3D sound and hearing protection for helicopter missions

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Summary

PERTIA is a French-Australian research program to study and to evaluate helicopter crew perception of virtual 3D sound in operational environments.

A prototype audio system able to present synthetically spatialised sounds to pilots, in very noisy environments and providing hearing protections based on “Communication Ear Plugs”(CEP) has been developed.

Experiments have been conducted in order to better understand the impact of each factor on 3D sound operational performances, and to propose efficient ways to integrate 3D sound in military helicopter.

User’s synthetic sound spatialisation is generated through a “Head Related Transfert Function”. Pertia aims to define a simple way to calculate HRTF personal parameters.

A helmet with wireless CEP have been realised to improved audio protection.

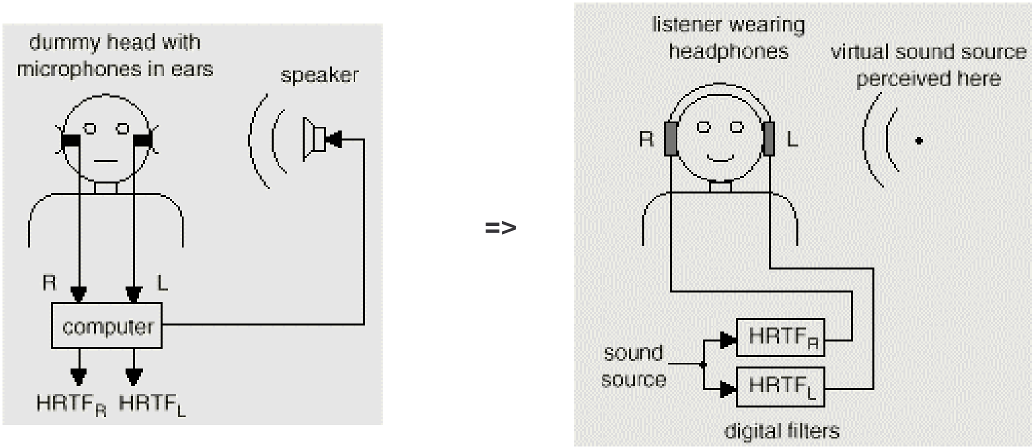
Experiments focussed on aural communications spatialisation advantages for hearing comprehension.
Technical and operational scenarios have been defined to evaluate if and how 3D sound can reduce crew workload.
Evaluations by operational pilots on a ground simulator and in flight are to come.

Introduction

<u>3D sound interest</u>
Human Machines Interfaces (HMI) for aircraft cockpits relies mainly on pilot vision. Human vision is a fast, precise and efficient way to get information so, year after year; cockpit’s designers have increased the density of data visually usable. Classically, pilot needs to shift his line of sight inside cockpit to scan instrument information on so called Head Down Display (HDD). Some more recent displays have been used to provide a few critical data visually superimposed on the outside view. Theses are called Head UP Display (HUD). They permit to keep good situation awareness as long as the displayed symbology is light enough to maintain view of the outside scene. Nevertheless, the number of information to be presented to the pilot has been increasing with the complexity of avionics system and other means of exchanging data with crew had to be found. One of them is “audio display”.
Until recently, sound usage in cockpit has been limited to a monaural form, mainly for audio radio communications and warning messages.
The addition of 3D audio has been proposed as a supplementary method to reduce crew workload by helping the understanding of messages and increasing efficiency of visual detection with complementary information.

<u>Virtual 3D sound</u>
The human brain does the identification of incoming direction of a sound by interpreting the unbalanced spectral sound received by the two ears. As these variations are linked to subject’s morphology (pinnas, head and bust), a given sound will be sensed differently by each person.

For a given person, it is possible to determine, alterations of sound received by ears in function of its spatial origin. These information's can be modelled in a mathematical function called HRTF (Head Related Transfer Function).



Applying HRTF to a sound before sending it to the subject ears makes him feel the spatial direction of the source of the sound.
Synthetic 3D sound generation is based on detection of the user's head orientation and real time computing of signal to be delivered to each ear, taking into account correct relative spacialisation through personal HRTF. This is also known as “Binaural Synthesis”.

