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Steve Thatcher

Lakhmi Jain

Colin Fyfe

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Steve Thatcher
Aviation Education, Research and Operations Laboratory,
School of Electrical and Information Engineering
University of South Australia,
Adelaide, Australia.

Lakhmi Jain
Knowledge-based Intelligent Engineering Systems Centre,
School of Electrical and Information Engineering
University of South Australia,
Adelaide, Australia.

Colin Fyfe
Applied Computational Intelligence Research Unit,
The University of Paisley,
Paisley, Scotland.

In this paper we discuss the problems associated with a small remnant of seemingly non eradicable accidents in contemporary aircraft landings and propose three autonomous agents whose task it is to jointly monitor the aircraft and its flight crew. Two of these agents will monitor the path of the aircraft, one armed with prior knowledge of how planes tend to land at a particular airport, the other with the ability to extrapolate forward from the plane's current position in order to identify potential dangers. The third agent will monitor the flight crew's behavior for potentially dangerous actions or inactions. These three agents will act together to improve safety in the specific process of landing the aircraft. This paper focuses on the development of the third agent.

Introduction

No one would disagree that air travel, especially in large airliners, has become extremely safe. This has been particularly apparent in the last few decades. The improvement in safety has largely been due to technological innovation in the design of on-board systems and the widespread development and implementation of flight crew training in team management and group effectiveness. Crew resource management (CRM) training has been used by airlines all aver the world in an effort to increase the safety of airline operations. Thatcher (1997, 2000) has suggested that CRM effectiveness could be increased if CRM techniques were introduced much earlier in a pilot's training, at the ab-initio level. This strategy is currently being implemented at the University of South Australia's Aviation Academy. However, given all these advances in aviation safety there remains a statistically constant, and somewhat stubborn, remnant of air crashes which are seemingly not eradicable. Of these accidents, worldwide, Helmreich and Foushee, (1993) have suggested that 70% are due to flight crew actions or in some case inactions. This is despite the fact that pilots are extremely technically competent and well trained in CRM. Pilots undergo regular line checks in both the human factors and technical areas of line operation. Within airlines flight crews are highly trained to operate in the modern cockpit environment. There is consensus that CRM has increased aviation safety. This raises the question as to why these accidents happen and, perhaps even more disturbingly, why they continue to happen, albeit at a very low level of incidence.

In this paper we discuss the problem of continuing accidents in contemporary aircraft approach-and-landings and propose three intelligent software agents whose task it is to jointly monitor the aircraft and its flight crew (Thatcher et al 2004a, 2004b).

The trio of intelligent agents within the proposed paradigm will be organized as follows: Two agents will be physically situated onboard the aircraft. The remaining agent will be physically situated at the destination aerodrome. The agent positioned at the airport will monitor the flight path of the aircraft as it commences its approach. This agent (the Anomaly Detection Agent) will have knowledge of typical aircraft approach profiles for that particular aerodrome.

The other two agents within the paradigm will be situated onboard the aircraft. One of these agents (the Prediction Agent) will have the ability to predict the airplane's future position using its current three dimensional position and vertical and horizontal velocity variables. The predicted future position of the aircraft will be used to identify potential terrain threats. The other agent (the Pattern Matching Agent) also situated onboard the aircraft will monitor the flight crew's behavior and determine if the flight crew are losing situation awareness on the landing approach. This research is in its early stages but the communication and interaction between these three agents is considered essential to the research and future research will concentrate on this area.

This paper will outline the proposed knowledge-based intelligent landing support paradigm with particular emphasis on the third agent, the Pattern Matching agent.

Controlled Flight into Terrain and Approach and Landing Accidents

A controlled flight into terrain accident or CFIT accident can be defined as an accident involving impact with the ground or water by an airworthy aircraft where the flight crew was unaware of the proximity of the ground or water. The majority of CFIT accidents occur on approach and landing and can also be classified as approach and landing accidents (ALA's). However, some CFIT accidents occur in the take off, climb and cruise segments of flight.

Why do such accidents happen and, perhaps more disturbingly, why do they continue to happen?

