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Assessments on human-computer interaction using touchscreen as control inputs in flight operations

Wen-Chin Li[1], Yung-Hsiang Liang[1], Wojciech Tomasz Korek[2&3], and John J. H. Lin[4]

[1] Safety and Accident Investigation Centre, Cranfield University, United Kingdom
[2] Dynamics, Simulation and Control Group, Cranfield University, Cranfield, United Kingdom
[3] Faculty of Automatic Control, Electronics and Computer Science, Silesian University of Technology, Poland
[4] Institute of Science Education, National Taiwan Normal University, ROC

Wenchin.li@cranfield.ac.uk

Abstract. The developing technology on innovative touchscreen applied in the cockpit can integrate control inputs and outputs on the same display in flight operations. Flight systems could be updated by modifying the touchscreen user interface without the complicated processes on reconfiguring cockpit panels. There is a potential risk on touchscreen components constrained by the issues associated with inadvertent touch, which may be defined as any system detectable touch issued to the touch sensors without the pilot's operational consent. Pilots' visual behaviours can be explored by using eye trackers to analyze the relationship between eye scan patterns and attention shifts while conducting monitoring tasks in flight operations. This research aims to evaluate human-computer interactions using eye tracker to investigate the safety concerns on implementation of touchscreen in flight operations. The scenario was set to conduct an instrument landing on the final approach using future system simulator. Participants were required to interact with all the control surfaces and checklists using the touchscreens located on different areas in the cockpit. Each participant performed landing scenario as pilot-flying (PF) and pilot-monitoring (PM) in random sequence. Currently PF and PM perform different tasks related to control inputs and control outputs monitoring in the flight deck. The PF's primary obligation is to fly the aircraft's flight path, and the PM's main responsibility is to monitor the aircraft's flight path and cross-check to the PF's operational behaviours. By analyzing participants' visual behaviours and scanning patterns, the findings on HCI related to applying touchscreen for future flight deck design would be applicable. There are some benefits on the implementation touchscreen for future flight deck design if the human-centred design principle can be integrated in the early stage.

Keywords: Attention Distribution; Flight Deck Touchscreen; Human-Computer Interactions; System Usability; Visual Behaviours

1 Introduction

The applicability of touchscreen in modern flight deck has been investigated for a long time. There is a potential risk on touchscreen components constrained by the issues associated with inadvertent touch, which may be defined as any system detectable touch issued to the touch sensors without the pilot's operational consent. That is, a pilot may activate touchscreen control buttons inadvertently because of turbulence, vibrations, or aspects of the pilot's physical and cognitive workload which may have serious consequence of operational error and incidents [1]. The developing technology on innovative touchscreen applied in the cockpit can integrate control inputs and outputs in the same display on flight operations. Flight systems could be updated by modifying the touchscreen user interface without the complicated processes on reconfiguring cockpit panels. Other advantages of touchscreen including reduced space and weight, improved operational efficiency and accessibility [2, 3]. However, air turbulence and factors caused to aircraft vibration are the challenges for the potential use of touchscreen in flight operations. Previous research revealed that moderate levels of simulated turbulence could increase data entry times on touchscreen, error rates, fatigue, and perceived workload while compared with no turbulence scenario [4]. Previous research demonstrated that an effective method for determining if a control button on a touch screen device has been inadvertently touched using eye tracking technology [5].

Visual behaviours can be explored by using eye trackers to analyze the relationship between eye scan patterns and attention shifts while conducting monitoring tasks in flight operations [6]. Eye scan pattern

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is one of the methods for assessing a pilot's cognitive process and situation awareness (SA) in the cockpit based on physiological measures [7]. Furthermore, eye movements are a sensitive and automatic response that may serve as a window into the process of pilots' mechanism of situational awareness (SA) and reflect their mental state [8]. Fixation is defined as the eye movement pausing over informative stimulus for the purposes of interpreting the information [9]. The patterns of fixations on the areas of interest (AOIs) can reveal a pilot's visual trajectory of attention on the processing tasks [10]. Fixation duration is the total time fixating on an instrument that can reflect the level of importance or difficulty in extracting information [11]. The nature of human beings is such that they tend to distribute longer fixation duration to relevant AOIs than to those irrelevant areas [12]. Attention blurring is characterized by small number of fixations and increased number of transitions between instruments and not able to actually interpret the information [13]. Pilot's scan patterns and visual parameters have been successfully applied to evaluate the performance of situational awareness during flight operations. Eye tracking technology has been applied to evaluate pilot's situation awareness and human-computer interactions to validate the effectiveness of aviation training and flight deck design. Visual characteristics can reveal pilots' attentional distributions and provide scientific evidence to assess pilots' cognitive process. Figure 1 demonstrated while interacted with augmented design, pilots' pupil dilations are smaller and fixation duration are shorter compared with traditional design [14].