PERTIA study

Background

Previous studies have revealed that 3D sound, under operational workload, was not intuitively used by some pilots, and thus did not lead to many operational improvements. The potential causes are multiple, and can be combined. They include:

- Technology factors (signals latency, modelling of HRTF…)
- Training issues: pilots training do not always increase their performances with 3D sound
- Human psychophysiology: some humans are more sensitive than others to 3D sound; furthermore, in critical situations, the human brain has a limited cognitive bandwidth and must thus prioritise the information; therefore the lack of reliability experienced by the pilots with 3D sound pushed them to a low use of 3D sound.

On the other hand, constraints on hearing protection equipment are more and more critical. The levels of sound atmosphere in aircraft cockpit are very important and the compliance to hearing protection regulation is becoming a key factor in pilot acceptance of their head equipment while the weight allowed for the protection means is decreasing. Therefore, a compromise between these different requirements need to be found.

"Communication Ear Plugs”(CEP) include an ear plug and an audio transducer. This combination provides significant advantages in term of weight, volume and noise reduction. Furthermore, Wireless CEP (wCEP) facilitates the installation of the equipment for the pilot.

Major Objectives

The major objectives of PERTIA project can be summarized as follows:

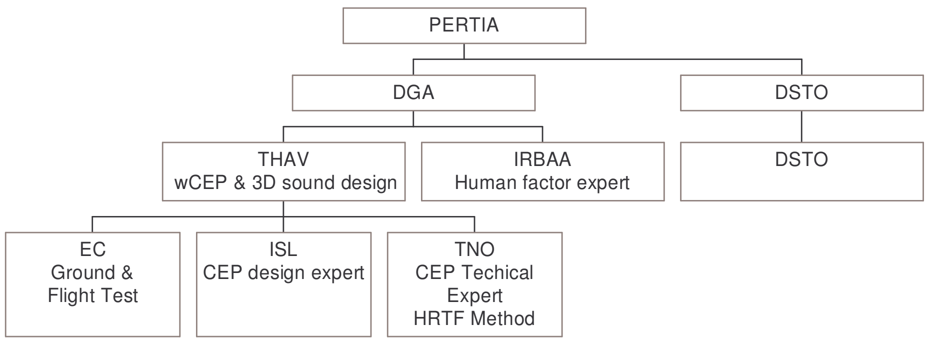
- analyse of pertinent information to be spatialised in military operational mission;

- Study and development of an audio system able to present 3D sound to pilots, in very noisy environments such as military helicopter operations;
- Study of human perception of virtual 3D sound in operational environments;
- Evaluation in flight of the performances of 3D sound in the helicopter environment;
- Study and development of a robust solution for hearing protection, based on Communication Ear Plugs, able to efficiently operate in noisy environments encountered in military helicopters.

Study Organisation

PERTIA (**PER**formance audio et **T**ransducteurs **I**ntra **A**uriculaires) is a research collaboration between France and Australia led during years 2006 to 2010, in which different partners gathered in order to study, and evaluate in simulations and in flight, advanced audio technologies for the pilot head equipment (Helmet Mounted Display).

PERTIA Organisation



DGA :Délégation Générale pour l'Armement (French DOD):
DSTO : Defence Science and Technology Organisation (Australian DOD)
THAV: THALES Avionics (France)
IRBA: Institut de Recherche Biomédicale des Armées (France)
EC : Eurocopter (France)
ISL : Institut Saint Louis (France/Germany)
TNO : Netherland Organisation for Applied Scientific Research TNO (Netherland)

Works done or on going

Development of wCEP prototype

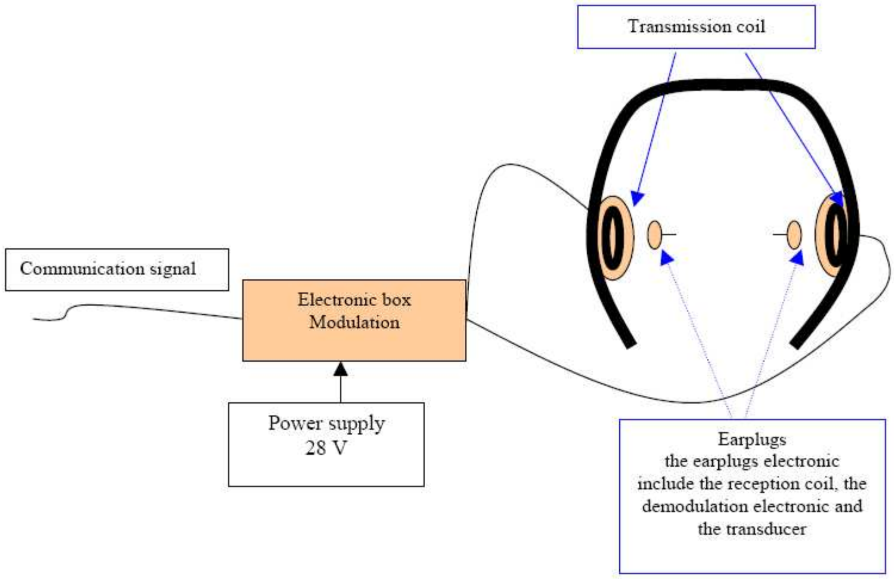
PERTIA main targets are:

