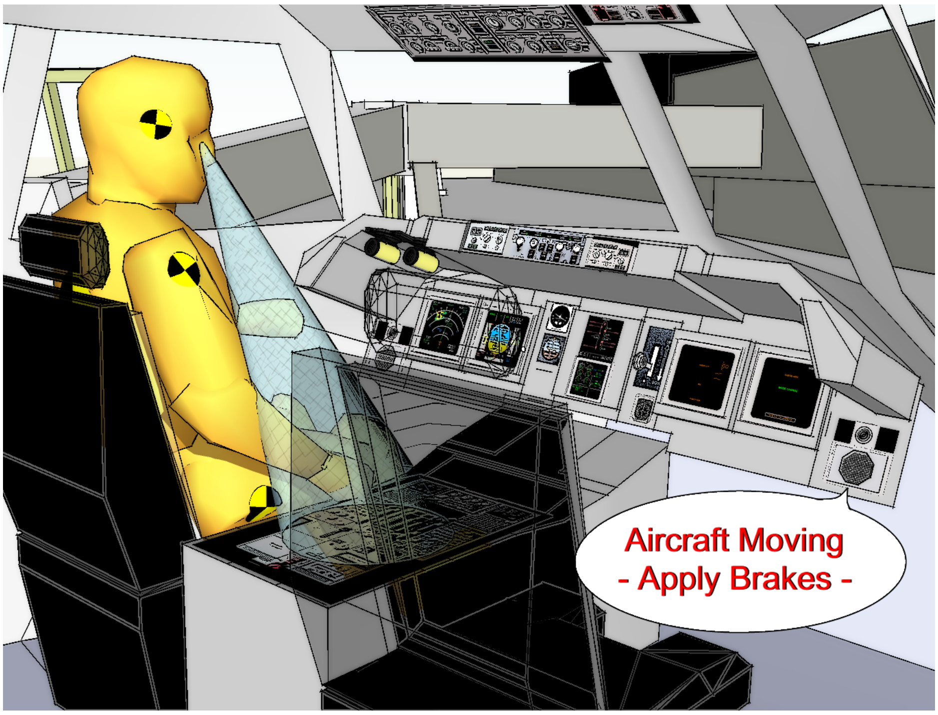
Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

Executive summary

Adaptive Pilot Assistant for Taxiing



Problem area
Perception is of fundamental importance in obtaining good situation awareness and failure to notice important events can have major consequences regarding safety. A system that identifies critical events and detects whether or not these events are perceived by the human operator may positively influence safety in aircraft operations. In order to investigate this, an exploratory study concerning adaptive automation in civil cockpits has been conducted. Initially, the focus of this study will be on the unintentional transition between standing still and moving during ground operations. Several incidents and accidents that are related to this subject have been reported, and therefore this problem area has been selected for this exploratory study. Positive results of this study will allow the possible follow-ups in extending into other operations as well.

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This report is based on a presentation held at the HCI-Aero 2010, Cape Canaveral (FL), U.S.A., 3-5 November 2010.

Description of work

An Adaptive Pilot Assistant for Taxiing (APAT) system has been developed with the initial goal of preventing unintentional transition from standing still to moving during ground operations. The system analyses the pilot's intentions by monitoring control inputs and also gaze using a non-intrusive camera based head and gaze tracking system. In addition, the aircraft's state is monitored and once the aircraft starts to move without indications that the pilot is aware of this movement, the system enables a warning and/or automatic braking system that assists the pilot with regaining control over the aircraft.

Results and conclusions

The APAT system is implemented in a cockpit simulator and a human-in-the-loop experiment with airline pilots has indicated that the APAT system works as intended. It prevents unintentional movements by only enabling when needed. The system was able to determine the pilot's intentions regarding the movement initiation by examining the pilot's gaze and (throttle) control inputs and warns and/or intervenes when these conflict with the aircraft's state. The investigation indicated that the APAT system was preferred by the participating pilots. Also, the experiment clearly indicated that the APAT system significantly reduced the distance travelled during mishaps.

Applicability

Using the positive results of this investigation, successful extension of the APAT system to other fields within or outside of the aviation domain seems feasible. For example, it may be possible to detect the pilot's intentions during centerline deviations while taxiing, or even during glide-path deviations on approach. Other examples with regard to aviation include anti-terrorism measure by using the facial recognition capabilities, counteracting 'tunnel visioning' when malfunctions occur, and assuring good division of attention between crewmembers. Extension outside aviation includes the automotive domain, for instance, in an application that tries to prevent rear-end collisions in traffic jams. Some car manufacturers and aftermarket suppliers already offered driver monitoring systems that increase safety.