Fig. 1. Pilot's fixation at the altitude indicator (red-cross) and pupil dilation (right-hand side) on augmented design of PFD recorded by Pupil Eye Tracker (from [14])

Visual parameters are objective data reflected to cognitive costs on task performance which are relevant to the HCI issues on applications of touchscreen in the flight deck design. Attention distorting is described by small number of fixations and increased number of transitions between instruments and not able to actually interpret the information [13]. Pilot's scan patterns and visual parameters have been successfully applied to evaluate the performance of situational awareness during flight operations. Eye tracking technology has been applied to evaluate pilot's situation awareness and human-computer interactions to validate the effectiveness of flight deck design [10]. The evaluating HCI issues on touchscreen applications should be covered the finger and hand occlusion in the flight deck setting using eye tracking technology. Some of the errors observed in previous studies were likely due to the finger and hand occluding targets, and in the safety critical cockpit environment it is important to know whether bracing postures increases susceptibility to this type of error [1]. Furthermore, prior findings show that humans adapt their hand postures as they move towards targets, in preparation for a suitable grip once contact is obtained [15]. In a similar manner, the principle on HCI research may have to explore how pilots manipulating their fingers towards target buttons in the complicated operational environments while a braced touch posture is aimed. To ensure operational safety, the pilot-flying (PF) and the pilot-monitoring (PM) must conduct cross checks by moving their head and eyes to the levers and displays on different positions in the flight deck. The application of touchscreen technology in this area can reduce pilots' head-down

time and to increase SA, which is a significant advantage of using touch screens. However, the application of touchscreen in the flight deck may inadvertently create some safety concerns during hazardous situations including turbulence and vibration scenarios which are stressful for pilots on precisely controlling the aircraft [16]. Therefore, implementation of touchscreen on the flight deck must demonstrate high usability and safety requirements with regards to human-centered design.

2 Method

2.1 Participants

There are 12 participants aged from 21 to 53 years old (M=29.92, SD=10.97) with varying levels of flight experience (M=1150, SD=4019.9) attended in this research. The research proposal was submitted to Research Ethics System for ethical approval before conducting data collection. As stated in the consent form, participants are anonymous and have the right to terminate the experiment at any time and to withdraw their provided data at any moment even after the data collection.

2.2 Research Apparatus

Future Systems Simulator (FSS): research apparatus has applied the Rolls-Royce award-winning FSS, which provided the ability to quickly model current and future aircraft configurations [17]. The FSS is a highly reconfigurable modular flight simulator, in which seat positions, displays, side sticks, thrust levers and touchscreens can be repositioned (Fig 2). The FSS builds reassuringly on familiar aircraft controls, with information presented on up to four large reconfigurable touchscreens and two smaller side screens. This allows pilots to explore the potential impact on future flight decks design for single pilot operations including smarter, more autonomous engines, as well as revolutionary new technologies.



Fig. 2. Participant wears eye tracker performing landing scenario as pilot-flying interacting with touchscreen on Future Systems Simulator

Pupil Labs core: A light-weight eye tracker which consists of a headset and two cameras for participant's visual behaviours and pupil dilation data. The eye camera is connected to the eye camera via the ball joint allowing six degrees of rotation to get a good image of the eye. The world camera can rotate up and down to align with participant's field of view (FOV). There are four areas of interests (AOIs) identified as follows: Primary Flight Display (PFD), Navigation Display (ND), Checklist Display (CD) and Central Upper Display (CUD), containing mode control panel for autopilot control, engine display and digital levers for flaps, Landing Gear and spoilers. The 'world-camera' is mounted on the right top

of the headset showing the orientation and view of participant's FOV and the eye-camera is mounted offset right and low and is adjustable to suit different facial layout and track their pupil parameters accordingly [18]. Data recorded by two cameras can be synchronized after calibration.

2.3 Scenario

The scenario used in the trail is an instrument landing which participants were required to interact with flaps, landing gears and spoilers and checklists using touchscreen located on different areas in the flight deck. Based on the standard operational procedures (SOPs). Pilot-flying is expected to coordinate with pilot-monitoring to perform cross-check. Therefore, each participant has to conduct two landing scenarios randomly to eliminate practice effects.