A Flight Safety Foundation (FSF) report concluded that from 1979 through 1991 CFIT and approach-and-landing accidents (ALAs) accounted for 80% of the fatalities in commercial transport-aircraft accidents (Flight Safety Foundation, 2001) The FSF Approach-and-landing Accident Reduction Task Force Report (Khatwa & Helmreich, 1999) concluded that the two primary causal factors for such accidents were "omission of action/inappropriate action" and "loss of positional awareness in the air".

It seems that most of the CFIT accidents are due to a momentary loss of concentration or awareness during which the flight crew did not consciously notice that a necessary event did not occur, or that an adverse event did occur. Subsequent events are perceived by the flight crew in terms of their current mental model, or awareness, of the situation. Thus it is acknowledged that an event can only be perceived within the framework of the existing paradigm. This is termed situated cognition (Lintern, 1995). Data will continue to be perceived and restructured in terms of the existing mental model until an event happens which forces an unsettling recognition that the pilot's mental model of the world (*weltanschauung*) is actually false. If this happens too late on in a critical process, the result can be an adverse event. This is termed loss of situation awareness.

Situation awareness is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (Endsley (1987; 1988)).

One solution to the problem is to increase the level of automation onboard the aircraft. However, automation has associated human factors problems and may lead to a decrease in situation awareness amongst the flight crew. In terms of situation awareness and automation on the flight deck Endsley and Strauch (1997) maintain that "despite their high reliability, accurate flight path control, and flexible display of critical aircraft related information, automated flight management systems can actually decrease" a flight crew's "awareness of parameters critical to flight path control through out-of-the-loop performance decrements, over-reliance on automation, and poor human monitoring capabilities." Further, pilots can in some respects configure the Flight Management System to present a view of the physical world which supports their interpretation of the world or their mental model of the current operating environment. Weiner (1988) describes reports of pilots creating flight paths to wrong locations which went undetected and resulted in collision with a mountain.

We will investigate the critical period associated with ALA's and CFIT accidents when the primary causal factors occur.

Existing Terrain Awareness Technologies

In 1974 the Federal Aviation Administration (FAA) mandated that all heavy airliners be fitted with a Ground Proximity Warning System (GPWS) or Terrain Awareness and Warning System (TAWS). The early GPWS used information from the aircraft's radar altimeter and air data computer to determine the aircraft's vertical distance from the terrain below. The system was somewhat limited because it only perceived in real time the vertical separation between the aircraft and the ground directly below. The Flight Safety Foundation (FSF) CFIT Task Force recommended that early model GPWS be replaced by Enhanced GPWS (EGPWS) or Terrain Awareness and Warning Systems (TAWS) which have a predictive terrain hazard warning function. (Khatwa & Helmreich ,1999).

In response to the report the FAA mandated in 2001 that all heavy transport aircraft be fitted with EGPWS and further, that all turbine aircraft with 10 or more passenger seats be fitted with EGPWS from 2003.

For example, the circumstances which lead to the loss of situation awareness by the flight crew of American Airlines (AA) Boeing 757 that struck a mountain while on descent for a landing at Cali, Colombia, on December 20, 1995 have been investigated (Endsley and Strauch, 1997). Even though the GPWS onboard the aircraft functioned correctly, somewhat surprisingly, it did not help the pilots avoid the collision with high terrain. The reason for this was the operational design parameters of the GPWS

Enhanced Ground Proximity Warning System

The EGPWS compares the aircraft's position and altitude derived from the Flight Management and Air Data computers with a 20MB terrain database. In the terrain database the majority of the Earth's surface is reduced to a grid of 9x9 km squares. Each square is given a height index. In the vicinity of airports the grid resolution is increased to squares of 400m x 400m. The height index and the aircraft's predicted 3 dimensional position 20 to 60 seconds into the future are compared to see if any conflict exists. If it does the EGPWS displays an alert or warning to the flight crew. Other than to initially alert the pilots of "TERRAIN" up to 40-60 s before impact or warn the pilots to "PULL UP" up to 20-30 s before impact it does not offer any other solution to the potential problem.

