Visual Scan Patterns in Tower Control: Foundations for an Instructor Support Tool

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***Abstract*—Although where to look, when, and in what order is crucial for situation awareness and task performance in tower control, instructors are lacking support systems that can help them understand operators' visual scan behaviours. As a way forward, this paper investigates the existence and characteristics of visual scan patterns in tower control and explores a novel support tool that can help instructors in searching for and exploring these patterns. First, eye-tracking data from two controllers were collected in a high-fidelity tower simulator. Second, a workshop was conducted with three instructors to discuss specific scan patterns that can be expected in relation to the approach scenarios used in the eye-tracking data collection. Six template visual scan patterns were identified during the workshop. Finally, an interactive visual sequence mining tool was used to identify and explore instances of the template scan patterns in the recorded eye-tracking data. Four of these could be detected using the tool: runway scans, landing clearance, touchdown and landing roll, and phases of visual focus. The identification of template scan patterns provides additional insight for formalising controllers' visual work in tower control. The ability to detect and explore visual scan patterns in the proposed tool shows promise for improving instructors' understanding of controllers' visual scan behaviours, and for improving training effectiveness.**

***Keywords*—Automation, Training, Eye-tracking, Air Traffic Control, Sequence mining, Visual perception**

I. Introduction

A challenge the Air Traffic Control (ATC) community is facing is how to prepare and train air traffic controllers (ATCOs) to cope with modernisation changes, particularly given the introduction of increased automation support. Current ATCO training methods are both costly and demanding. This raises the question of how the effectiveness of ATCO training can be improved to meet the future's more automation dependent working environment.

The use of template visual scan patterns is considered fundamental in many domains for building situation awareness required to handle tasks safely and effectively, especially in stressful and time-critical situations (e.g. [1], [2]). Student car drivers are instructed to follow simple but critical scan patterns, for example, before making a turn. In aviation, novice pilots are taught the *T-scan* and *wagon-wheel* techniques for scanning the most critical instruments, and the *side-to-side* or *front-to-side* 'block' techniques for scanning the outside view in collision avoidance [1]. Similarly in ATC, research has shown that ATCOs' visual scan behaviour is central for their situation awareness and performance during critical episodes (e.g., approaches and landings) [3], [4], handling non-nominal events [5], and in conflict detection [6]. Several studies have studied ATCOs' visual scan patterns of radar displays in terminal and en-route ATC [2], [7] and found that a circular scan pattern often is used when searching for conflicts [8].

It follows that operators' visual scan patterns are an important aspect to assess both in initial training and re-training. However, a long-standing issue is for the instructor to understand what the trainee is looking at. While eye-tracking equipment can be used to track a person's gaze, the instructor must also know what gaze patterns to look for. Well-established visual scan patterns are lacking in tower control, with a few exceptions for visual cues to be considered during landing/take-off clearance delivery [3], [4], [9]. As such, there is a need for identifying template scan patterns that can be expected for different events and tasks.

A challenge in analysing scan patterns is that of *sequences*. The instructor needs to know to what extent the operator has looked at the "right" regions, in the right order, versus the temporal sequence of what goes on. Since knowledge of what is "right" lies with the instructor, there is a need for analysis tools that seamlessly incorporate input from a domain expert. This paper proposes the use of visual sequence exploration to enable the interactive analysis of an ATCO's visual activity, as derived from eye-tracking measurements. An interactive visual sequence mining tool, previously proposed by the authors [10], has been adapted and extended with functionality appropriate to meet these newly posed challenges.

To address the issues and challenges stated above, this paper answers two questions:

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- What templates of systematic scan patterns that standardize best practices are there in tower control, in particular for safety-relevant events such as approaches?
- To what degree can these template patterns be detected and visualized using an interactive visual sequence mining tool for exploring collected eye-tracking data?

The next section briefly overviews eye-tracking research in the context of ATCO training. Section III describes the method consisting of an eye-tracking data collection, workshop with instructors to identify template visual scan patterns, and the researchers' search for these patterns with the interactive visual sequence mining tool. Six template visual scan patterns are presented in Section IV, together with an analysis of these using the tool. Section V discusses the potentials and limitations of the study and explored instructor support tool. The paper concludes with suggestions for future work continuing the exploration of visual scan patterns in applied training contexts.

II. Applying eye-tracking in ATCO training

Eye-tracking equipment provides an effective means for measuring a person's point of gaze, i.e. the spatial locations looked at in the field of view (FOV). The mathematical filtering of a feed of raw gaze points yields fixations and saccades. A fixation describes the location and duration at which something is looked at, often comprising multiple gaze points. Saccades are the links between the fixations. Combined, the output of fixations and saccades over time form a scan path [11], which can be used to describe a person's visual scan behaviour, or *scan pattern*. Eye-tracking data is typically analysed by dividing the person's FOV into different areas of interest (AOI) against which the distribution of fixations and saccades is explored.