2.4 Research Design

This research involved in assessing HCI in flight operations using innovative touchscreen in the FSS and eye tracking device. All participants undertook the following procedures; (1) complete the demographical data including age, gender, working experience and total flight hours (5 minutes); (2) briefing the purpose of the study and familiarized with touchscreen layouts (15 minutes); (3) seat in simulator for calibration on eye tracker (5-10 minutes); (4) perform the scenario on instrument landing as pilot-flying or pilot-monitoring randomly to eliminate practice effects (10-15 minutes); (5) debriefing and answering participants' questions (5 minutes). It took around 50 minutes for each participant to complete the experiments.

2.5 Data analysis

The fixation counts (FC) and fixation duration (FD) were used to measure pilots' visual behaviours on HCI in the flight deck. Both FC and FD were adopted in other studies focused on flight deck design and the results suggested these two visual parameters were effective on detecting pilots' visual attention and evaluating SA in flight operations ([19], [10]). For each participant, eye movement parameters on both fixation duration and fixation counts were collected for data analysis using Pupil Player. These two measures are sensitive to the visual responses t when a participant was synchronously performing the instrument landing on both PM's or PF's positions. Participants consecutive gaze points that fall into a circle with a radius with 1.5 degree and a duration longer than 150 ms is defined as a fixation point in current study. Specifically, there are three research questions as followings:
RQ1. What is the difference between PFs and PMs on fixation counts for four AOIs?
RQ2. What is the difference between PFs and PMs on fixation duration for four AOIs?
RQ3. What are the correlations among AOIs?

3 Results

3.1 Sample characteristics

Given each participant performed both roles on PF and PM randomly, repeated measure-based analysis was conducted throughout this study. In addition, Pearson's correlation analysis is applied to evaluate eye movement parameters among Primary Flight Display, Navigation Display, Checklist Display and Central Upper Display between PFs and PMs. Furthermore, repeated measure analysis of variance (RM-ANOVA) was conducted to compare the difference between PFs and PMs on the fixation duration and fixation counts among four AOIs. The assumption of sphericity was examined in terms of the Mauchly's test. Suppose the assumption of sphericity is violated, the results of multivariate tests would be used. Post-hoc analysis was performed using the Bonferroni correction after a significant effect is confirmed [20]. The effect size of RM-ANOVA was evaluated by partial eta-square [21]. Table 1. shows the descriptive statistics of FC and FD among four AOIs between PF and PM.

Table 1. Descriptive statistics of mean and standard deviation for online and offline measures.

Measures	PF			PM		
	N	Mean	STD	N	Mean	STD
CD_FC	12	3.83	6.87	11	54.18	15.37
CD_FD	12	171.02	137.14	11	252.21	32.44
CUD_FC	12	19.58	22.56	11	50.27	11.87
CUD_FD	12	248.10	44.90	11	245.36	48.76
ND_FC	12	21.17	13.19	11	59.64	71.89
ND_FD	12	244.37	36.82	11	249.57	59.82
PFD_FC	12	120.75	75.47	11	119.64	65.40
PFD_FD	12	302.79	76.39	11	302.62	61.71
Total_FC	12	388.92	106.93	11	388.09	146.82

3.2 Visual parameters among AOIs

To evaluate the visual attention and scanning patterns between PFs and PMs, it is suitable to apply RM_ANOVA with AOIs as the factor was computed. The main research interest is whether participants spent more time fixating on a specific AOI. The results suggested FC on AOIs were different for PFs, $F(3, 9) = 10.58$, $p = .003$, $\eta_p^2 = .78$. Post-hoc analysis suggested PFs focused on PFD more frequently than Checklist Display (CD), Central Upper Display (CUD) and Navigation Display (ND). In addition, PFs focused on ND more frequently than CD. For PMs, results suggested FC on AOIs were different, $F(3, 8) = 8.69$, $p = .007$, $\eta_p^2 = .77$. Post-hoc analysis suggested PMs focused on PFD more frequently than CD and ND. Figure 3 illustrates FC on the four AOIs for PFs and PMs.