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Adaptive Pilot Assistant for Taxiing

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ABSTRACT
As an exploratory study concerning the use of adaptive automation in civil cockpits called Adaptive Pilot Assistant for Taxiing (APAT) system has been developed. The initial goal of this system is to prevent unintentional transition from standing still to moving during ground operations. The system analyses the pilot's intentions by monitoring control inputs and also gaze using a non-intrusive, camera based head and gaze tracking system. In addition, the aircraft's state is monitored. When the aircraft starts to move without indications that the pilot is aware of this movement, the system activates a warning and/or automatic braking system that assists pilots into taking back control over the aircraft. A simulator experiment with airline pilots revealed that the system prevents unintentional movements effectively and the adaptive nature of the system prevented nuisance alerts. Using the positive results of this investigation, successful extension the APAT system to other fields within or outside of the aviation domain seems feasible.

Keywords
Adaptive Automation, Gaze Tracking

INTRODUCTION

Situation Awareness (SA) is considered an important factor for efficient and safe operation in complex environments like aircraft cockpits. Perception is crucial for obtaining good SA, as without basic perception of important information it is difficult or even impossible to form a correct picture of what is going on. Consequently, failure to notice or perceive critical events represents a substantial source of aviation accidents on ground and in the air [1].

With this background, one way to increase safety is to develop a system that tries to identify potentially critical events and, more importantly, detect whether or not these events are perceived by the human operator. Detecting if an event is noticed is a key aspect, because in essence all events that go unnoticed can potentially turn into dangerous situations. An example of a seemingly harmless event is the transition between stopping and moving during ground operations. Several aircraft ground incidents and accidents have been reported that are related to unintentional movement of an aircraft while it was intended to be safely parked. The causes of these occurrences are very diverse. They can range from parking brake failures and miscommunication between ground crew and pilots, to small distractions of pilots at unfortunate moments or even the absence of a pilot behind the controls while it starts to move.

An adaptive system is characterized by the ability of the system to fit the provided level of assistance (e.g. automation) to the needs of the operator [2]. Changes in the state of automation, operational modalities and the number of active systems can be initiated by either the human operator or the system [3, 4]. This way, adaptive automation enables the level or modes of automation to be tied more closely to the operator's needs at any given moment. [4].

Within the framework of the European Union funded research project HILAS (http://www.hilas.info/mambo/), an adaptive system has been developed at the National Aerospace Laboratory NLR that has the potential to identify possible critical events and is able to detect if these event are perceived. In order to make a first evaluation of this system, the initial focus is to prevent unintentional movement during ground operations.

In order to prevent unintentional rolling, a rolling prevention/warning system has been implemented and, according to the adaptive automation principle, this system only acts when it is needed and thereby adapts to the pilot's state. The system is called Adaptive Pilot Assistant for Taxiing (APAT). Although the system is limited to unintentional rolling for now, extension to other events remains possible once this exploratory study is completed successfully. The study contains a human-in-the-loop flight simulator experiment that will be conducted to thoroughly examine the system's functioning and determine if the system is accepted as support system by pilots.

This paper presents the Adaptive Pilot Assistant for Taxiing system and the experiment that is conducted to test it. It is structured as follows. First, the method of how to prevent an unintentional transition from standing still to moving is discussed. Then, the implementation of such a method using adaptive automation is presented. Finally, the results of a pilot-in-the-loop simulator experiment are discussed. The goal of this experiment was to evaluate if the developed Adaptive Pilot Assistance for Taxiing (APAT) system can assist pilots in preventing unintentional movement during ground maneuvering.

PREVENTING UNINTENTIONAL ROLLING

A system that prevents movement is simple. Monitor the rotation of a wheel and apply brake pressure when it starts to rotate will limit the aircraft's motion. Determining whether the movement is intentional or unintentional, however, is more difficult. Such a system needs to monitor the pilot's state and actions to determine whether or not (s)he is aware that the aircraft is moving. An analogous system that monitors a driver's attention to driving is patented by Koninklijke Philips Electronics N.V. [5]. The described system monitors a driver's attention to driving a vehicle using camera imagery that determines gaze and facial pose by image processing. It may include an alarm that is responsive to deviations between the gaze and the direction of travel. Recent developments in face recognition and image analysis have enabled the ability to implement such a camera based gaze tracking system. The company Seeing Machines has developed faceLAB, a head, gaze and fatigue analysis tool. This software package uses a set of cameras (figure 1) as a passive, nonintrusive measuring device. Another advantage of this software package is that calibration can be done automatically within a few seconds or semi automatic, to obtain higher accuracy, which takes approximately 30 seconds. Note that the system is able to analyze video images in real time and does not need to record any imagery. Also, the camera's can register information in the visual as well as the infrared spectrum. Infrared transmitters can be used to shine infrared light on the subjects face to allow the system to function in completely dark conditions.