Tower control training documentation provides limited guidance on ATCOs' visual activity, detailing only high-level objectives such as requirements for continuous monitoring (e.g. [12], [13]). While considerable research has been devoted to study and map visual information cues in tower control (e.g. [14]–[16]), few studies have investigated how these cues are used over time to form scan patterns. Research has largely focused on the transition between looking outside (head-up) and inside (head-down, e.g. [9], [17]). A common visual scan pattern of ATCOs during landing on final approach was found by [18] consisting of runway checks, approach airspace and radar scans in a "triangle".

For gaining an understanding of an ATCO's visual scan behaviour, the instructor can be provided with a display showing raw eye-tracking data in terms of overlaying gaze point data on the FOV. But monitoring gaze point movement in real-time is very demanding and requires constant attention since individual scan patterns feature inter- and intraindividual variances. These differences may be perceived as 'noise', making it difficult to assess whether a scan path complies to a trained standard. Moreover, the vast amount of gaze data collected by eye-trackers can be complicated to analyse because of its noisy characteristics (not all data is relevant to the task being studied). The use of traditional built-in eye-tracker tools, such as heat maps, is typically not efficient as they fail to capture relevant sequences (e.g. [19]).

An alternative approach for teaching effective visual scan patterns is by showing videos of experts' scan patterns extracted from eye-tracking measurements. Kang and Landry showed that novices' false alarm rates in en-route conflict detection (i.e. incorrectly identifying a conflict) reduced by approximately 73% when they were first shown experts' scan paths [8]. However, pure scan pattern replays do not establish clear templates as all the visual 'noise' is retained. There is a need to define standardized templates of visual scan patterns that reflect ATCOs' best practice in tower control services. Such templates can provide a benchmark against which the compliance of an ATCO's scan patterns can be assessed.

III. Method

A bottom-up approach was employed to identify template visual scan patterns in approach scenarios and determine whether these could be detected using interactive sequence exploration. These templates are described in section IV-A.

A. Eye-tracking Data Collection

An eye-tracking data collection took place at the Swedish Air Navigation Service Provider LFV's training facilities in Halmstad, Sweden. Data was collected from two ATCOs, both males with three years of working experience or more.

1) Scenario: Simulator experts from LFV aided in scripting realistic traffic movements at a generic single runway aerodrome with a single taxiway between apron and runway. Four movements were scripted in the following order: two approaches with landings and two departures. The first movement was an Instrument Flight Rules (IFR) precision approach made by a medium-sized jet (Boeing 737). The next movement was a visual approach made by a small-sized propeller aircraft (PA28) under Visual Flight Rules (VFR). Each approach took around six minutes. The two departures consisted of an IFR jet aircraft followed by a small VFR propeller aircraft. The scenario was designed in summertime daylight with good visibility, no clouds, and 14 kts headwind for runway 18. The use of a simple scenario, with no competing (traffic) movements, was deemed important for simplifying analysis and identification of scan patterns. The scenario was representative for the type of scenarios encountered early in ATCO training.

2) Eye-tracking system: The TOBII Pro Glasses 2 head-mounted glasses were used for gaze data collection. Gaze data was sampled with a frequency of 50Hz and featured by a time synchronised scene camera video located in the frame of the glasses. A visualisation of view direction in the working environment was created by overlaying the gaze data on the scene camera video using TOBII Pro Lab 1.76. For smoothing the gaze data, the TOBII I-VT filter setting was applied that identified saccadic eye movements at a threshold of 30 deg/sec.

3) Procedure: Participants controlled traffic in a full-scale state-of-the-art SAAB tower simulator. Eight aligned screens providing a virtual representation of the outside view. Participants used a conventional paper flight-strip board to aid their cognitive work of sequencing, separating, and monitoring traffic over time. A radar display provided an overview of the aerodrome and its surrounding airspace, depicting aircraft as small symbols with history dots representing their direction of movement. An Automated Weather Observing System (AWOS) provided atmospheric information, such as wind, pressure, and temperature. A Runway Control Panel (RCP) provided settings for runway lights and navigation equipment on a separate display. No training was required as participants were familiar with both the simulator and aerodrome. Participants encountered identical traffic movements in the same order. An instructor acted as both simulator instructor and pseudo pilot. A researcher observed the experiment and controlled the eye-tracking equipment.

