DESIGN CONSIDERATIONS FOR A BACKGROUND AUDITORY DISPLAY TO AID PILOT SITUATION AWARENESS

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ABSTRACT

Pilot Situational Awareness (SA), namely, the pilot's ability to accurately perceive, understand and predict events, is an essential requirement of effective decision-making [1]. Good 'visibility' of aircraft state and environment is instrumental in maintaining a high level of SA. 'Cockpit transparency' indicates the capability of the cockpit to provide such visibility. The project described in this paper investigates the ability to enhance cockpit transparency and reduce the tendency for 'peripheralisation' of the pilot through implementation of a background auditory environment. A computer-based tool using currently available software and off-the-shelf hardware is being developed to produce an initial demonstration of ideas.

1. INTRODUCTION

Situational Awareness (SA) is a term used to describe the pilots' ability to accurately perceive and understand, as well as predict future events within their operating environment [2]. Good aircraft 'visibility' [3], i.e. how attainable aircraft state information and the possible set of actions are to the pilot, is instrumental in maintaining SA. Feedback when a human interacts with any system is important [1]. The term 'glass cockpit' originated from the use of cathode ray tube (CRT) displays in the cockpit producing a 'glass' appearance. They denoted a departure from the old style analogue displays towards a new computerised cockpit with integrated multi-function displays. This term is now increasingly used to suggest a more 'transparent' cockpit implying increased aircraft visibility. However, 'cockpit transparency' and 'glass cockpit' indicate the reality that all too often metaphors develop into literal translations as illustrated by the heavy reliance upon visual displays to provide such visibility.

With the introduction of the 'glass cockpit' came a highly integrated and increasingly automated operational environment. This inevitably decreased aircraft visibility in some respects. Additionally, there are concerns that technological advancement may have cultivated a form of complacency in the cockpit scenario, reducing the cognitive and physical exploration thought also to aid the pilot in acquiring and maintaining SA [4]. The pilot may become peripheralised, i.e. pushed out of the control loop, potentially leading to a subsequent inability to step back 'into-the-loop' when required. Increasing pilot 'direct engagement' (term noted by William Gaver, personal communication as a concept applicable to any human-machine interface), providing an increased sense of task involvement, may in some way help to prevent complacency and 'peripheralisation'. This project investigates whether a background auditory environment controlled through the application of auditory displays can be used to increase aircraft 'visibility' and enhance pilot 'direct engagement'. If the displays can be instinctively associated with, and accepted as part of, the aircraft, success is more conceivable. It is appreciated that the auditory channel of the pilot is essentially used to display critical information and enable communications and therefore it is imperative that any additional usage does not interfere with these processes. Careful assessment and consideration of the entire auditory environment [5][6] of the pilot, coupled with knowledge of the capabilities of our physical and perceptual auditory systems, should enable designers to produce effective and non-disruptive displays. Implementation will require a method of complete control of the auditory environment, most promisingly through headphones. However, it is important that the above difficulties should not intimidate the designer and discourage more novel uses of the pilot's auditory channel. The aim is to ensure that future cockpit evolution moves closer toward the notion of complete perceptual transparency. This project is intended to investigate possible ideas and produce a tool that will facilitate designers in creating such auditory displays.

1.1. Auditory Warnings

Much research has been conducted into the use of different sensory modalities in the cockpit. A great deal of research has illustrated the benefits of auditory display within the cockpit of both civil and military aircraft. Auditory warnings in particular have enjoyed comprehensive investigation in many application areas. Researchers have illustrated the ability to design highly informational warnings conveying an appropriate level of urgency and tackling user confusion and compliance issues [7][8]. The implications of such research alongside the guidelines provided by Patterson [6] must be considered due to the critical nature of existing auditory stimuli within the cockpit (e.g. the implications of auditory masking).

1.2. Representational and Metaphorical Auditory Displays

The potential benefits of representational 'auditory icons', a term introduced by Gaver [9], within auditory displays have been widely investigated. Cockpit examples include the touch panel study of Begault, Stein and Loesche [10], using recordings of a real aircraft switch to indicate finger contact and engagement of virtual switches on a touch screen computer panel. Edworthy and Adams [7] also note the potential of representational auditory icons within cockpit auditory displays as well as the use of more abstract (but arguably metaphorical) sounds such as those used within the study of 'trendsons', trend monitoring sounds for helicopters [11][12][13]. A 'trendson' was developed for each of rotor overspeed, rotor underspeed, torque, positive g forces and negative g forces. The trendson developed for positive g forces used inharmonicity to convey meaning, an initial study indicating associations between inharmonicity and the adjectives 'full', 'heavy' and 'solid'. The above studies in their demonstration of synesthesia [14] illustrate the possibilities of implementing a perceptually transparent cockpit.