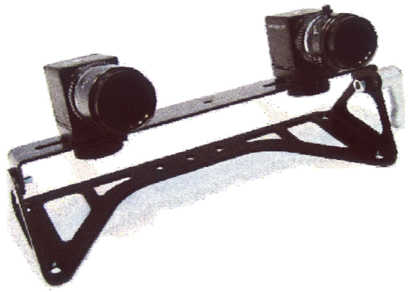

Figure 1: FaceLAB nonintrusive head and gaze tracker

Monitoring gaze is one factor in being able to determine if a transition from standing still to moving is intentional or unintentional. If the pilot is looking outside when the aircraft starts to move, for instance, it may be valid to assume that movement is intentional, or at least noticed. On the contrary, can it also be concluded that movement is unintentional when the pilot is not looking outside? It seems likely that situations can occur in which the visual attention and intentions of pilots look contradictory. For this reason it is deemed necessary that more variables should be monitored to derive the pilot's intentions. A practical variable besides the pilot's gaze seems to be the throttle setting changes. It is suggested that movement can be labeled as intentional once the pilot has increased thrust. Two factors are now identified that can be used to determine the pilot's intentions in relation to starting to taxi. It is suggested that movement initiations should be labeled intentional or at least perceived if either the pilot is looking outside or increasing thrust. When neither pilot is looking through the window nor thrust is increased and the aircraft still starts to move for any reason, then this movement is labeled unintentional and assistance is needed. This strategy will form the basis of the automation system that will adaptively assist the pilot and tries to prevent unintentional rolling.

USING ADAPTIVE AUTOMATION

The National Aerospace Laboratory, NLR has developed an Adaptive Automation Architecture (AAA) that supports the implementation of adaptive automation concepts in (simulator) cockpits for research purposes. This architecture (figure 2) was used to implement the Adaptive Pilot Assistant for Taxiing (APAT).

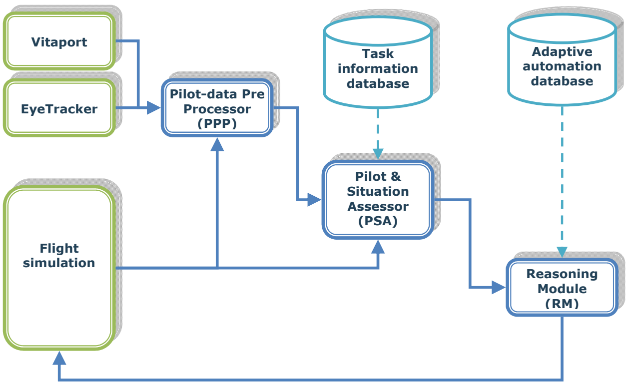

Figure 2: Adaptive Automation Architecture

The AAA (figure 2) consists of three main components; the Pilot-data Pre-Processor (PPP), Pilot & Situation Assessor (PSA) and the Reasoning Module (RM). The PPP takes raw data from different systems as input and is able to make an assessment regarding fixation statistics and even workload. This assessment is then transferred to the PSA and/or can be presented graphically within the PPP. The PSA then takes these pilot-data and combines them with the simulator input to assess the pilot's state. This means that the PSA tries to identify what the pilot is doing and with what certainty this task identification is made. After identifying the task(s) they are transferred to the RM. The RM uses the information from the PSA to conclude how the pilot can be supported at that moment and determine in real time which level of automation is required.

These system components communicate among each other but also with three external systems, namely; Vitaport, Eye

Tracker and the flight simulation. The Vitaport system monitors heart rate and respiration data that can be used for a workload assessment in the PPP. The Eye Tracker monitors eye data such as gaze, fixations, and blinks. Initially, the only Eye Tracker that could be used to connect with was the ASL 6000 by Engineering Systems Technologies (EST). This is a head mounted system that offers very high accuracy. In order to be able to develop the APAT system, the compatibility with Eye Trackers has been extended by enabling the faceLAB head and gaze tracker to be connected. Compared to the ASL 6000 system, faceLAB offers a less intrusive tracking system but it gives in some accuracy. It should therefore be noted that conclusions regarding fixations may be more difficult to obtain, but at least a general viewing direction can be acquired which is sufficient for this investigation. Communication with other flight simulation components is needed to determine what buttons have been pressed, in which flight phase the aircraft is situated and what control inputs are given by the pilot. Also, the RM feeds back its conclusions to the flight simulation to enable or disable support systems and/or increase the level of automation if necessary.

Furthermore, the PSA and RM obtain predefined definitions from databases. The PSA determines which task is being performed by the pilot using the task definitions that are provided in the task information database. The detected task is valid within a specified Task Time Window (TTW) and is prolonged or removed depending on detection of this same task inside the time window. The RM establishes whether additional support is needed and which level of automation is required using the information from the adaptive automation database.

