Acoustic vector sensors for passive 3D trajectory monitoring of rotary wing aircraft

Outcome of IGOR EFFP

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In general, avionics is a source of noise pollution. It is possible to predict the noise pollution if the sound radiation of the individual aircraft is known. In general the noise radiation of aircraft is strongly directional. Prediction tools only can predict the noise pollution if these directional noise emissions are known. Once the noise pollution predictions are reliable one is able to predict what flight path is optimal with respect to noise pollution.

There are two ways to determine the directivity of an aircraft. One can simulate the noise radiation and verify simulations with measurements. Secondly, it is possible to directly measure the complete directional noise emission of an aircraft. In this paper the last option is presented.

Usually, acoustic measurements that involve aircraft are very expensive, since airtime in a conditioned environment is very expensive. The method presented here does not rely on test flight in a conditioned environment. It can be applied anywhere desired, which saves a lot of effort.

The measurement system in this paper is able to acoustically detect, classify and locate aircraft. Once the 3D location and heading of an aircraft is known, it is possible to calculate its sound radiation in a certain direction. Because the aircraft is moving, the sound radiation is obtained at various angles. If the same or similar aircraft are passing the measurement system at different flight paths it is possible to compare the directional sound radiation.

The core of the system is an acoustic vector sensor (AVS), which measures pressure and acoustic velocity [1]. Such sensors can be used to detect, classify and locate various noise sources. In early years, the AVS was used in automotive industry for locating interior noise problems. In that area, the sensors are mainly used in laboratory conditions. In order to make it possible to measure rotary wing aircraft, the AVS is developed further. They are ruggedized, windscreens are developed and the system is made to be battery powered and remotely operated. The AVS systems showed to be reliable for weeks of outdoor use.

Apart from improving the hardware, algorithms are developed that enable to detect and classify rotary wing aircraft. With the classified signals, aircraft can be localized, meaning that the projected position on the ground, the height and the heading of the aircraft can be calculated. The system is shown to be operational outdoors, detecting and locating rotary wing aircrafts.

1. INTRODUCTION

This paper describes the status of the development of a system that is able to measure the directional radiation of an aircraft. This aircraft can be a propeller driven aircraft or a rotary wing aircraft. The system requires a harmonic acoustic signature to detect and classify the aircraft.

In aviation, acoustic measurements are expensive, since it is very difficult to create 'laboratory conditions' with if the subject of measurement is a flying aircraft. The aim of this project is to create a system that has low operational cost. In other words the system must be usable in a normal setting for aircraft; an airport is therefore the best suitable location for the system. The measurements take place without the need to interfere with the airport's usual business in any way.

With this requirement, a system is developed that is used outside the airport in line with the runway. The acoustic systems (called unattended ground sensors or UGS) are small, battery powered and can be remotely controlled. The systems can run more than a week on one battery. The acoustic systems are capable of recording acoustic data for 12 hours continuously.

Apart from the acoustic systems (UGS) an electro-optical camera pan tilt zoom is installed. The camera is aimed at the runway.

During a measurement campaign, the systems are positioned in the field for a week. The locations of the UGS are measured in with GPS and next to this, the spacing of the systems is measured.

The system only records the data of the event (including timestamp) when an aircraft is detected. In this way the recorded data is reduced substantially. The system also triggers the electro-optical camera. After a week of measuring, the acoustic systems (UGS) are collected and data is copied to a PC.

The data from these recordings are time signals (that can be extracted for listening). This data is converted a time frequency direction of arrival visualization, see Figure 4. This visualization shows how acoustic signals in the frequency domain that vary in time and direction. This representation is very useful to asses if measurements can be used for further analysis.

From the timestamps of the data that is used for further analysis, matching video recordings are used to visually verify the aircraft type.

If the type of aircraft is known, the acoustic data is processed further in order to get a 3D localization of the aircraft as function of time. This is done by using data of the three UGS.

Once the 3D trajectory of the aircraft is known, the distance and direction to each of the UGS is known as function of time. The AVS also provides the pressure signal. This way it is possible to determine the sound pressure level (SPL) as function of time is known at each of the positions of the UGS.

If now the aircraft is seen as a point source, its radiated power can be calculated (from the SPL at the ground and the distance to the aircraft). The radiated sound power (accounted for distance) as function of angle is determined for three positions. This measurements give direct information of the directional radiation of the aircraft.