1.3. Spatial Auditory Displays

The ability to create virtual spatialised sound furnishes the designer with the ability to create truly immersive displays [5][15]. Extensive research into the generation and perception of virtual 3-D sound has spurred development within the cockpit application. Examples of systems using audio 3-D alerts include the Virtual Audio Guidance and Alert System for commercial aircraft [16] and the head-up auditory display for Traffic Collision Avoidance System advisories [17]. The T-NASA (Taxi Navigation and Situation Awareness) System developed by the Ames Research Center uses 3-D audio alerts to indicate traffic incursions [18]. The ability to spatialise threat warnings and indications of aircraft health has also been embraced [19][20]. Aitchison and Byrne [20] also indicate the potential for spatialised audio cues to aid navigational aspects of flight. The tendency of our auditory systems for stream segregation based on localisation [21] has been exploited within research aiming to improve speech communications within critical aerospace applications [5]. Possibly of most interest to the current project is the idea of an 'ambience' display of aircraft state [19].

1.4. Background Auditory Displays

The alerting nature of our auditory sense has obvious benefits within the cockpit, but Wenzel [15] also notes our sensitivity to acoustic change. Buxton [22] and Edworthy and Adams [7] indicate that we seem to have an ability to ignore (leave unattended) and yet still monitor background auditory channels. Significant deviations within these channels are thought to draw our attention [22]. The extent to which 'Echoic Memory', referring to the short-term sensory store of the auditory modality [23][24], is actually 'pre-attentive' [24] is unknown. Whether our attention is focused upon pertinent information due to the facilities of 'preattentive processes' [23], the acquired skill of the expert perceiver [25] or the mechanism of a filter [26] is also unclear. However, we do appear to have such ability, indicating perhaps that a low-level background auditory environment may provide informational benefits without unnecessarily diverting attention. Further, it is possible that we attend to a previously ignored channel not because the auditory information changes, but because the information deviates from our expectations or mental image of our environment. If this is the case, background auditory information may present a promising method of ensuring the pilots mental image of the aircraft and its environment does not deviate from the actual state of the aircraft and environment without being updated i.e. maintaining SA.

1.5. Implications of Multi-Modal Display of Information

The implications of multi-modal display of information (the auditory display envisaged here would present redundant information already provided visually to the pilot) are vast and require the attention of the designer to a host of cross-modal effects [21]. Modality dominance, especially when ambiguity arises in one or other modality, must be considered. Whether the interplay of multi-modal information will always enable faithful interpretation of the auditory stimulus is also an issue (for instance issues of stream segregation are important).

The auditory environment under consideration here is intended to enhance and reinforce but not compete with the visual cues already accessible to the pilot. It is inherently difficult to isolate auditory or visual perception from perception as a whole and it could be argued that the study of the isolated sense might never provide a true illustration of its capacity to aid the individual. Context, expectations, knowledge as well as sensory information all play vital roles in perception and all these cues are used to decipher our complex perceptual environment [21]. Perhaps we need to furnish the pilot with more such cues to ensure perception is efficient and veridical.

2. DEVELOPMENT OF A BACKGROUND AUDITORY ENVIRONMENT

2.1. Purpose as an Aid to Situation Awareness

The background auditory environment (display) investigated here is intended primarily to provide an impression of the state of the aircraft relative to the outside world as well as an indication of basic aircraft system state. The display is not intended as a warning display, or indeed as the display component of a warning system. Warning systems play essential and well-defined roles within the cockpit. This system, an aid to SA, may maximally be seen in terms of warning prevention. As O'Leary [4] indicates, if a warning is merited, pilot SA has already degraded. Perhaps it is a logical conclusion that a cockpit that successfully enhances pilot SA has a lesser requirement for the current proliferation of warnings. The goal is to design an auditory environment than can be instinctively associated with the pilot's flight environment so that it may be accepted as an integral part of that environment.

2.2. Design Theory

A spatialised auditory environment will be used to provide the pilot with an intuitive auditory image of his/ her aircraft and environment. The authors believe that it is necessary to investigate what may be classed as basic important 'entities' (aircraft and environmental) to the pilot and which of these may be classed as sound producers ('sources' in any virtual environment used to implement the display) and which are predominantly sound processors. The type of sounds used must also be investigated, whether it is possible to use 'representational' sounds and therefore the auditory characteristics of the entities themselves or whether it is necessary to simplify the entities to make relevant meanings (to the pilot) more apparent and their auditory characteristics more useful.

