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Current commercial airplane cockpits generally require two pilots; a captain and First Officer. The autopilot has become an essential aspect of commercial flying as it can reduce the pilots' workload and increase accuracy. Since present autopilot implementations work independently from the pilot, the pilot must adopt a monitoring role. This design is not without its limitations, however, especially concerning the pilot's situational awareness. One possible relief for these limitations is the synthetic teammate, a specialized type of artificial intelligence agent intended to mimic a human operator. It integrates with current autopilot systems and provides pilots with context for action instead of merely recommendations or direct control inputs. The haptic shared control, where both the pilots and the synthetic teammate continuously maintain contact with the control surfaces, is an example of the synthetic teammate implementation. This paper aims to explore a synthetic teammate system's effectiveness in assisting a pilot's situational awareness.

Literature Review

The current commercial flight deck generally includes a captain and a First Officer (FO). Each pilot's role is unique, depending on the phase of flight. While taxiing, the captain usually controls the airplane from the gate to the runway and vice versa. The FO, on the other hand, handles the radio communications, monitors ground navigation through charts or airport diagrams, and provides an additional set of eyes for obstruction clearance. When in the air, the roles of the captain and first officer switch between either Pilot Flying (PF) or Pilot Not Flying (PNF), also known as Pilot Monitoring (PM). Generally, PF and PM roles alternate between each leg of a trip, with the captain at the controls for the first leg of the trip and the FO at the controls during the second, or vice versa. (Jentsch, Barnett, Bowers, & Salas, 1999).

Some tasks, regardless of the phase of flight, remain fixed to each ranking crew member. No matter the pilots' roles for that particular flight, the captain, the higher ranking crew member, has legal responsibility for the aircraft and its actions. Emergencies, tactical, and strategic decisions also remain with the captain, but in some situations, the captain may delegate the actual decision-making process to the FO (Jentsch et al. 1999). Pilot Flying (PF) and Pilot Monitoring (PM) have their specific roles as well. The PF manipulates the trajectory of the aircraft with the controls or via the autopilot control panel. The PM assists with radio communications, setting up instruments, preparing charts, and monitoring the PF's performance (Jentsch et al. 1999). The main reason for separating these duties is to maintain Situational Awareness (SA) throughout a flight. SA is a broad concept that includes gathering every possible bit of information about an event, analyzing it, and deciding how to react to that event. SA is the result of a human's view and awareness of the surrounding environment, which is then processed to understand the received information (Billings, 1995). To gather information and maintain SA, the pilot(s) must attend to both the outside environment and the flight deck instrumentation. While each pilot in a crew is responsible for monitoring and analyzing all of the information, communicating it to each other is critical to team-SA or Crew Resource Management (CRM) (Jentsch et al., 1999). According to Endsley (1994), to attain true situational awareness, pilots cannot simply be provided with multiple pieces of information. Instead, a higher level of understanding and prediction of the situation must be used to formulate and expect a desired result.

Why an autopilot is essential. The autopilot can help improve a pilot's SA, but it can also degrade it. The PF and PM must have proper knowledge of the autopilot's condition and must also be involved in its operation (Billings, 1995); otherwise, SA could be lost because neither human pilot is now in physical control of the aircraft. Pilot and autopilot interaction has become somewhat of a problem which can be described as lack of mode-awareness, mode-confusion, or automation surprises (Degani & Heymann, 2000). Accident and incident reports have indicated that when automation is a causal factor, there either was not enough information presented to the pilots on the status of the automation, or the pilot simply did not understand what the automation was doing (Degani & Heymann, 2000).

Simply put, an autopilot is intended to reduce crew workload so the crew can focus on other flying-related tasks. However, an autopilot's actions are always assumed by the system to be correct, but resulting actions may not be the pilot's desired result. Some pilots may try to reprogram the automation to correct the aircraft's trajectory, but that may make matters worse. Sometimes it is best to simply eliminate automation from the equation, returning to the primal state of manual flying, then bringing automation online when allowable (Curry, 1985). Faulty interactions with automation generally lead to two kinds of reactions, self-blame or blame on the system, the latter of which usually leads to a maintenance write-up claiming a malfunction (Degani & Heymann, 2000). However, Curry (1985) concludes that pilots should simply be trained to turn off the automation instead of programming their way out of an undesirable situation.