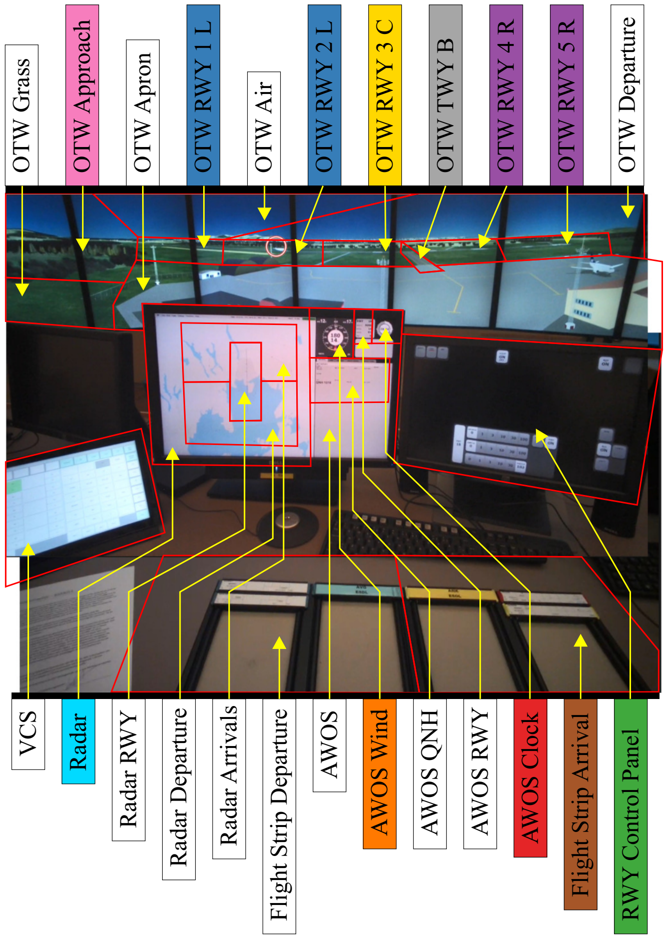
B. Workshop: Identifying Template Scan Patterns

1) Participants: A workshop was held with three tower ATCO instructors (two male, one female) to identify template visual scan patterns. The average age was 55 years (*SD=13.3*), average ATCO experience 29.7 years (*SD=12.1*), and average instructor experience 27.7 years (*SD=16.6*). One of the instructors was also one of the ATCOs participating in the eye-tracking data collection.

2) Procedure: Three stimuli were used in the workshop: video replays of eye-tracking recordings showing the gaze overlaid on the scene camera; task analyses based on the scenario approaches; and printouts of the eye-tracker's scene camera (depicting the FOV). The instructors identified scan patterns in relation to sub-tasks outlined in the task analyses and illustrated these on the scene camera printouts by annotating the position of visual cues and drawing lines between them. These illustrations were later used to distinguish between different AOIs. The researcher (R) triggered the discussion of scan patterns between participants (P) by asking:

- R: *What were the critical visual checks in this approach?*
- P1: *One important check is to scan the runway for threats.*
- R: *Where should an ATCO look, and is there a specific order in which information is looked at?*
- P1: *You should look at the aircraft and then along the runway in the direction of landing.*

3) Defining AOIs: As a requirement and input for analysing eye-tracking data in the proposed tool, an AOI division covering the FOV for the reference scenarios was created based on knowledge elicited from the instructors in the workshop. Fig. 1 illustrates the 24 unique AOIs. To detect meaningful scan patterns related to moving objects (e.g. aircraft), logical areas reflecting one object (e.g. radar and runway on OTW view) were divided into several AOIs.



AWOS = Automated Weather Observing System
VCS = Voice Communication System
OTW = Out The Window
RCP = Runway Control Panel
RWY = Runway
QNH is a reference for atmospheric pressure

Figure 1. The 24 unique AOIs derived from the instructors workshop illustrated on the FOV. Colours are assigned to the AOIs used for the visual analysis performed in ELOQUENCE.

C. Computer Aided Analysis of Scan Patterns

Three researchers explored the collected eye-tracking data in a candidate instructor support tool to determine the extent to which template visual scan patterns identified in the workshop could be detected. A prototype system called ELOQUENCE (for ExpLOratory seQUENCE mining) [10] was extended with an algorithm for mining patterns from long-duration event sequences and with two additional views (video and event overview). ELOQUENCE is an interactive visual sequence mining tool that allows the analyst to guide the execution of a pattern-growth algorithm through a visual interface to identify *sequential patterns* from large numbers of discrete event sequences. A sequential pattern in this context is a subsequence of events that occurs frequently across the data. In the eye-tracking data used in this work, events correspond to AOI visits. A number of filters and constraints are available in ELOQUENCE for pruning the search space according to the analyst's interests (described in detail in [10]). Most relevant to the approach scenario in this study, are event filters allowing the analyst to discard uninteresting events from the mining process and time constraints for defining the maximum allowed temporal distance between events in mined patterns.