2. UNATTENDED GROUND SENSOR

An unattended ground sensor (UGS) is approximately 30cm in diameter, 15cm in height, 2kg in weight and consumes 2W power.

Each UGS has an acoustic vector sensor (AVS) and a processing unit (DSP) that is capable of detecting, classifying and localizing various sound sources. The UGS readings are stored with a maximum of 12 hours of continuous data.

A UGS is shown in Figure 1. The UGS is placed on a triangle which is oriented. An antenna is shown next to the UGS. This makes it possible to communicate with the UGS wirelessly to a computer to e.g. switch it on/off or to be able to monitor its status. It is not possible to download the acoustic recordings wirelessly.

The UGS is powered with a normal car battery and can be operational for over a week. Up to now the system is used in snow, rain and heat up to 35 °C in full sun.

Figure 1: An unattended ground sensor (UGS) with an antenna.

3. CLASSIFICATION

One of the main elements of the measurement procedure is the ability to classify. The signals are only recorded after classification and the electro optical camera is triggered by the acoustic classification of the aircraft.

Classification takes place inside the UGS. The acoustic signals are recorded by the acoustic vector sensor and converted to the digital domain. The digital signal processor (DSP) in the UGS converts the time signals in to the frequency domain.

First, distinct frequencies are considered and once harmonic sounds are found they are marked with a circle, see Figure 2. A harmonic sound shows as a horizontal line in the time frequency plot (Figure 2).

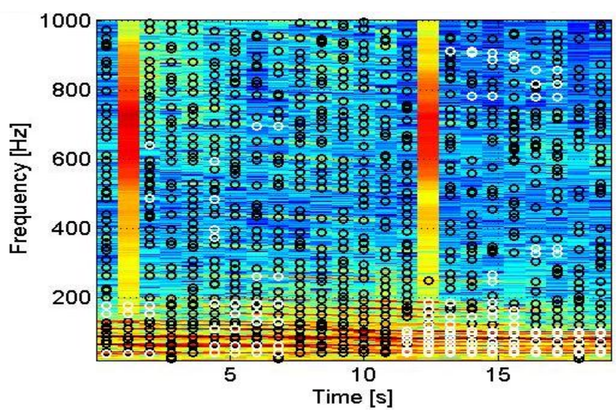

Figure 2: Time-frequency plot of a helicopter passing. Harmonic signals are marked with a circle.

If the number of lines matches the multiples of a ground frequency it is called a ‘harmonic line’. Once the number of harmonic lines exceeds a certain threshold, it is classified as an aircraft, see Figure 3.

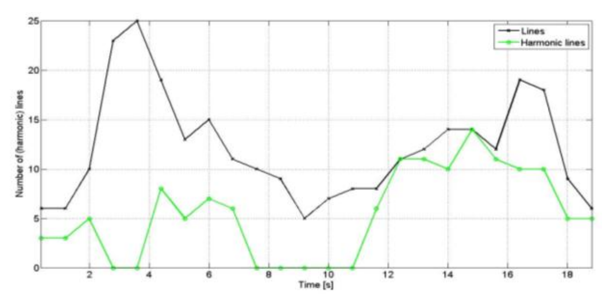

Figure 3: Lines and harmonic lines found in Figure 2 .

4. TIME FREQUENCY DOA

The first step in analyzing the recorded data is to consider the time frequency direction of arrival (DOA) visualization of the data. An example of such data is shown in Figure 4. The DOA is the direction from where the sound comes from, it is represented by a color. In Figure 4 right it shows that purple is N-NE and yellow is W-NW [2]. The left side of Figure 4 shows a helicopter passing and the yellow color indicates that it arrives in the W-NW direction and leaves in the N-NE direction. In this passing signal, purple lines are found during the full 40 seconds. This is caused by another aircraft that was starting up. The measurement is therefore not directly usable. It is possible to filter out the other aircraft.