Using this AAA the APAT system is designed. Initially, pilot workload has not been included in the APAT system. Possibly, future extensions the system may use pilot workload as input measure, but for now gaze and control input data seem sufficient. For this reason, the Vitaport, that monitors heart rate and respiration, is not connected. As mentioned before, faceLAB is used as eye tracker within the APAT system. Primarily, the APAT system is designed to provide assistance when an aircraft (unintentionally) starts to move. For this design goal, it is sufficient to be able to tell when the pilot is looking outside 'through the window'. The raw data from the eye tracker are then processed by the PPP and passed on to the PSA, which determines if the pilot's current actions contains monitoring the environment outside the cabin. The PSA also examines the pilot's control inputs of which changes in throttle input are of particular interest to the APAT system. Any increase in throttle setting will be translated to an 'increasing thrust' task. Furthermore, the PSA monitors the aircraft's state to detect state changes, for instance, the transition between stopping and moving. All detected tasks are transferred to the RM, which tries to identify when the pilot needs assistance. Regarding the system discussed in this paper, the need for assistance comes down to the situation where the aircraft starts to move unintentionally. This translates to the detection of the following task:

- Aircraft starting to move

While the following tasks are <u>not</u> detected:

- Pilot is monitoring the environment outside the aircraft (looking outside through the window)
- Thrust increase

However, at the moment either of the two tasks above is detected, assistance is not (or no longer) necessary.

This setup is designed to detect unintentional movement and consequently detect the need for assistance. But how should this assistance be provided? Two options are examined. The first option uses an automatic braking system that is designed to simply apply full toe brakes when enabled. This option uses the automatic braking system by activating it adaptively depending on detection of unintentional movements. In addition this option will provide an audio and text message when the system is enabled to inform the pilot about the current situation. The second option uses a lower level of automation [6], and does not take over control by using the automatic braking system. This option purely provides a warning (audio and text) when the pilot does not seem to be aware that the aircraft has started to move, and suggests applying the brakes.

Now a solution to prevent unintentional rolling using adaptive automation has been defined, the question may arise of whether it is not simpler to solely monitor the aircraft's movements and inform the pilot when the aircraft starts to move. This seems like a much simpler solution to the problem. A possible drawback of this system is that it will inform the pilot frequently without apparent need, risking that the pilot starts to regard the messages as nuisance. To be able to make a straightforward comparison, this simple system will be tested next to the two adaptive automation variants.

EXPERIMENT

The goal of the experiment was to evaluate if the developed Adaptive Pilot Assistance for Taxiing (APAT) system can be used to prevent unintentional movement of an aircraft during ground maneuvering. Preventing unintentional movement is the first implementation of the APAT system and after successful evaluation is can possibly be extended to provide assistance during other situations and/or flight phases.

After some training runs to get familiar with the simulation and the APAT system, the experiment was divided into two parts.

The participants were asked to complete the first part by performing 20 experimental runs. Each run started with the aircraft standing still on a taxiway with the parking brake enabled. The participants were asked to perform two tasks. The primary task was controlling the aircraft, which in this case came down to assuring that the aircraft remains stationary. The secondary distracting task consisted of pressing smiley symbols that popped up randomly (see figure 4). The subjects were informed that a parking brake failure would occur after a certain random time. The result of this parking brake failure was that the aircraft accelerated and slowly started moving. Once the subjects noticed that the aircraft was moving unintentionally, they were expected to apply the toe brakes and safely stop the aircraft from moving.

For this experiment, a parking brake failure was chosen to cause the aircraft to begin moving, but this can also be caused by another mishap, for example, by a miscommunication between pilot and ground crew concerning chock placement. Due to the fact that the subjects were informed on the repeating occurrence of parking brake failures in each experimental run, consistency over the experiment runs was assured. The philosophy behind this way of conducting the experiment was that subjects would adopt a control strategy in which their attention was divided between the primary and the secondary task. Their state of awareness was said to be comparable to a driver that had just experienced unintentional movement in a vehicle and is on higher alert for it to happen again (e.g. comparable to a automobile driver that stopped in front of a traffic light on an inclined road, moved slightly backward and has to stop at the next light).

For the second part of the experiment, the participants were asked to interact with the system on their own behalf and truly put the system to the test. This second part was included to enable participants to give their honest opinion about the system's functioning without being constrained to a predefined scenario. Also, possible areas for improvement that were not thought of beforehand can be identified by giving participants 'free play'.

Method

The experiment is conducted in the NLR's fixed base cockpit simulator APERO (Advanced Prototyping & Evaluation for Research & Operations). For this experiment the APERO simulator (figure 3) is configured to represent an Airbus A320. The simulator is PC-based and includes five high resolution LCD touch screens, side sticks, rudder pedals with toe brakes and Airbus Flight Control Unit (FCU). The pilot will operate as single pilot on the captain's position in the cockpit.

Figure 3: APERO cockpit simulator

The APERO simulator is equipped with a camera based monitoring system called faceLAB that tracks the pilot's head position and gaze. It uses a passive stereo pair of cameras mounted underneath the glare shield to capture video images of the pilot's face. These images are processed in real time to determine the 3D pose of the pilot's head as well as the eye gaze direction. The system is also able to detect facial expressions and eye closure to determine blink rates, but this information is not used in this experiment.

Subjects and Instructions to Subjects

Eight students and two airline pilots participated in the experiment. The mean age of the students was 23. All subjects had a driver's license and several had some flight (simulator) experience. Two students had corrected vision by glasses. Both of the airline pilots were male and had uncorrected vision. One pilot was a captain in a Boeing 747-200 with a total flight experience of 7600 hours and at age 43. The second pilot was a fist-officer in a Boeing 747-400 with a total flight experience of 6250 hours and at age 33. All subjects were given the same instructions. They were instructed to assure that the aircraft kept stationary, while performing the secondary task.