This research aims to extend the EGPWS by using three intelligent software agents which can plot a course around, or over, possible conflicting terrain and present a solution to the pilot on the cockpit display system or as input to the autopilot.

Intelligent Agents

Wooldridge (2002) describes an intelligent software agent as a program that performs a specific task on behalf of a user, independently or with little guidance. It performs tasks, tailored to a user's needs with/without humans or other agents telling it what to do. To accomplish these tasks, it should possess the characteristics such as learning, cooperation, reasoning and intelligence. By analogy, a software agent mimics the role of an intelligent, dedicated and competent personal assistant. In this application we propose developing three agents, one ground based and the other two aircraft based, which will aid pilots during the critical approach and landing phase. In effect the two onboard agents will act as another flight crew member.

The Anomaly Detection Agent

The anomaly detection agent will be situated on the ground in the air traffic controller centre. Each airport will have its own anomaly detection agent and each agent will be monitored by the local ATC.

A typical airport has many safe landings each day. These are recorded by the air traffic control authorities but not used for automatic sensing of dangerous landings: this is the task of the air traffic controller who has ultimate authority in advising the pilots of potential conflict with terrain or other aircraft. Similar to a human which operates within the cognitive, affective and behavioral domains a software agent can be said to have beliefs, desires and intentions (BDI model). We propose creating an agent using the BDI model (Thatcher et al, 2004a) whose:

- Beliefs are in two major areas: firstly it retains a knowledge of all previously successful landings at that airport. This database itself can be hand-crafted by the (human) air traffic controllers since there may have been some successful landings in the past which, despite being successful, followed a pattern of activity which the air traffic controllers deem to be not good practice. Secondly the agent will have beliefs centered on the current landing – the aircraft's height, horizontal distance from landing strip, speed, heading, lateral distance from landing strip, type of aircraft, weather conditions and any other factors which affect landing performance.
- Desires are that the aircraft lands safely.
- Intentions are to do nothing unless the plane is deemed to be deviating from the historical norm. If such a deviation is noted, the agent informs the air traffic controller who has responsibility for the plane and the pilot himself.

This agent will use anomaly detection as its basic method. Consideration was given to a neural network anomaly detector (e.g. Kohonen's anomaly detector (Kohonen, 1988)) but because it is critical that the warning be given clearly identifying why the warning has been raised, an expert system approach will be used for this application. Thus a series of "if … then … " rules will be created from the database of past successful landings and the current flight's data compared with the rules associated with this database.

The Prediction Agent

Two agents will be situated onboard the aircraft: the Prediction agent will be monitoring the aircraft's position, heading etc and the Pattern Matching Agent (next section) will monitor the pilot's behavior. The Prediction agent is essentially an improved version of the existing EGPWS software described above. The improvements are intended to give a more "intelligent" solution and earlier warning of potential problems than the existing software.

The Prediction Agent has Beliefs about;

- the aircraft's position, heading, speed, rate of descent etc.,
- the landing strip's position,
- weather conditions,
- surrounding ground topology, particularly where dangers are to be found,
- the pilot. This may be controversial to the Pilots' Unions but one must concede that different pilots will tackle tasks differently.

Similarly to the last agent, this agent desires that the plane be landed safely. It again has the intention of doing nothing unless the patterns it is monitoring match potentially dangerous conditions. It might be thought that the Prediction Agent is duplicating the work done by the last agent (Anomaly Detection Agent) but this agent will monitor the descent in a very different manner. The Anomaly Detection Agent will use a database of previous landings *to that particular airport* to ensure that the current landing is *bona fide* and within the parameters of a safe approach. The Prediction Agent will take its knowledge of current position, speed, etc. and knowledge of the local geography to extrapolate the plane's position 5 minutes ahead in order to predict dangerous conditions before they actually occur. This prediction will be derived using an artificial neural network trained with the standard radial basis function methods (Haykin, 1998). A full description of radial basis function networks is given in (Haykin, 1998). The Prediction Agent will be designed as follows: the terrain database derived from the onboard database or from topographical information of the area will be used to generate a grid comprising i=n squares. Each square i at any time t will be assigned variables such as temperature (T(i,t)), atmospheric pressure (P(i,t)), wind component (W(i,t)), terrain height (TH(i,t)), terrain gradient (ΔTH(i,t)), cloud height (CH(i,t)), visability (V(i,t)), and the current aircraft performance variables speed (v(i,t)), altitude (a(i,t)), track (tr(i,t)), and rate of climb (dA/dt(i,t)). A neural network will be trained with this test data until an optimal solution is reached based on the performance of the system using the output measures such as accuracy, sensitivity, false positive and false negative ratios.