In the context of tower control training, ELOQUENCE can provide the instructor with the possibility to specify a subsequence of interest and visually inspect the distribution of it across the data set. This allows the instructor to explore an ATCO's visual scan patterns with respect to the specified sequence, get an overview of its temporal distribution and duration, and make conclusions about its execution. The ELOQUENCE interface is described in the results section, together with examples of how visual scan patterns were explored.

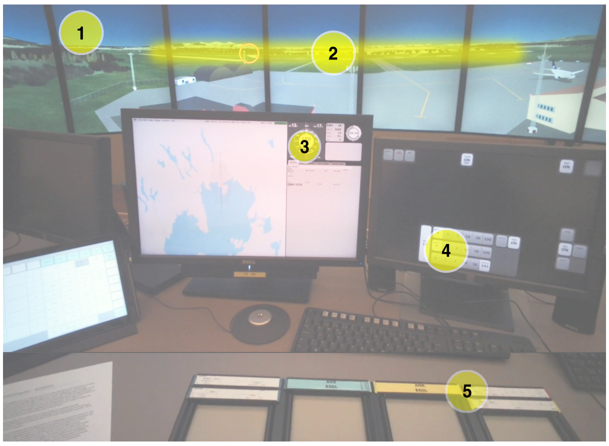


Figure 2. FOV with landing clearance visual scan pattern template.

IV. RESULTS

This section summarises the results, starting with the template visual scan patterns identified in the workshop. These templates were then used as a reference for the interactive exploration of scan patterns in ELOQUENCE. In the following, only patterns relevant to the approach scenario are discussed.

A. Identified Templates of Visual Scan Patterns

In total six template visual scan patterns were identified for single aircraft approaches in tower control.

1) Runway scan: The runway scan is where the ATCO scans the runway for threats. This pattern is fast, one or a few seconds, and typically starts with looking at the aircraft and then along the runway in the aircraft's direction of travel (Step 1 and 2 in Fig. 2). Instructors noted that several runway scans can be expected in a single aircraft approach scenario.

2) Landing clearance: Fig. 2 illustrates the template scan pattern that ATCOs are expected to follow when they clear an aircraft to land. It comprises the following visual steps:

1) Look at aircraft and its surroundings on OTW view.
2) Scan runway on OTW view (in direction of travel).
3) Look at wind instrument on AWOS.
4) Look at RCP and verify correct runway light settings.
5) Look at aircraft strip as it is moved one step.

Parts of the visual activity can be expected to occur in parallel with communicating the landing clearance. For example, when saying: *Scandinavian 356, wind 180 degrees 14 knots, runway 18 cleared to land*, the ATCO is expected to look at the wind instrument when verbalising the wind information (Step 3). The pattern is complex because gaze fixations do not require to occur in a strict order. Step 4, for instance, may have been accomplished sometime before the landing clearance is communicated. Instructors, however, pointed out that it is considered "good practice" to verify the correct runway light configuration when issuing the clearance. For step 5, instructors commented that ATCOs, with experience, often move the strip without directly looking at it.

3) Touchdown and landing roll: The touchdown and landing roll pattern starts when the aircraft lands and ends when it has slowed down to taxi speed on the runway. The following visual steps describe this pattern template:

1) Look at aircraft on OTW view as it lands.
2) Look at clock (to note landing time).
3) Look at aircraft strip (to write down landing time).
4) Monitor aircraft on runway OTW view as it slows down.

In Step 1, focus should be on the aircraft as it lands. The ATCO makes a mental notation of the landing time (Step 2), which later is written down on the flight-strip (Step 3). Instructors noted that Step 2 may be achieved just before the aircraft lands. While Steps 1-3 comprise quick fixations, Step 4 reflects a longer time period during which the ATCO follow the aircraft as it slows down on the runway.

4) Phases of visual focus: Phases of visual focus reflect changes in visual attention that can be expected to occur in a given scenario. Instructors were interested in how much visual attention different areas in the FOV receive over time (e.g. in percentage). The focus is on general shifts in attention from one area in the FOV to another, not on single shifts in fixations between visual cues.

For an approach and landing scenario, instructors expect three phases. *Phase 1: Radar display.* Initially, visual attention should be on the radar where the first visual contact with an arriving aircraft is made (if equipped and transmitting a transponder signal). *Phase 2: Approach area in OTW view.* Attention should shift from the radar to the approach area in the OTW view as the ATCO attempts to establish direct visual contact with the aircraft. *Phase 3: Runway in OTW view.* Upon landing, attention should change from the approach area to the aircraft as it decelerates and rolls out on the runway.