Independent Variables

One independent variable was varied in the experiment namely, the enabled system to prevent unintentional rolling. There were four different experiment conditions with different system enabled:

a) APAT with automatic braking system and callouts
b) APAT with callouts (no automatic braking)
c) Movement warnings (no adaptive automation)
d) Conventional system

Dependent Measures

Four dependent measures were appointed: 1) Distance Travelled (DT) after the parking brake failure; 2) Reaction Time (RT) of the pilot and system; 3) Secondary Task Score (STS); 4) Subjective rating of each condition/system on a scale from 1 (low/worst) to 10 (high/best) given by the participants. The means and standard deviations of these variables represent the experiment results.

Description of the Experiment

Aircraft Model

The aircraft model that was used in the experiment was a nonlinear model of the Airbus A320. The aircraft is in taxi configuration and will accelerate when the brakes are released under idle thrust. The maximum acceleration of this aircraft when starting to roll in forward direction stays under 0.1 g. This means that the acceleration stays below the indifference threshold and pilots will generally be unable to detect this acceleration using their vestibular senses under normal workload conditions [7].

Secondary Task

Participants were asked to conduct a secondary task besides keeping the aircraft safely parked on the taxiway. This secondary task consisted of pressing smiley symbols on a touch screen that is located on the aft pedestal. The target smiley that had to be selected was colored yellow and had a full smile. After selection it disappeared and a new one faded in. There were five other smiley symbols that popped in and disappeared at regular intervals of one second. These symbols had a random color and the smile on their faces was a function of performance of this secondary task. The higher rate of selecting the target smiley, the happier the other smiley symbols became (figure 4). This direct performance feedback of the secondary task was included to subtly encourage participants to perform above a desired level (making all faces smile) and assuring that the secondary task gets the necessary attention. Also, the difficulty of the secondary task increases with increasing performance. Higher performance led to more happy faces that made distinction between the target and random symbols more difficult.

The secondary task also took care of the 'random' occurrences of parking brake failures. By including buttons that were not visible to the pilot and generated parking brakes and randomly 'appeared' and 'disappeared' at constant intervals of one second, these parking brake failures seemed absolutely random to the participant and even the experiment leader (figure 5). The participant unknowingly pressed a button that generated a parking brake failure and the aircraft started to move while the participant was still conducting the secondary task while occasionally looking outside to detect possible movement as the primary task.

After each experimental run, the main performance parameters of the primary (distance traveled) and secondary task were visualized on the same screen as the secondary task.

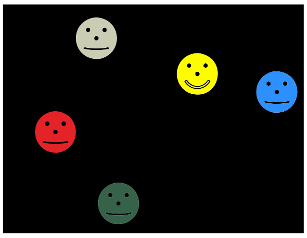

Figure 4: Sec. task.

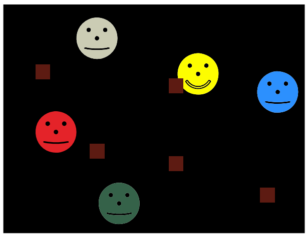

Figure 5: Sec. task with (hidden) failure buttons.

Experiment Hypothesis

It was hypothesized that the addition of any support system (condition a, b, and c) to the conventional condition (d) will improve performance by reducing the pilot reaction time to parking brake failures and consequently decreasing the distance travelled. Furthermore, it is expected that the condition with automatic braking (condition a) will perform best regarding distance travelled, while the two conditions that only generate warning will have comparable performance. It is expected that the difference between the systems with adaptive automation and without will become apparent when pilots subjective judgment is taken into account, because the application of adaptive automation principle tries to prevent nuisance alerts.

Furthermore, the Secondary Task Score (STS) is expected to be the same for each experimental condition. There are no reasons to expect any noticeable differences, because the subjects will be unaware of which experimental condition is being executed. It is, therefore, likely that they will adopt a similar control strategy for each condition.

RESULTS AND DISCUSSION

The main results of the experiment are summarized in this section

Statistical Analysis of the Dependent Measures

The means and 95% Confidence Intervals (CI) of the dependent measures are shown in figure 8 to figure 19. An analysis of variance (ANOVA) was conducted in relation to these measurements.

Primary task performance: Distance Traveled (DT)

As was hypothesized, the distance travelled by the aircraft after the parking brake failure was significantly influenced by providing a support system that prevents unintentional movement (see figure 6, $F_{1,198} = 64.526$, $p \leq 0.01$).

There was no significant difference between the primary task performance Distance Travelled (DT) of the two airline pilots and the eight other participants in the experiment (figure 7). This supports the notion that the performance data are comparable between the pilots and non-pilots.

