Advanced Speech Watermarking for Secure Aircraft Identification

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Abstract

AIT, a system for putting a small "Aircraft Identification Tag" onto the voice communication between pilots and controller was presented in [4]. The system is based on spread-spectrum watermarking techniques and consists of an encoder, an autonomous data acquisition module and a decoder. In this PhD study the future research aims for major improvements in data capacity, inaudibility, reliability, security and speech quality of the system. This involves multidisciplinary research in communication engineering, audio signal processing, psychoacoustics and adjacent fields.

Introduction

The air-ground voice communication between the air traffic controller and all aircrafts in a specific flight sector is done over an analogue VHF radio channel. For identification, pilots have to start every message with their call sign. There is a potential risk that the controller registers no or incorrect call-sign information. A previous joint study [1, 2, 3] demonstrated the feasibility of speech watermarking for the embedding of a digital aircraft identification tag into the voice communication between pilot and controller. This system allows transmitting a short digital message over the analogue radio communication link by adding an almost inaudible broadband signal to the voice signal.

AIT – Aircraft identification tag

Figure 1 shows the general outline of the proposed AIT core system. Only the grey parts represent AIT modules, whereas all other parts are already existing aircraft equipment. Therefore especially the transceivers in the aircrafts remain unchanged, which is an important issue in terms of system costs and certification.

Triggered by the PTT switch, the encoder embeds with a robust watermarking technique the data provided by the data acquisition module into the analogue speech signal. This is transmitted via the conventional VHF transmitter to ground systems and surrounding aircrafts.

These can receive and listen to the message without any special equipment. If they are equipped with the watermark decoder, they can extract and display the data which is embedded into the signal. Integrated into the air traffic control system, the airplane which is currently transmitting could for example then be automatically highlighted on the controller's display.

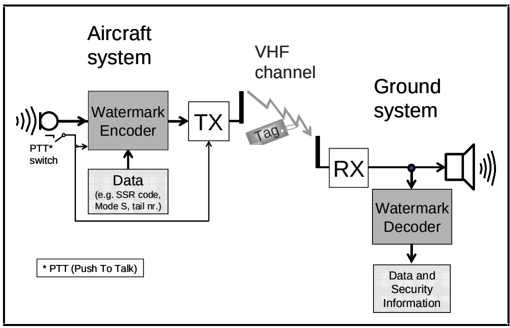

Figure 1. Voice communication link with embedded data.

Encoder

The watermark encoder is working in the digital domain and currently bases on direct-sequence spread spectrum technology and frequency masking.

The first step in the encoder adds redundancy to the digital data by an error control coding scheme. This highly increases the reliability of the system and is necessary because of the distortions occurring in the VHF transmission.

In the next step, this coded data is spread over the available frequency bandwidth by a well-defined pseudo-noise sequence. This watermarked signal is then spectrally shaped with a LPC filter and embedded into the digitized speech signal, exploiting the frequency masking property of the human perception. As a last step, the digital signal is converted back to analogue domain.

Decoder

After transmission and conversion to digital domain again, the decoder applies a whitening filter on the incoming signal to compensate for the spectral shaping in the encoder. After the decoder's synchronization to the data stream, the signal is de-spread and the watermark data extracted. With the redundancy included in the encoding stage, the decoder can correct errors which occurred during the radio transmission.

Data Module

The purpose of the data extension module is to provide the payload data (e.g. SSR code) and PTT switch status to the AIT system. For simplified cockpit integration and certification, the data should be acquired autonomously without connection to the aircraft's internal data busses and without any user interaction required.

Current research evaluates the feasibility of integrating two simple radio receivers into the data module. One of them detects active VHF transmissions, which implies that the PTT switch is currently pressed. The second receiver continuously monitors the SSR identifier which is broadcasted by the aircraft's transponder.

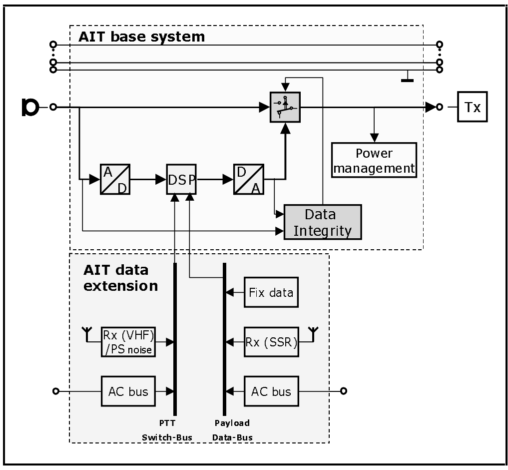

Figure 2. AIT aircraft system architecture.

Therefore it seems possible to integrate the AIT system into the connector of the pilot's headset, without any further modification to the aircraft equipment. Figure 2 shows some possible configurations for the aircraft system.

Target objectives and future research topics

The present research aims at substantial improvements of the speech watermarking system regarding its design and its range of applications.

Whereas the author's research focuses on the following issues on an algorithmic level, the development on system level, implementation and cockpit integration are carried out in cooperation with external partners.

Capacity

We have strong believe, that the payload data rate of the system can be increased to 100bit/s. In this case for example the position of the aircraft can be transmitted as well. To achieve this, we will conduct in-depth research in state-of-the-art watermarking and data hiding algorithms and adapt them to the specific needs of the AIT application.

Inaudibility

To achieve the desired data rate, a certain amount of noise in the signal will be unavoidable. We want to minimize the nuisance by exploiting psychoacoustic principles of human hearing. Therefore we will examine the speech impairments which are due to signals above the auditory masking thresholds.

Reliability

A key parameter of the system is the achieved Bit Error Rate. We want to keep the error-rate for incorrectly reported data smaller than 10^{-4}. For this purpose, a detailed knowledge about the air-ground communication channel is necessary. We therefore intend to study and simulate the influence of the channel and to consolidate the results with measurements under realistic conditions.

Security

The present system enhances already air traffic safety by helping to establish the correct aircraft identification in the difficult working environments of air traffic controllers. To avoid misuse of the voice communication system, e.g. by impostors who fake the aircraft identification tag, security measures such as public key systems or synchronized chaotic modulation and demodulation will be investigated.

Speech quality

After transmission of the watermark we can combine knowledge of the decoded message (=channel input) with knowledge of the received waveform (=channel output) for adaptive channel estimation. If the channel distortions are identified from this procedure, they can also be removed from the analogue voice signal which is transmitted over the same channel. This should result in quality enhancements for the speech output. For this purpose, algorithms for joint and iterative decoding and equalization for time-varying systems will be studied.

Conclusion

The AIT system not only makes the radio communication tamper-proof and improves the controller’s working conditions, but, with the aircraft position included, it offers a whole range of new applications. As no radar or other position detection systems are currently in use for oceanic aviation, the minimum separation distance between aircrafts is set to up to 100 nautical miles (185.2 km). With recurrent aircraft position reports via the HF voice communication channel, AIT would for example provide a means of surveillance for the oceanic airspace and might therefore allow the reduction of separation minima.

References

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