5) Time glass: A time glass was used as a metaphor to describe a desirable scan pattern template covering the whole approach and landing scenario. The shape of the time glass represents how visual focus is expected to 'flow' with the aircraft. Instructors explained that an ATCO's visual focus on the aircraft is expected to increase gradually as it approaches the runway (top chamber), reaching a maximum at touchdown (narrow tube), and then decrease again as the aircraft slows down on the runway (bottom chamber).

6) Wagon wheel: The wagon wheel pattern template reflects a general scan technique for maintaining focus on what is most important: often the aircraft under control. The aircraft represents the *hub* of the wheel. The *felloes* (outer rim) represent information cues relevant to the ATCO's work (e.g. potential threats along the expected flight path, wind information, or the flight-strips). The *spokes* connecting the hub with the rim represent gaze movements (saccades) between information cues (fixations).

B. Interactive Exploration of Scan Patterns in ELOQUENCE

In this section, we use the tool ELOQUENCE to find instances of the template visual scan patterns in the collected data. Figures are provided with reference to the collected eye-tracking data. Red bounding box annotations and explanatory text comments have been added for illustration purposes. Before the exploration of template instances in the data, a brief introduction to the four main views in the ELOQUENCE interface is provided. Three of these are illustrated in Fig. 3.

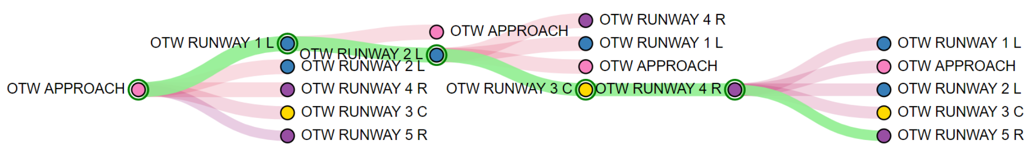
The *pattern tree view* is used to interactively grow a sequence of interest (e.g. a template scan pattern) by stepwise clicking on the nodes (representing different AOI) of the tree starting from the root (Fig. 3(a)). To guide exploration, when a node is clicked, the succeeding nodes available for building up sequences that match the set constraints are shown.

The nodes of a selected sequence (green line in pattern tree view) are highlighted in the *sequence view* (top part of Fig. 3(b)) and the *event overview* (bottom part of Fig. 3(b)) so that their frequency of occurrence and distribution in the data can be studied through visual inspection. In the sequence view, events (AOI visits) belonging to the explored sequence are drawn opaque while other events are drawn transparent. In the event overview, timelines of each event are stacked on top of each other. The event overview depicts the entire scenario duration, while the sequence view only depicts a selected portion. The time axes in both views show relative time in milliseconds from the start of the experiment (i.e. $t_0 = 0ms$). Instances of the template pattern emerge in the event overview by locating the positions where the events composing the explored sequence occur in close proximity to each other and preferably in the template order.

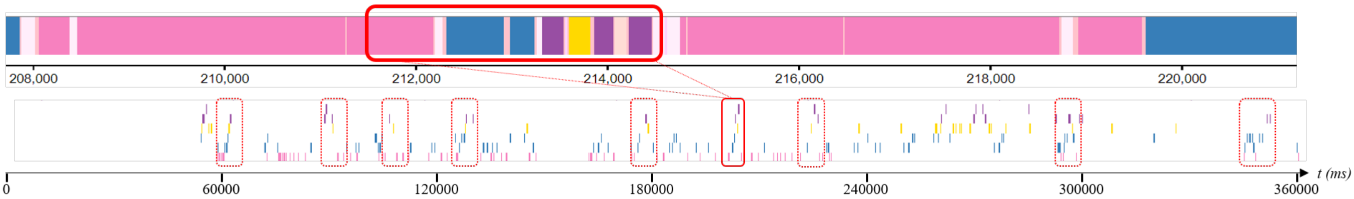
The *video view* (not shown) displays the original scene camera video of the FOV as recorded by the eye-tracking equipment. All views of ELOQUENCE are linked. Selecting a sequence in the pattern tree view highlights instances of the selected branch (e.g. the explored template) in the sequence view and event overview. Clicking on an event in the event overview places that event in focus by centering it in the sequence view. Finally, clicking on an event in the sequence view activates the video recording, which automatically 'jumps' to showing that event. In this way, it is possible to closer explore and verify the activity around the explored pattern sequence.