AI in the cockpit. As mentioned previously, artificial intelligence (AI) is a massive advancement that integrates into the aviation industry. That being said, it comes in the form of a technology that still requires a lot of learning, correction, and understanding. Within the cockpit, AI can be used in various ways. Button (2019) highlights that a preliminary test for researchers dealing with AI is to examine the reaction time of a pilot in control of the aircraft in contrast with an AI system's reaction time. Instances like these presumably ensure that AI has the capability to outwit even the brightest pilots. Though, that is not always the case. According to Button (2019), edge cases are a critical component to the downfall of artificial intelligence systems. They are described as things that are complex, unique, and seemingly unpredictable. It is not surprising that AI software systems have their critics. Looking back at research from Billings (1995), the claim that AI systems can't be 100% relied upon is validated. A pilot's situational awareness can be altered either positively or negatively through the use of automation. Regardless of how much good comes from the automation systems, the negatives are still there and create a potential hazard to safety.

The synthetic teammate. Autopilot systems used today typically work independently from the human operator; while the autopilot system controls the aircraft, the pilot's role becomes primarily to monitor the aircraft systems. This could result in problems when there is a misunderstanding between both the pilot and the automation. This approach could cause the pilot to lose SA. To better integrate automation into the cockpit, some have proposed implementing the synthetic teammate. Synthetic teammates are a type of artificial intelligence agent intended to replace a human operator in some cases (Doherty, 2003). The author elaborates that the idea of synthetic teammates is to provide the pilots with context for action in addition to merely providing them with recommendations or even direct control inputs. Doherty (2003) continued by listing the synthetic teammate implementation guidelines using a human-centered design approach. Firstly, the pilot must be given the final authority of the flight. Secondly, the pilot has to be informed continually of the synthetic teammate's intentions. Thirdly, the synthetic teammate's actions must be predictable. Finally, the synthetic teammate's goal must support the pilot's goal. A synthetic teammate can be implemented by using the haptic shared control method. Shared haptic control could meet the above objectives. Under the shared haptic control objectives, both the pilots and the synthetic teammate (the autopilot, for example) continuously maintain contact and control with the control surfaces such as the yoke or foot pedals. An example of this approach is to have the system create guiding push and pull forces to guide the operator away from unsafe regions such as outside of the stipulated operating boundaries of the aircraft, for example (Abbink, Mulder, & Boaer, 2011; Rosenberg, 1993).

The pilot must have the final authority of the flight. This approach places the human operator (the pilot) in a position of unchallenged authority (Abbink et al., 2011; Doherty, 2003). This concept allows the synthetic teammate to determine if the operator is about to operate their aircraft outside of its safety boundaries and intervene if necessary. In the shared haptic feedback approach, this can be done through the use of control forces (Rosenberg, 1993), such as friction or stiffness on the control surface (Abbink et al., 2011). However, Doherty (2003) stated that the system must ultimately yield full authority to the pilot by allowing him/her to override its inputs at any time.

The pilot has to be informed continually of the synthetic teammate's intentions. Keeping the pilot informed of the synthetic teammate's intentions is essential to prevent automation surprise. This approach also helps to maintain situational awareness by allowing the pilot to intervene or to react accordingly based on the action of the synthetic teammate (Doherty, 2003). For example, if a plane banked abruptly to the right as soon as the pilot disengaged the autopilot and took manual control, it is evident that both pilots were not aware of the plane's right turning tendencies and that the autopilot intentionally maintained level flight by using the ailerons and spoilerons. With haptic shared control, the pilots would be aware of the synthetic teammate's intentions as the pilot will maintain physical contact with the control surfaces and would notice strong left aileron pressure to compensate for the aircraft wanting to bank to the right.