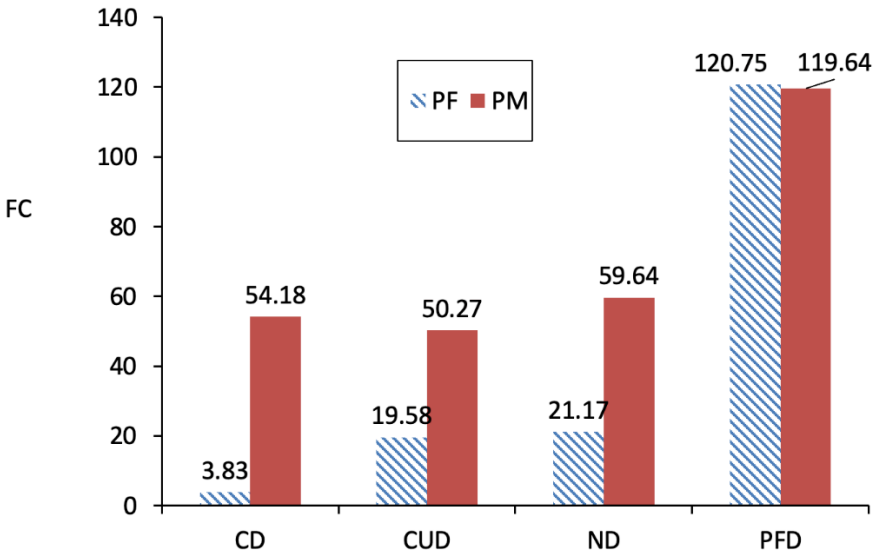


Fig. 3. An illustration of FC on the four AOIs for PFs and PMs.

Regarding FD, results suggested FD on AOIs were different for PFs, $F(3, 9) = 10.10$, $p = .003$, $\eta_p^2 = .77$. Post-hoc analysis suggested PFs focused on PFD longer than CD. For PMs, results suggested FD on AOIs were different, $F(3, 8) = 5.57$, $p = .023$, $\eta_p^2 = .68$. Post-hoc analysis suggested PMs focused on PFD longer than CD. Figure 4 illustrates FD on the four AOIs for PFs and PMs.

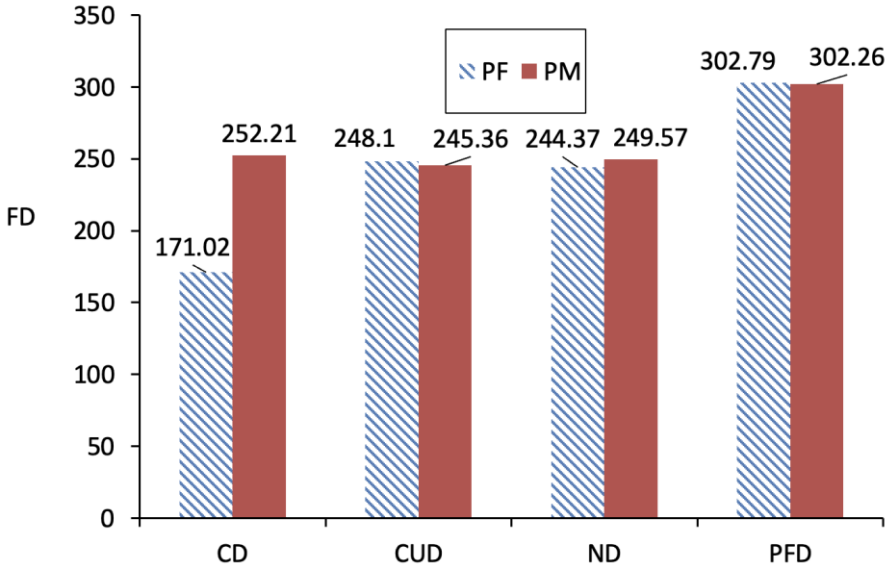


Fig. 4. An illustration of FD on the four AOIs for PFs and PMs

3.3 Correlations between PM and PF's visual parameters among AOIs

The results suggested significant positive correlations among eye movements. For examples fixation counts on between PM and PF, $\gamma = .65$, $p < .05$. There is a negative correlation between fixation count and fixation duration on CUD, $\gamma = -.68$, $p < .05$. Furthermore, there is significant correlations among eye movement measures. To avoid redundancy, please refer to Table 2 which shows the correlations on PM and PF's visual parameters among AOIs. In addition, the number of significant correlation coefficients for PFs are smaller than that of PMs

Table 2. Correlation coefficients and p values for eye movement measures among AOIs