- Ability to display 3D sound ;
- Analysis of operational acceptability and usability;
- Improved hearing protection. The noise encountered in military helicopters can be very high (up to 120 dB) while, maximum acceptable noise is 85 dBa.

In PERTIA, we initially chose a wireless communication earplugs (wCEP) solution, based on magnetic induction.

The wCEP is made of three main components:

- An electronic box in charge of the modulation of the communication signal and its transmission to the transmission coils that are located on the helmet
- Two transmission coils on the helmet and closes to the earplugs to transmit the communication signal to the earplug. The transmission is done through a magnetic link. It uses the induction effect.
- Earplugs, integrating the reception coils, the demodulation stage and the transducers that bring the communication signal to the human ears.



Due to limited audio performance of wireless CEP components, a backup wired CEP solution was developed.
After experimenting both solutions with PERTIA ground bench and in a noisy rotorcraft environment, we decided to conduct in flight experiments with wired CEP in order to secure PERTIA 3D sound evaluation.

Development of an HRTF selection procedure

The major drawback of binaural synthesis is that the HRTF, which are related to the listener's morphology, are strongly individual.
To provide users of 3D-audio systems with an optimal listening experience, it is generally necessary to measure the user's individual HRTF. Such a measurement requires specialized facilities such as an anechoic room and equipment to generate sounds from hundreds of locations around the user's head. The HRTF measurement process is a costly and time-consuming affair.
PERTIA project aims to develop a method to quickly (in around 20 to 25 minutes) determine an acceptable HRTF for new users.

We assessed the current state of individualization techniques (ray tracing, wave equations and finite element methods, anthropometry and morphing) and found them promising but not sufficiently mature for implementation during the lifetime of the PERTIA project.

Our current approach is quite different. We use a large database of HRTFs (currently containing data of 79 individuals) and assume that for most users an HRTF can be found in this database, that sufficiently approximates the characteristics of the users' own HRTF and permit to obtain the same or perhaps better performances. The question we addressed is how to find this HRTF using a selection procedure that only takes the above-mentioned short amount of time.
Because localizing a small range of localized sounds spatialised with a given HRTF may take at least 1-2 minutes, it is not feasible to have a new user listen to sounds processed with the entire database. This would take two to three hours, far exceeding the allocated time.
Our line of attack was to use clustering techniques, in which we find out which HRTFs are close to each other. Using this information it should be possible to close in an appropriate HRTF in a small number of steps without having to try all the HRTFs.
To determine the appropriateness of any given HRTF from the database, we defined a small listening test, in which a set of 16 dynamic and static localized sounds are categorized by the user. Our goal was to find a selection procedure that would need at most 15 of these tests, each lasting less than 1.5 minutes, so that the total amount of time would fall within the prescribed range

3D Sound symbology characteristics and analysis

Previous research indicated that the sound spectrum must be broad and relatively flat for the it to be accurately localised, especially for the elevation and front-versus-back hemi field localisation.

The work we did showed that the accuracy with which sounds could be localised decreases with the increase in both the width of the frequency bands and the amplitude of the sound level variation

PERTIA examined the spectral integration time of the auditory localisation system.
In particular it was found that:

- the sound duration had no impact on lateral error
- the elevation error and the front-back confusion was minimum from a 5 ms duration
- Therefore, for better localisation accuracy, in addition for the sound to be broadband:
- the amplitude of sound-level variations should remain reasonable
- the width of the frequency bands shall remain slight

In addition, for a better localisation accuracy in all the directions (especially improvement in elevation localisation and front-back confusion), the spectral integration time shall be about 5 ms