Automation must be predictable as the pilot must anticipate the future intentions or actions of the synthetic teammate as it aids in his/her decision-making (Doherty, 2003). This predictability gives the pilot sufficient time to coordinate a response if needed. This rule can be implemented with shared haptic control by using visual or audio cues. An example could be using a digital screen that displays the synthetic teammates' future intentions or actions.

Automation must play a supporting role for the pilot. Doherty (2003) states that the ultimate goal of the synthetic teammate must be to provide support in decision-making, problem-solving, information collection, and analysis. The use of shared haptic control can accomplish this by following the rules stipulated above, such as through providing haptic guidance to the pilot if the pilot is straying away from the operational boundaries, while also yielding final decision-making to the pilot.

AI and pilot responsibilities. The introduction of AI to the cockpit, which may mimic human intelligence and reasoning, can present a conflict of duties between who is supposed to be in control of the aircraft. How do these responsibilities change, if at all? Holford (2020) begins by defining the Pilot-in-Command's (PIC) responsibility and authority. He quotes three different aviation authorities for these definitions. The International Civil Aeronautics Organization (ICAO) (2005), the Code of Federal Regulations (CFR) (2021), and the International Air Transport Association (IATA) (2020) all reference the PIC, or Commander in some cases, as the final authority as to the operation of the aircraft. IATA (2020) goes a bit further to say that the Commander "may delegate duties to qualified personnel but remains always responsible" (Clause 3.1.1).

When an airline pilot becomes a Captain, they accept enormous responsibility every time an aircraft moves. This responsibility can be divided into four separate categories, all of which are intertwined. They are causal responsibility, whether directly or indirectly; legal responsibility; moral obligation; and role responsibility (Dalcher, 2007; Holford, 2020). Due to the relation of each of these, Dalcher (2007) provides an example of moral responsibility in relation to causal responsibility. Professional pilots can always be held morally responsible if they do not act appropriately in any given situation. The PIC, quite plainly, must always have the obligation and ability to control the aircraft if danger is imminent. In order to attribute the responsibility defined by the CFR (2021), ICAO (2005), and IATA (2020), Holford (2020) mentions for this technology to be implemented safely, the operator must be able to override the system, therefore meeting all responsibilities at the onus of the pilot.

Gaps in Existing Research. Research gaps can be seen in Unmanned Aerial Vehicle (UAV) flight operations. When adding an AI component to these vehicles, it makes for a very complex piece of machinery. Ackerman (2020) further explains the correlation they have seen between humans and their AI software counterparts. Pilots with manual control of the aircraft still seem to have better agility than automation when reacting to real-world environmental changes (Ackerman, 2020). Ackerman (2020) also highlights the fact that simulator vs. real-world operations can be drastically different. For example, a pilot in training may feel no fear in taking risks (higher tolerance) due to the lack of consequences for their actions. However, a pilot maneuvering equipment in a real-world scenario is likely to take fewer risks (lower tolerance) due to the potential consequences of their actions.

Another missing piece to the puzzle is a lack of accidents strictly due to AI systems. Looking at most of the incidents or accidents that occur, it can be claimed that the pilots were not familiar with precisely how the system worked. When an autopilot system is engaged, the pilots need to be well aware of all aspects of it, including tasks that the autopilot will not do.

Conclusion

There are many use cases for artificial intelligence in the aviation industry. An autopilot is an essential tool in flying; however, it has its fair share of limitations inferring from the literature review above. The goal of the synthetic teammate is to attempt to provide the pilot with additional useful information, such as the context for action instead of just the action, which depends on artificial intelligence. Shared haptic control is a promising approach to implementing the synthetic teammate, as it objectively meets the synthetic teammate implementational recommendations laid out by Doherty (2003). Artificial intelligence systems have proven their effectiveness. However, there is still a lot to be implemented for these programs to be relied upon entirely. Already, it is evident just how big an impact automation can play on the commercial and even up-and-coming drone operations.

Future Research

Some use cases for the haptic shared control exist in the automotive industry, such as the Lane Keep Assist technology found on some modern vehicles. However, this technology has not been implemented in the aviation industry on a scale that allows its efficacy to be researched. Additional research is therefore required in this area.

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