For instance, another aircraft could be imagined to be a sound producer in the pilot's actual environment and is therefore implemented as a representational sound source locatable within the 3-D virtual environment. The source enters the virtual environment and then leaves as the real aircraft approaches and then retreats within the real environment. This particular example is similar to the aircraft threat displays noted in section 1.3 above, but the concept can be applied and broadened to any justifiable 'sound producer'. A mountain or the ground however is not generally assumed a generator of sound; instead the mountain acts to process any sound waves within the environment. Assigning sources to represent objects in the real world that are not associated with sound creation may create an unnecessarily cluttered virtual environment. A virtual mountain may be created within our virtual environment to process our virtual sound sources. Perhaps we need only indicate a wall or barrier in our virtual world as it could be argued that to a pilot, the 'affordances' [27] of a mountain and a barrier are the same. This may be classed as a simplification whereby a real 'entity' is simplified into an object whose natural affordances (to any individual) form a pertinent subset (ideally) of those of the original. A 3-D virtual rendering engine may be used to calculate and implement the processing effected on the source signal(s) when reflected off such a virtual mountain, as heard from the position of the 'listener' in the environment (the pilot). This implicates the requirement of a physically based reflection modelling system. Through listening to such effects, the pilot may be able to gain environmental information. However, it may be necessary to scale down the virtual environment to make the information more attainable. This too is a simplification, objects within an environment assume meaning to the individual, in part, by virtue of their position. A human scaled acoustic environment may indicate such meanings more instinctively to a person than the aircraft scaled (real) environment.

Effectively sound sources (informational in themselves) are being used in a modified sense to auralise in the virtual world what is relevant to the pilot in the real world. This implicates the necessity of at least one ever-present source in order to 'light up' the environment. A source related to the aircraft (arguably a justifiable sound source) may be able to fulfil this criterion whilst providing valuable information relating to the aircraft itself. This could be seen as some form of sonar system or an application of human echolocation [28], but within this scenario, there may be several signal emitters not all necessarily originating from the navigating vessel. Additionally this system is not intended for precise navigation, it is simply a display (fed by the accurate data provided by the aircraft's existing systems) to give an impression of the pilot's world. Each source that is used has the potential to provide redundant cues to the real environment through the nature of processing that the virtual environment exercises on the source signal. The extent to which the pilot can gain information at all from effective auralisation within this context remains to be seen but almost undoubtedly already lies within a combination of research areas, including echolocation, auditory ability of the blind and the field of auralisation itself. Again it is possible that through actual simulation of the flight task and the display, therefore setting the context and situation in which the pilot's perceptual system will act, the ability of the individual to gain information from such auditory information may be enhanced. A flexible research tool is required to assess whether we can feasibly provide auditory images through reflection modelling or whether design that is more abstract is needed.

3. DEVELOPMENT OF A RESEARCH TOOL

A 3-D audio rendering system was required with the facility for real-time source manipulation and some form of geometry based environment reflection modelling, interfaced to a flight simulator. The task set was to demonstrate some of the above ideas with tools accessible to any researcher, a PC, Windows operating system and inexpensive off-the-shelf hardware. A Visual C++ development environment was decided upon. Although the above precludes accurate reflection modelling various C/C++ application programming interfaces are available which boast the ability to spatialise sources with varying degrees of environmental modelling. The Application Programming Interfaces (APIs) intended for research domains (AM3D [29], SLAB [30], AuSIM [31]) at the time of writing have yet to incorporate reflection modelling of more complex geometry. However, this seems to be the future direction of many of these systems, which inevitably will provide future PC users with access to accurate and versatile rendering systems. APIs intended more for the gaming industry (e.g. Creative EAX [32]) appear to be based upon general perceptually based models of the environment.

3.1. Aureal™ Sound Engine

The Aureal A3D™ 3.0 (Aureal Inc.) Software Development Kit [33] provides an API to the Aureal™ sound engine implementing early reflection modelling and 'geometric reverb' using Head Related Transfer Functions (HRTFs). This model uses programmer specified geometry and therefore at present provides the most justifiable solution, necessitating however a sound card with the Vortex™ 2 chipset. The Visual C++ application currently under development will receive control data (position, orientation and environment data) from a flight simulator, which will subsequently be passed to the Aureal™ sound engine. Sound source manipulation will be implemented via threads triggered by notifications from the Aureal sound source buffers. These threads will manipulate the base acoustic data of the sound sources according to data received from the flight simulator, streaming the resulting data into the buffers. When requested to render the current frame, the Aureal™ engine performs the necessary calculations controlling processing of the audio data via the sound card. Headphones are used to feed the acoustic scene to the user.

4. CONCLUSION

Auditory displays within cockpits and flight decks have evolved to embrace new methods of displaying data through sound. The development of spatialised auditory virtual environments has enabled designers to supply the pilot with direct spatially related information. Many researchers have already exploited this. The provision of an entire low-level spatial sound environment is also within our technological capabilities and arguably has the potential to enhance pilot situation awareness and reduce peripheralisation. Flexible research tools are required to investigate the possibilities of background auditory environments within cockpits and flight decks.

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