The following constraints were set in ELOQUENCE for the exploration of template visual scan patterns. Only gaze fixations related to twelve AOIs of interest for this analysis were included in the mining process (seen in colour in Fig.1). A time constraint of 30 sec was set to limit the time allowed between pattern events. Thus, AOI visits with a larger time interval than 30 sec were not considered part of the same visual scan pattern. Detection of the time glass and wagon wheel templates was not supported by the static AOI division used in this study. These are therefore not explored.

1) Runway scan: A runway scan is made by looking at several points along the runway. The number of points looked at and distance between them can vary over time and between individuals. With the static AOI division proposed (Fig. 1) the pattern can be expected to comprise the following AOI visits (aircraft landing left to right): (1) Approach area where aircraft is (`OTW_APPROACH`), (2) Runway left (`OTW_RUNWAY_1_L`, `OTW_RUNWAY_2_L`), (3) Runway centre (`OTW_RUNWAY_3_C`), and (4) Runway right (`OTW_RUNWAY_4_R`, `OTW_RUNWAY_5_R`).



(a) Runway scan pattern highlighted in the pattern tree view



(b) Runway scan patterns shown in the event overview (bottom part). A selected runway scan pattern match shown in the sequence view (top part).

Figure 3. Example of runway scan patterns explored in ELOQUENCE (IFR approach).

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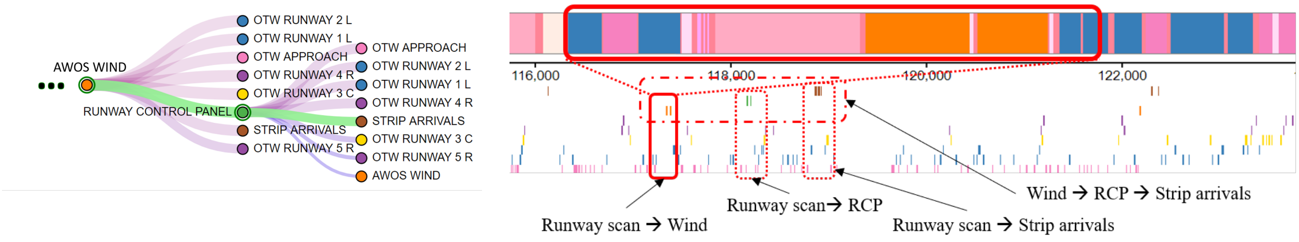

(a) Landing clearance sequence in pattern tree view.

(b) Landing clearance AOI highlighted in event overview (bottom) and sequence view (top).

Figure 4. Example of landing clearance pattern explored in ELOQUENCE (IFR approach).

The pattern can be defined by selecting the above AOIs in the pattern tree view (green in Fig. 3(a)). As a result, all instances of runway scans are shown in the event overview and sequence view (Fig. 3(b)). The event overview indicates that nine runway scans were made. The first one was made after around one minute ($t = 60000ms$). Runway scans were performed relatively regularly until the fourth minute ($t = 240000ms$), and less frequently after that (only twice). The event overview and sequence view indicate variations in the order of AOI visits for different runway scans. This could be due to errors in the eye-tracking data collection or can indicate "errors" in the ATCO's scan pattern. It may also represent a novel scan pattern that deviates from the template. The possible causes and implications of such observed variations are left for an instructor to judge and probe.

2) Landing clearance: The landing clearance pattern consists of a runway scan followed by controlling of wind, runway configuration, and moving the flight-strip. For exploration in ELOQUENCE, the previously explored runway scan template (Fig. 3(a)) is expanded by adding the following AOI visits in the pattern tree view: AWOS_WIND, RCP, STRIP_ARRIVALS (Fig. 4(a)). Fig. 4(b) shows the temporal distribution of AOIs highlighted in the event overview and sequence view.

These views reveal interesting information about how the template scan pattern is realised in the data. The ATCO checks the wind, RCP, and strip arrivals in that order, but not directly after one another. Runway scans occur between each of these checks. When investigating these AOI fixations in the video view, it can be seen and heard that the ATCO moves the flight-strip, without looking at it, when issuing the clearance.

The pattern tree view allows for investigating variations in the order of pattern events, including the absence of expected patterns. Fig. 5 shows an example exploration of a landing clearance sub-sequence AWOS_WIND→RCP→STRIP_ARRIVALS for a VFR approach scenario. This strictly defined sub-sequence is not supported in the data, as indicated by the red-dashed annotated path (STRIP_ARRIVALS does not follow AWOS_WIND→RCP). Instead, the pattern events appear with variations as indicated by the red dotted annotated paths in Fig. 5.