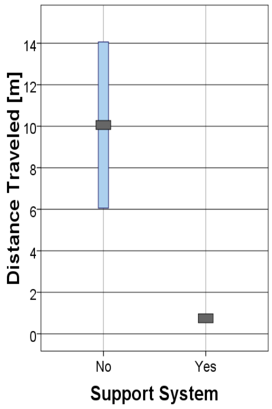

Figure 6: DT with and without support system.

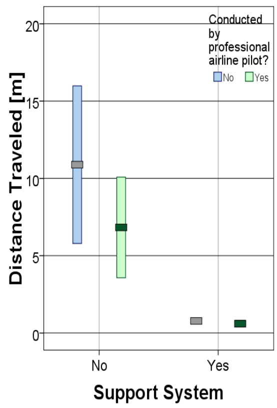

Figure 7: DT for pilot and non-pilots.

Furthermore, the DT was also significantly affected by the type of assistance (see figure 8, $F_{2,148} = 24.587$, $p \leq 0.01$). Post hoc analysis (Student-Newman-Keuls (SNK), $\alpha = 0.05$) showed that experimental condition a, the APAT system with automatic braking, resulted in the best performance and smallest DT as was expected. As hypothesized, conditions b and c, that both provided warnings concerning aircraft movement, did not result in significant differences in DT. Surprisingly, the standard deviation is larger for experimental condition b that uses adaptive automation to suppress unnecessary warnings, compared to condition c that simply provides a warning whenever the aircraft starts to move.

In order to investigate this unexpected effect, the gaze behaviour of the participants was analyzed. This led to the conclusion that the relatively high deviation of the DT for experimental condition b is caused by four experiment runs in which the pilot had just looked outside within the Task Time Window (TTW) of four seconds after the parking brake failure occurred. Consequently, the APAT system initially determined that the pilot was aware of the movement initiation and did not intervene. After the TTW of four seconds had surpassed and the pilot had not looked outside within this time, the APAT system noticed that the movement was unintentional and enabled the warning system. This effect is illustrated by extracting these few occurrences from the data (50 runs per condition) and placing them on a scatter plot and combining this plot with a error bar of the means and 95% CI of the remaining data (figure 9). The standard deviations of the remaining data for experimental condition b and c are much more comparable after extracting these few occasions. It can also be observed that there was one such an occurrence for condition a, resulting in a smaller deviation after extraction. Naturally, the three similar occurrences for experimental condition c are of no influence, because this system does not take the pilot's intentions into account and always gives a warning concerning movement initiations.

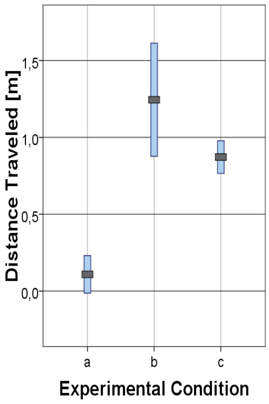

Figure 8: DT with and without support system.

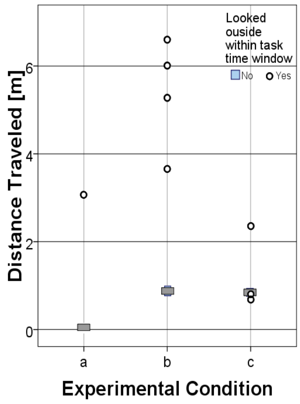

Figure 9: DT for pilot and non pilots.

Reaction time of the system and pilot

The reaction time of the system does not significantly differ between experimental conditions a, b and c (figure 10). Still, there is a noticeable difference between the standard deviations of conditions with APAT system (a and b) and without (c).

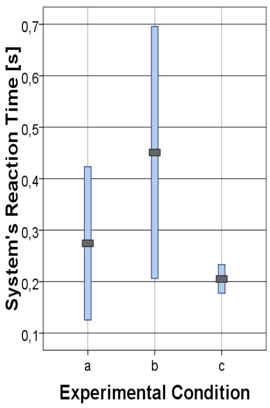

Figure 10: Reaction time for each support system.

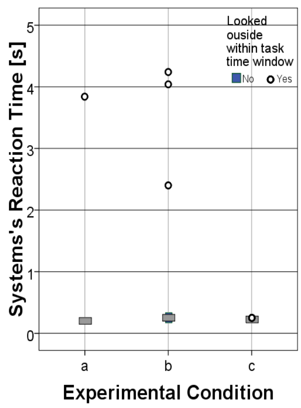

Figure 11: Reaction time (scatter) plotted.

Again, this difference is likely to be caused by the events in which the APAT system had detected that the pilot was looking outside within the TTW and evaluated the movement initiation as unintentional with a delay. Figure 11 illustrates this by plotting these events separately from the rest in a scatter plot and presenting the means and 95% CI of the remaining data using error bars. As expected, there was a significant difference between runs with and without APAT system regarding the pilot's reaction time between parking brake failures and applying the toe brakes (figure 12, $F_{1,198} = 167.035$, $p \leq 0.01$). Again, there is no significant difference between the reaction time of airline pilots and the other participants (see Figure 13).