		PM								
		1.	2.	3.	4.	5.	6.	7.	8.	9.
PF	1.CD_FC	1	-0.18	0.04	-0.54	0.23	-0.54	0.57	-0.01	0.51
	2.CD_FD	0.36	1	.774**	.687*	-0.60	0.56	-0.58	.631*	-.798**
	3.CUD_FC	.647*	.632*	1	0.39	-.606*	0.23	-.648*	.611*	-.621*
	4.CUD_FD	0.16	0.17	0.39	1	-0.20	.777**	-.656*	0.47	-.641*
	5.ND_FC	-0.18	0.16	0.28	0.11	1	0.03	.632*	-0.54	.765**
	6.ND_FD	-0.24	-0.06	0.16	0.17	.640*	1	-0.43	0.10	-0.42
	7.PFD_FC	0.07	0.20	0.14	-.684*	0.31	0.09	1	-0.36	.768**
	8.PFD_FD	0.04	0.54	0.52	0.21	0.34	0.56	0.28	1	-.655*
	9.Total_FC	0.39	-0.03	0.42	-0.05	0.38	-0.15	0.24	-0.33	1

Note: 1. Lower triangle show correlations for PFs; upper triangle show correlations for PMs.

2. $p < .05$*, $p < .01$**.

4 Discussion

Touchscreen could be an innovative design for improving human performance in the flight deck if it followed human-centered design principles. Modern technologies have paved the way to recreate high fidelity flight scenarios in the safe simulated environment. Developments and research in flight simulation technology have resulted in the Future Systems Simulator (FSS) with touch-screen display which can model all types of advanced aircraft. While advanced technology shows many promises, one must consider HCI challenges and pilots' operational behaviours and limitations [22]. This research assessed PF and PM's visual behaviours while using touchscreen on the FSS. Moreover, practical applications from a HCI standpoint are discussed.

The difference among four AOIs on fixation count is significant between PF and PM. PFs focused on PFD more frequently than CD, CUD and ND (table 1 & Fig 3). The result suggested that PFD might be the main source of information for instrument landing, since all the flight data that correlated with maintaining the aircraft attitude (angle of attack, air speed, altitude, vertical speed) are all displayed on the PFD. Additionally, PFs focused on ND more frequently than CD. Similarly, PMs focused on PFD more frequently than CD and ND. Another finding is that PMs had more FC on CD, CUD, and ND, except on PFD. This could be due to the fact that PMs required evaluating whether the operations of PFs were following the standard operating procedures (SOPs) by cross-checking the aircraft configuration with checklist display. Therefore, PMs needed to validate by checking CD, CUD, and ND more often than PFs to ensure the aircraft configuration is correct on final approach which may lead to more FC on the three AOIs for PM. In contrast, PFs need to perform landing in a limited time frame. Therefore, the FC of PFs is fewer than that of PMs on those three AOIs in the flight deck but more FC on the runway and precision approach path indicators (PAPIs) shown in Fig. 5.



Fig. 5. PF's fixations switching between the centre of runway and cockpit displays demonstrated the attention distributions to maintain SA (left); PM's scanning patterns and fixations moving around AOIs to conduct cross-check with PF's operational procedures for instrument landing (right)

The results also demonstrated that there is a significant difference among four AOIs on fixation duration between PF and PM. PFs focused on PFD longer than on CD (table 1) demonstrate that PFD might be the main source of information for instrument landing, whereas all the critical information related flight operation are presented on this AOI. Similarly, PMs focused on PFD with longer fixation duration than CD. Furthermore, the results reveal that fixation duration at each AOI for PFs are roughly equal to PMs, except CD, in which PMs had longer fixation duration than that that for PFs. Such findings provided valuable information regarding minimal fixation duration that were necessary for PFs and PMs to extract information from CUD, ND, and PFD are roughly equal. On the other hand, as a PM, the fixation duration required to extract information and validated cross-check to PFs' operational behaviours from CD taken longer time.

There are significant correlations among four AOIs on visual parameters between PM and PF. The numbers of significant correlation coefficients for PFs are smaller than PMs. In other words, PFs inclined to make a decision after cross-checking 1-2 AOIs; while PMs inclined to cross-check more AOIs to confirm PFs' operational responses and decision-making following SOPs. Such differences might result from different tasks to be done between PFs and PMs inherently on the current design principles for two-pilots flight deck design. As a PF, the main task is to perform a safe landing task; in contrast, a PM is expected to validate the operations of PFs operational behaviours and providing necessary support to maintain safety in flight operations, which could lead to more cross-checking than PFs. Another finding is that PMs switched the attention among AOIs more frequently, and the durations tend to be longer as well. In summary, for a PMs to complete their task, more cross-checking and fixation counts with longer fixation duration are required.