3) Touchdown and landing roll: The instance of touchdown and landing roll template is shown in Fig. 6 for the same scenario as the runway scan. The AOI visits involved in this pattern are the following: (1) Aircraft lands at threshold (OTW_RUNWAY_1_L), (2) Clock (AWOS_CLOCK), (3) Flight-strip (STRIP_ARRIVALS), and (4) Monitor aircraft roll out on runway (OTW_RUNWAY_1_L; OTW_RUNWAY_2_L; OTW_RUNWAY_3_C).

An AWOS_CLOCK fixation and subsequent STRIP_ARRIVALS fixation is seen following a fixation on the OTW_RUNWAY_1_L AOI. This combination of AOI visits reveals the expected position of the touchdown along the timeline, which can be confirmed by viewing the video replay (not shown in figure). In Fig. 6, the stepwise shifts of multiple fixations along the runway AOIs (Step 4) indicate that the ATCO monitored the aircraft on the OTW view as it slowed down on the runway.

4) Phases of visual focus: To determine phases of visual focus, eye-tracking data is analysed over the entire scenario. The event overview is appropriate for this task as it reveals the frequency and distribution of AOI visits. The event overview in Fig. 7 is generated from selecting the twelve main AOI visits in the pattern tree view (IFR approach scenario). Note that while the event overview depicts all five runway AOIs at different rows, the runway AOIs have been aggregated in the legend: OTW_RUNWAY_L for OTW_RUNWAY_1_L and OTW_RUNWAY_2_L; and OTW_RUNWAY_R for OTW_RUNWAY_4_R and OTW_RUNWAY_5_R. Three phases of visual focus are clearly visible, matching the template as identified during the workshop. Initially, the ATCO's visual attention focused on the radar (light blue AOI

Figure 5. Example of how the absence and variations of a template pattern can be detected in the ELOQUENCE pattern tree view (VFR approach).

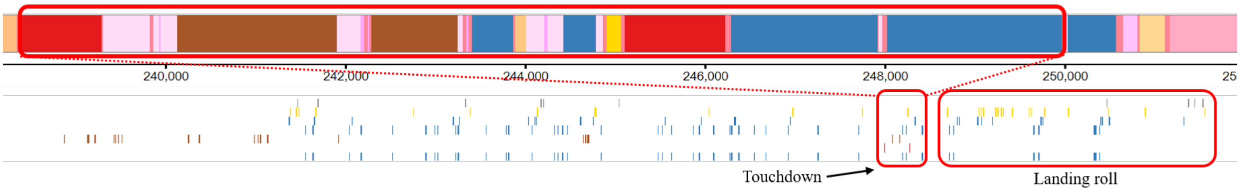

Figure 6. Example of a touchdown and landing roll pattern highlighted in the event overview (bottom) and sequence view (top) of ELOQUENCE.

in Fig. 7, *Phase 1*). The transition to *Phase 2* occured as the ATCO's attention shifted from the radar (light blue AOI) and other "desk displays" to the approach area in the OTW view (pink AOI); indicating the search for and establishment of direct visual contact with the aircraft. Noticeable is also the numerous runway scans made by the ATCO. *Phase 2* continued until touchdown, after which the approach AOI was mostly ignored and instead longer and more fixations were made on the different runway AOIs. This indicates the shift to *Phase 3*. In Fig. 7, the data shows that the ATCO visually followed the aircraft as it slowed down on the runway after landing (`OTW_RUNWAY_L`→`OTW_RUNWAY_C`→`OTW_RUNWAY_R`).

V. Discussion

This paper set out to bridge two challenges for realising the benefits of using eye-tracking data and measurement of visual scan patterns in tower control simulators. First, an instructor should know what scan patterns to look for in the data. Six template visual scan patterns for approach and landing scenarios in tower control were identified. Second, an instructor support tool visualising this data should allow the instructor to learn to what extent these patterns have been followed, and provide information about the quality of performed patterns. The collected eye-tracking data showed that ATCOs complied with four of the template scan patterns, although not necessarily in the specific order expected. The tool supported the detection of variations in visual scans within a template (e.g. runway scan and landing clearance patterns). The tool allowed the analyst to apply their individual experience and knowledge in judging the appropriateness of variations in observed scan patterns. The tool also allowed for exploring novel scan patterns, which potentially can be used to identify novel templates. The analysis of eye-tracking data should be complemented with additional input, such as simulator logs, physical interactions, and verbal communication, to derive a whole picture.

With a tool such as ELOQUENCE, instructors can attain a better understanding of trainees' visual behaviour in terms of their compliance with template scan patterns representative for different tasks and events. The added insight can provide valuable information as to why a trainee is performing poorly. Instructors can provide direct feedback on a trainee's visual performance, and how it can be improved. Moreover, the template scan patterns can be used to teach novices "best practice" scan patterns, or correct experienced ATCOs' inappropriate visual behaviour. The templates can also be used as an anchor, or a checklist, for performing scan patterns in stressful situations with many competing tasks.