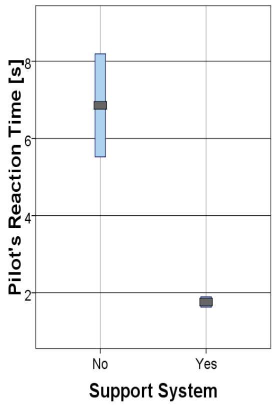

Figure 12: Pilot reaction time with(out) support.

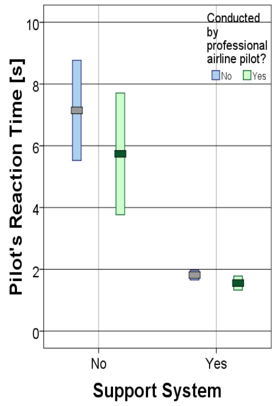

Figure 13: Reaction time for (non)pilots.

The reaction time of the participants to the support system did not show any significant differences between the experimental conditions (figure 14). Again, there was no significant difference between pilots and non-pilots concerning this experiment measurement (figure 15).

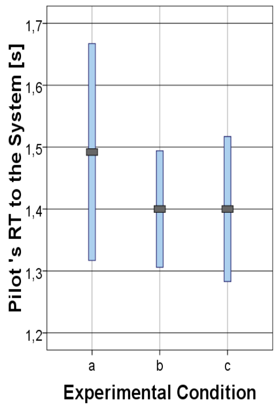

Figure 14: Reaction Time (RT) for each support system.

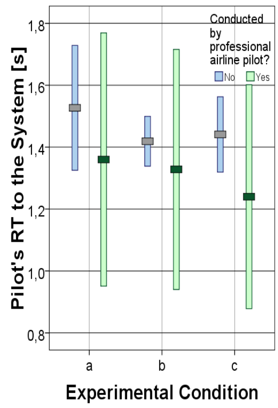

Figure 15: RT for each system for (non)pilots.

Secondary Task Score (STS)

As expected, there is no significant difference in STS, neither between the different experiment cases nor between pilots and non-pilots (see Figure 16 and Figure 17).

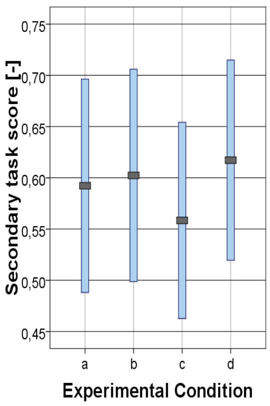

Figure 16: Secondary Task Score (STS) for each condition.

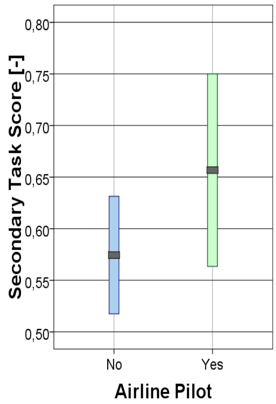

Figure 17: STS for pilots and non-pilots.

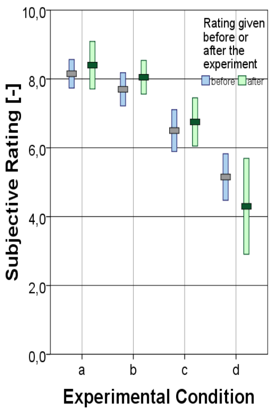

Figure 18: System rating given before and after the experiment.

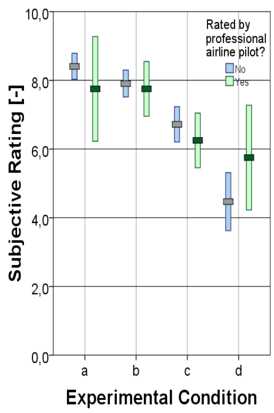

Figure 19: Rating given by pilots and non-pilots.

Subjective rating

The participants clearly rated the two APAT systems as best, with a slight preference for the APAT system with automatic braking (figure 18). Subjects were asked to rate each system before and after conducting the experiment. The participants tended to rate the support systems higher after working with them, than they did before conducting the experiment (figure 18). The two airline pilots were more moderate in their judgements but still tend to prefer the adaptive system over the other cases. Still, they did not have a consenting opinion on preferring the APAT system with or without automatic braking (figure 19).

Pilot questionnaire

All participants gave positive feedback concerning the experiment and the implementation of the adaptive automation concepts. The function of the APAT system (both variants) to determine when assistance is needed and consequently diminish nuisance alerts was received very well. Most participants mentioned that a simple movement warning did the trick, but that in an everyday situation the high frequency of unnecessary alerts could have negative side effects. These side effects could be faulty dismissal of warnings or omission of other relevant information. With regard to the APAT system, nearly all participants, students and pilots, mentioned the possibility of unwanted braking during system failures as a negative side effect. Also, relying too much on this (backup) system was considered a negative side effect.

A few participants mentioned that actual motion sensation, not present in the fixed-base simulator, may be needed to further evaluate the system. More frequently mentioned was the lack of peripheral information. Vision through the side windows is said to be used to determine motion in large aircraft.

