic complexity;

identifying an eye signature associated with a tactical monitoring activity; and

integrating the calculated tactical air traffic complexity and the eye signature to deduce a monitoring strategy being applied.

18. The non-transitory computer-readable memory according to claim 17, wherein the operation of integrating the traffic data and the human data spatially and over time comprises:

synchronizing the traffic data and the human data based on timestamps.

19. The non-transitory computer-readable memory according to claim 18, wherein the operation of integrating the traffic data and the human data spatially and over time further comprises:

converting the synchronized traffic data and the synchronized human data into a same unit of measurement.

20. The non-transitory computer-readable memory according to claim 19, wherein the operation of integrating the traffic data and the human data spatially and over time further comprises:

aligning the converted traffic data and the converted human data to a spatial reference frame.

21. The non-transitory computer-readable memory according to claim 20, wherein the operation of integrating the traffic data and the human data spatially and over time further comprises:

fusing the aligned traffic data and the aligned human data.

22. The non-transitory computer-readable memory according to any one of claims 17 to 20, wherein the operation of calculating tactical air traffic complexity comprises:

forming three-dimensional (3D) aircraft movement shapes using aircraft flight parameters; and

determining a level of conflict activity based on a degree of overlap between the aircraft movement shapes.

23. The non-transitory computer-readable memory according to claim 22, wherein the operation of calculating tactical air traffic complexity further comprises:

generating a profile of the level of conflict activity over time.

24. The non-transitory computer-readable memory according to any one of claims 17 to 23, wherein the operation of identifying the eye signature associated with the tactical monitoring activity comprises:

plotting a fixation count and a fixation duration against an elapsed frame number for aircraft pairs-in-crossing; and

identifying a plurality of fixation peaks where the fixation count or the fixation duration is greater than an average number of non-zero fixation counts or non-zero fixation durations over time.

25. The non-transitory computer-readable memory according to claim 24, wherein the operation of identifying the eye signature associated with the tactical monitoring activity further comprises:

aligning the fixation peaks according to location to form a plurality of aligned fixation peak signatures.

26. The non-transitory computer-readable memory according to claim 25, wherein the operation of identifying the eye signature associated with the tactical monitoring activity further comprises:

evaluating the aligned fixation peak signatures by determining a number of non-aligned fixation peaks, a total number of aligned fixation peaks, a total fixation count and a total fixation duration of the aligned fixation peaks.

27. The non-transitory computer-readable memory according to claim 26, wherein the operation of identifying the eye signature associated with the tactical monitoring activity further comprises:

generating cumulative plots in respect of the total number of aligned fixation peaks, the total fixation count and the total fixation duration of the aligned fixation peaks against the elapsed frame number for aircraft pairs-in-crossing.

28. The non-transitory computer-readable memory according to any one of claims 17 to 27, wherein the operation of identifying the eye signature associated with the tactical monitoring activity comprises:

receiving a request to switch frequency in respect of an aircraft;

determining at least one fixation count in respect of the aircraft;

determining activation of a switching command in respect of the aircraft within a predetermined period; and

generating an aircraft frequency switch eye signature.

29. The non-transitory computer-readable memory according to any one of claims 17 to A12, wherein the operation of identifying the eye signature associated with the tactical monitoring activity comprises:

identifying a plurality of time intervals in which one or more mouseovers of an aircraft label and at least one fixation on the aircraft label occur over an aircraft flight path.

30. The non-transitory computer-readable memory according to claim 29, wherein the operation of identifying the eye signature associated with the tactical monitoring activity further comprises:

plotting total fixation count and total fixation duration of the identified time intervals against elapsed time to generate a time profile of the identified time intervals.

31. The non-transitory computer-readable memory according to claim 30, wherein the operation of identifying the eye signature associated with the tactical monitoring activity further comprises:

calculating aircraft sector duration;

calculating time difference between respective ones of the identified time intervals;

calculating a probability of each of the identified time intervals occurring based on the time difference between the respective ones of the identified time intervals and the aircraft sector duration; and

calculating an information entropy based on the probability of each of the identified time intervals occurring.

32. The non-transitory computer-readable memory according to any one of claims 17 to 31, wherein the operation of integrating the calculated tactical air traffic complexity and the eye signature to deduce the monitoring strategy being applied comprises:

identifying one or more instances of change in the calculated tactical air traffic complexity and the eye signature; and

contextualising the one or more instances of change to deduce the monitoring strategy being applied.

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