The scenario used in this study was simple and consisted of isolated, single, traffic movements (i.e. approaches) at a single runway aerodrome. More complex scenarios with multiple simultaneous movements, which are normal in ATC, can complicate the analysis and detection of the visual scan pattern templates identified in this paper. The analyst/instructor must be able to distinguish between which fixations that belong to which movement. This requires a thorough understanding of the visual scan patterns that can be expected for different movements. Further research of scan patterns for different movements is needed, in addition to studying more complex scenarios with multiple simultaneous movements. In the context of training, however, movements can be scripted to unfold in a somewhat orderly fashion. Then, it is possible to beforehand determine expectations of visual scan patterns in relation to specific scenarios.

The six templates identified represent expected common work practices that apply to approach scenarios at any aerodrome. At a general level, aerodromes share a similar setup: all have a window for looking out, weather information, a runway control panel, a communication system, and flight-strips. Because of differences in equipment and layout, however, the specification of AOIs cannot be generalised from this study as the working environment of each aerodrome is unique. Future

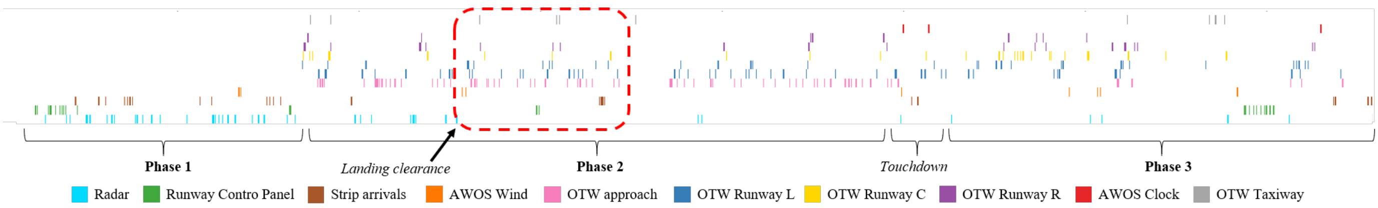

Figure 7. All AOIs related to the phases of visual focus template pattern explored in ELOQUENCE event overview (IFR approach).

research should explore the occurrence of the template patterns in eye-tracking data collected at other aerodromes.

Moreover, the templates are believed to be only a part of the patterns used by ATCOs in approach scenarios, representing the more critical tasks done. Further research should start building a more comprehensive set of template patterns for ATCO training. The approach undertaken in this paper could be used to harmonise scan behaviours in training, by formalising and exemplifying visual scan patterns. The use of sequence mining in practice will create a need for building a living set of template patterns, to be updated as the work environment and standard operating procedures evolve. The template scan patterns were identified by eliciting experience and knowledge from instructors, formalising what they expected to observe for a given scenario. Templates could also be derived empirically by collecting and analysing multiple eye-tracking data sets. Data could be collected during training, validation exercises, or during regular operations (e.g. [9], [18]).

The current build of ELOQUENCE allows for interactive exploration of collected data. This is a strength as it allows the analyst to freely specify constraints and explore patterns. In a training environment, and especially for operational use, this may not be feasible given time and resource limitations. Thereto, template patterns could be 'programmed' beforehand, to allow for the system to autonomously search for and present ATCO compliance with patterns.

While instructor support was the main application here, ELOQUENCE could be used for ATCO self-reflection. Through this tool, ATCOs could be presented with their own scan patterns during competence assessments or training. Other possibilities would be to use the tool for the evaluation of visual strategies or the assessment of situation awareness during system validations, indicating the effect of new procedures on the visual scan patterns.

VI. CONCLUSIONS AND FUTURE WORK

This paper has shown how ATCO visual scan patterns can be identified and analysed for a single aircraft approach scenario in tower control. A workshop with experienced instructors identified six templates of visual scan patterns and proposed a structure for defining AOIs in the FOV. The findings suggest that scan patterns can be formalised and visualized for enhancing instructors' understanding of ATCOs' visual scan behaviours in simulator environments. This is of importance given the centrality of visual information in maintaining situation awareness in current ATC work environments.

Actual ATCO scan patterns, captured with eye-tracking equipment, were used to explore the occurrence, frequency, and temporal characteristics of template scan patterns using the adapted novel interactive sequence mining tool ELOQUENCE. The possibility to apply constraints to the mining process in the tool has been a key for the analysis as shown in several examples. The support tool provided a powerful interface for visually exploring scan patterns. In this study, however, exploration was performed by researchers with support from ATCOs. Thus, further applied testing of the tool by instructors in an operational simulator training environment is required.

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