Moreover our study demonstrates than 3D sounds provide better detection and identification when several simultaneous sounds are played. Spatialisation of signals improves the perception of channels separation. A maximum of four sounds could be played together

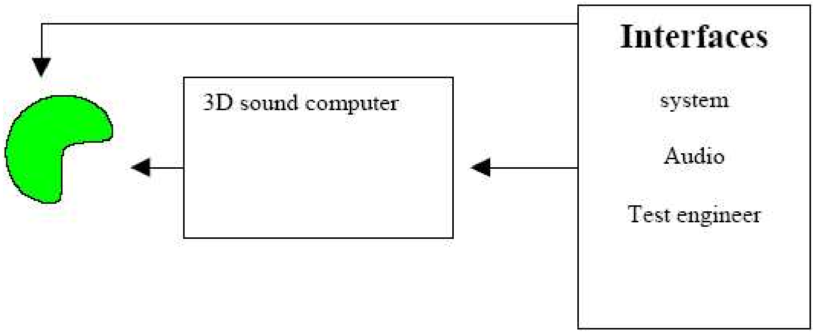
After having defined which of the Tiger helicopter sound alarms appear to be interesting for spatialisation, independently of the alarms emergency priority, we produced a set of Tiger 3D alarms, which followed the above-recommended rules.

Development of PERTIA prototype for flight test

The purpose was to develop a prototype system able to provide adequate hearing protection and to display 3D sound in a very noisy environment like military helicopters. The technological development was focused on two technological bricks:

- The head equipment. The target was to develop a prototype based on the TopOwl® Helmet Mounted Display, which will provide enhanced audio protection and enhanced communication performances (spatialised sound).
- The spatialisation computer, which provide the generation of virtual 3D sound, the implementation of the specific algorithms and manages the interface between 3D sound function and the helicopter intercom system. The management of interfaces and events required to play the scenarios to pilots during experiments are also integrated in this computer.

This computer along with man / machine interface tools have been gathered in the onboard bench



Ground and flight tests experiment

Experiments focussed on aural communications spatialisation advantages for hearing comprehension

Sound can be spatialised according to 3 specific reference systems:

- Earth reference system (sound origin appears to be a fix point with respect to earth whatever the pilot head or aircraft movements)
- Aircraft reference system (sound appears to come from a fix point in the cockpit)
- Pilot head reference system (sound origin appears to be following pilot's head movements)

Some events are naturally linked to the outside world (missile detection for example), others could more easily be assessed by the pilot if they are linked to a different reference system. PERTIA will evaluate which reference system to use in which case.

Ground and flight tests are organised in two different parts:

- Technical evaluation which deem to verify the capability of the tested system to provide acceptable 3D sound to the pilot;
- Operational tests to determine the operational gains brought by 3D sound in a work load situation representative of a typical military helicopter mission.

To analyze the interest of localized sound in military helicopter environments, we chose to evaluate selected critical situations (Critical Events or CE) best representing potential use of 3D Sound. From pilot interview we defined helicopter tasks potentially spatialisable.
Then, the most promising were selected with experts and pilots from French and Australian armies.
Operational test scenarios are composed of sequences of realistic flight phases where potential CE can happen during the pilot current tasks.

During 2010, experiments will be conducted with helicopters pilots from French and Australian armies, French flight test centre and the helicopter company.
During ground tests, pilots will have to participate to the selection of their HRTF, to learn 3D icons and to get familiarized with 3D usage and what kind of responses are to be given to specific CE.
For that, a ground system have been derived from PERTIA prototype for flight test, coupled with a lab NH90 avionics simulator and an outside visual display.

Finally, flight tests will be conducted to validate the results of ground test in a real helicopter flight environment.

Conclusions

While waiting for the conclusions of the analysis of ground and in flight tests we can already draw the following lessons from the realized works.

Comparative tests demonstrated that the defined HRTF selection procedure is accurate enough to be used efficiently with 3D sound systems.

Presently, available wCEP technology does not seem to cope with technical and morphologic constraints required for playing secured 3D sound.

During pilot interviews and task analysis, pilots were very clear on workload and efficiency aspects of 3D Sound in the Human Machine Interface:

- 3DS should not be a distracting superfluous noise
- 3DS should be in a form compatible with high workload
- 3DS should be easily understandable and intuitive

Although it remains an additional means and not a primary way of delivering data to the crew, the spatialised sound seems a promising mean to facilitate acquisition and understanding of information by the crew.

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