If the prediction suggests danger, it is intended that the Prediction Agent will contact the Anomaly Detection Agent and the Pattern Matching Agent. The Anomaly Detection Agent can assert that the current landing pattern is within the recognized safe zone but if it deemed to be close to the edges of this zone, an alert will be issued to the pilot and the air traffic controller.

The alert to the Pattern Matching Agent will be discussed in the next section.

The Pattern Matching Agent

The Pattern Matching Agent will also be based on the BDI model and has beliefs about:

- The recent past behavior of the pilot
- Typical behaviors of the current pilot
- Behaviors which are typical of pilots losing situational awareness, performing an inappropriate action or not performing an appropriate action.

Again its desires are that the plane lands safely and its intentions are to do nothing unless it matches the pilot's current behavior with dangerous practice.

The Pattern Matching Agent will be equipped with a database of behaviors which are suggestive of, or a prelude to, the loss of situation awareness. In other words, this agent will fulfill the role of a dedicated professional who, sitting in the cockpit, would identify the pilot's actions (or inactions) as worthy of concern. This pattern matching is accomplished by a simple Associative Artificial Neural Network (Haykin, 1998) which matches approximately existing patterns of behavior to those in the database.

There is a body of research that indicates that pattern matching together with schema and mental models facilitates the development of situation awareness (Kaempf et al, 1993). Endsley and Bolstad (1994) found evidence that fighter pilots with higher levels of SA had better pattern matching skills. Kaempf et al (1996) discovered that pattern matching to situation prototypes accounted for 87% of decisions by tactical commanders.

This research aims to develop a database of typical pilot behaviors or actions during an approach. Further data will be included in the database to describe rate of descent, speed, flap setting, speed brake armed, altitude etc. Perhaps this database could be described as a mental model of a descent? It might be difficult to envisage a software agent having a mental model of a typical approach. But we should consider that a software agent (Pattern Matching

Agent) could have a database of typical pilot behaviors that could be compared with the actual behaviors. How big the database has to be, for the agent to be considered as processing a mental model is a question for future research. However, for this agent to function in the cockpit and communicate potential hazardous behaviors, be they actions or inactions, the agent must develop SA within its beliefs, desires and intentions model.

All three agents will have the ability to communicate with each other at all times. To this extent each agent will have beliefs about the other two. When the Pattern Matching Agent received a warning from either of the others, it would respond with a degree of confidence about the pilot's current situation awareness. We currently intend the Pattern Matching Agent as a reinforcement mechanism for the other two agents. At this stage in the research we do not envisage this agent overruling warnings communicated by the other two. Further, the combination of the three agents would achieve the three levels of SA (Endsley, 2000)) Level 1 – Perception, Level 2 - Comprehension and Level 3- Projection.

Conclusion

We have identified the specific process of approach-and-landing accidents as one which might successfully be augmented with intelligent agent technology. We thus have proposed three agents:

1. The first will be situated on the ground and will have a knowledge of typical landings at the current airport.
2. The second will be situated onboard the aircraft and will be attempting to use the aircraft's current position and heading and knowledge of the local geography to predict potential dangers.
3. The third will be also onboard the aircraft and will be monitoring the behavior of the flight crew for actions indicative of the loss of situation awareness.

This research is in its early stages but we consider the interaction between these three agents to be central to the research and future research will concentrate on communication between the three agents.

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