To understand PM and PF' experience, there was a feedback session after the experiment was completed for the de-briefing. Both PF and PM expressed that information was clearly presented on the touchscreens, but important control buttons were initially difficult to find. Especially the layout of the flight-deck changed between PF and PM set-ups and looked different with current flight deck layout. However, as the experiment progressed, PF and PM found these touchscreen controls easier to locate after becoming familiar with the layout of displays. They also felt that selecting flaps and gear requires more cognitive attention when using touchscreens compared to conventional levers, hence monitoring performance of the PM may temporarily be compromised. Therefore, extra time was required to ensure the correct selection was made as PM conducting cross-check to PF's flight operations and control inputs alongside with checklists. This phenomenon may detract PM's attention and require extra time to confirm the SOPs during critical phases of landing. It should also be noted that the experiment was performed in a normal operational environment, yet turbulence could exacerbate the problems on the above scenario.

Currently PF and PM perform different tasks related to control inputs and control outputs monitoring in the flight deck. The PF's primary obligation is to fly the aircraft's flight path including managing the automated flight systems, and the PM's main responsibility is to monitor the aircraft's flight path and to immediately bring any concern to the PF's attention including radio communications, aircraft systems, other operational activities. Therefore, there are differences on the attention distributions among AOIs in the flight deck between PF and PM (Fig. 6). The system usability of touchscreen has been proved as beneficial to pilots' situation awareness on flight operations in normal operational environment [23] Their visual behaviours associated with task executions and monitoring while interacting with touchscreen were analyzed using eye tracking technology in current study. The application of touchscreens in the flight deck may have the potential for single pilot operations in the future, but the design of touchscreen must be consistent with human factors principles on cross-monitoring and integrated information to improve usability and pilots' situation awareness in flight operations.

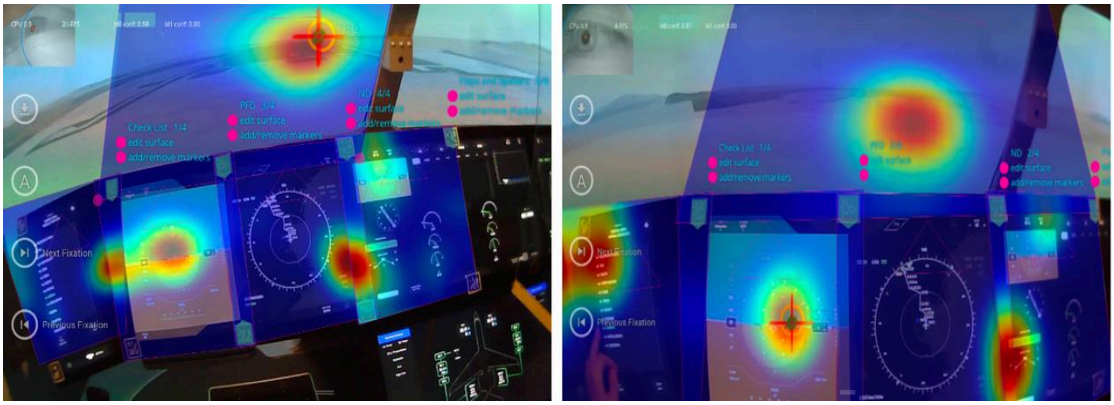


Fig 6. Attention distributions among different displays on the flight deck shown as heatmap between PF (left) and PM (right)

5 Conclusion

By analyzing participants' visual behaviours and scanning patterns, the findings on HCI related to applying touchscreen for future flight deck design would be applicable. There are some benefits on the implementation of touchscreen for future flight deck design if the human-centered design principle can be integrated in the early stage. Furthermore, there are different requirements for PF and PM's tasks in the current flight deck, whereby the cognitive workload and the attention distributions on monitoring performance are different. The significant differences of FC between PFs and PMs have been demonstrated in the heatmap (Fig. 6) and the illustration above (Fig. 2). Task for PMs was mainly concentrating on monitoring the flight data, conducting the checklist, and manipulating the control for PFs, whereas PFs were relatively focused on controlling the aircraft attitude and the altitude in the landing scenario. The potential limitations should be taken into account on current research, first limitation is the small sample size, which could lead to small effect sizes. To validate the findings, a large sample size would suffice for future study; the second limitation would be the difficulty of defining an AOI for outside view, which is one of the most common areas that pilots are fixating on outside cockpit. Various attention distributions between PFs and PMs could be identified by using eye tracking technology. Despite these limitations might have impacts to the contributions on current research, the innovative FSS touchscreen is an effective testbed for future flight deck design.

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