Approximately half of the student participants previously experienced unintentional movement in an automobile. The causes ranged from handling the radio while standing in a traffic jam, to enabling the parking brake with insufficient pressure. One of the two pilots had experienced unintentional movement in an aircraft. In this case, the aircraft moved backward for approximately 10 meters due to a miscommunication between pilots and ground crew concerning chock placement. Fortunately, the crew noticed the motion in time to safely stop from moving. The pilots also noticed that such a cause was more likely than the occurrence of parking brake failures as was simulated in this experiment.

The participating pilots had no objections to the idea of using a camera based system in the cockpit. The developed system does not need to record any information or camera imagery to function. The pilots mentioned that they are so used to being monitored, that the introduction of camera's in the cockpit is no problem, especially when the imagery is not recorded.

Some students identified the possible negative effects of wearing (sun)glasses or keeping one's eyes closed to the gaze tracker and APAT system's functioning. The effect of glasses has been proven to been minimal as the vision of two participants was corrected with glasses and no difference was noticed during the experiment or by analysis of the data. There could be an effect of wearing sunglasses, but this has yet to be investigated. Keeping one's eyes closed, however, did seem to have an unexpected side effect as one participant tried this during the 'free play' part of the experiment. It was assessed that the system used head pose as gaze direction when the eyes are shut. Now that this issue has been addressed it can be corrected in the next system update.

The possible future application of an (extended) APAT system in vehicles was reckoned possible by the participants. General aviation aircraft owners may find such a novelty very attractive, but for commercial airlines the trade-off between cost and savings may be challenging. Possible extensions of the system to other fields within aviation or without were also suggested. For example, it may be possible to detect the pilot's intentions during centerline deviation while taxiing, or even during glide-path deviations on approach. Other suggestions with regard to aviation included anti-terrorism measure by using the facial recognition capabilities, counteracting 'tunnel visioning' when malfunctions occur, and assuring good division of attention between crewmembers. Extension outside aviation included the automotive domain, for instance, in an application that tries to prevent rear-end collisions in traffic jams. Some driver monitoring systems that increase safety are already offered by some car manufacturers and aftermarket suppliers.

Discussion of the Experimental Results

As was hypothesized, adding a support system resulted in a smaller distance travelled after the occurrence of the parking brake failure. Even though the participants knew that the aircraft would start rolling after a while, the lack of a supporting system resulted in taxiway consumption in the order of ten meters. In real life, the participants would not be prepared for such a situation and the distance travelled without support system will probably be much larger. By adding a support system this distance was significantly decreased.

Even the most basic warning system, that simply informed the pilot when the aircraft started to move, reduced the travelled distance below one meter. Still, the adaptive systems were preferred by the pilots because these took the pilot's intentions into account and only intervened when necessary. During normal operations when the pilot was in complete control of the aircraft, the advantages of the adaptive variants were most evident. The adaptive system worked as the intended backup system while the non-adaptive system was clearly present and kept informing the pilot.

The adaptive system with automatic braking function clearly outperformed the other systems concerning distance travelled. Also, this system was rated slightly higher that the adaptive system without automatic braking. Still, there are some concerns about the possible malfunctioning of a system with such a high level of automation. However, this high level of automation basically demands a stringent testing procedure before implementation. A high level of automation by itself should not pose any objections to the system, but caution is advised. Also, the automatic braking system applied full brakes in unintentional movement events which is accaptable in an experimental setup, but in a real system the brakes have to be carefully tuned to prevent lockups and other unwanted effects.

There were a few occasions where the APAT system detected the unintentional movement with a delay of up to four seconds. This delay was caused by the fixed Task Time Windows (TTW) in the Adaptive Automation Architecture. Once the pilot looks out of the window, this is detected as a task of monitoring the environment outside the aircraft. This task stays valid during the TTW that was four seconds during this experiment. If the parking brake failure occurred within this TTW, the following aircraft movement was initially seen as intended. After the TTW had surpassed, the movement was still identified as unintentional albeit a little late. In order to improve the design of the APAT system, the TTW may needs to be adaptive instead of fixed. This is a suggestion for future investigation.

CONCLUSION

The Adaptive Pilot Assistant for Taxiing (APAT) system is able to prevent unintentional transitions from standing still to moving in a simulated aircraft. The system is able to determine the pilot's intentions regarding the movement initiation by examining the pilot's gaze and (throttle) control inputs and warns and/or intervenes when these conflict with the aircraft's state. Furthermore, the adaptive nature of the system prevents nuisance alerts and the system only enables when needed. Although several incidents and accidents have occurred, the transition between standing still and moving by itself is not of primary concern in increasing overall safety. Still, this investigation indicates that the APAT system was accepted by the participating pilots. Furthermore, the experiment clearly indicated that the APAT system significantly reduces the distance travelled during mishaps. Based on the promising results in this experiment, we believe that the APAT system and underlying technology allows for future extensions into other fields within and outside the aviation application domain.

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