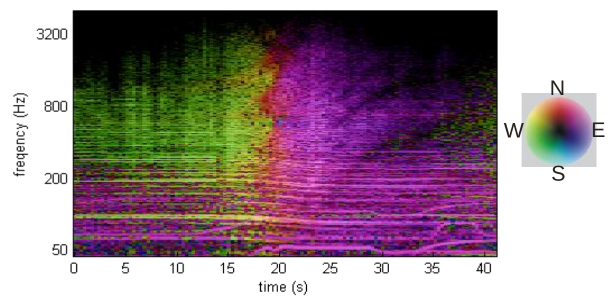

Figure 4: Time-frequency DOA plot of a helicopter passing.

Once the proper acoustic signals are selected the aircraft is classified. This can be done based on the acoustic signals or with electro optical sensing (see the following paragraph).

Once the aircraft is classified as interesting, it is localized, see 6: localization.

5. ELECTRO-OPTICAL SENSING

An electro-optical camera is set up that is triggered by the acoustic sensors. Each time the camera is triggered it makes a recording. From the video image the aircraft is extracted and a still image is captured and time stamped.

This is not absolutely necessary, but a desired procedure. If this procedure is not used, each detection needs to be viewed which takes approximately a minute. The electro-optical camera solution is only used as extra support and is in an earlier stage of development as the acoustic sensor system.

6. LOCALIZATION

The UGS are able to measure the DOA of the aircraft. The accuracy is tested by comparing the DOA of the UGS by a DOA determination with a beam forming array [1], [4].

Such array consists of multiple spaced sound pressure microphones that are positioned on the ground. Such array is large and dedicated for a small frequency bandwidth but it is used to verify the vector sensor data because it is a traditional proven technology.

It shows that the azimuth angle (that is DOA over ground) is accurate (usually up to 2 DEG) for all angles and the elevation angle is accurate (up to 5 DEG) for elevation angles larger than 20 DEG.

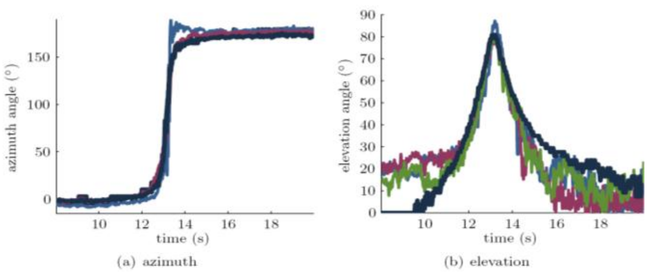

Figure 5: The azimuth and elevation angle measured by an UGS (blue, purple, green lines). And measured with a beam forming array (black line).

Out of the azimuth and elevation angles of the three fielded UGS the location of the aircraft is tracked in 3D. With a good placement of the sensors it should be possible to get directional behavior measurements.

7. DIRECTIVITY

The directivity is determined by assuming that the aircraft radiates acoustic power that behaves in such way that doubling the distance between the aircraft and the acoustic sensor on the ground reduces the sound pressure level by a factor of two. This is the so called inverse square law for sound. Any deviations of this reading are assumed to be caused by the directivity of the aircraft

Since the locations of the aircraft and the sensors are known it is possible to determine the radiated sound power as function of angle. As an example see Figure 6 . By using three UGS in this configuration, three of these lines can be constructed for each helicopter passing. If multiple aircraft tracks are recorded it is possible to construct a full spherical sound radiation figure which can be used directly to predict the noise levels on the ground.

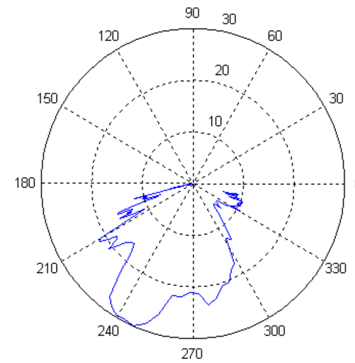

Figure 6: Radiated power as function of angle.

8. DISCUSSION

The UGS systems are tested and usable in the current state of the system. The localization algorithm is now based on triangulation of several azimuth and elevation angle measurements. It is possible to improve this localization algorithm by combining the three systems.

The integration with the electro-optical camera is new and only tested once. This innovation shows to be helpful for the classification of aircraft and can also be used for the improvement of localization.

The system can be used to determine the directional radiation of aircraft. This knowledge can be used for environmental prediction tools but also for applications which aim to avoid acoustic detection of aircraft.

9. CONCLUSIONS

This paper reports the development of a system that can determine the directional acoustic radiation of aircraft. It can be fielded and left alone for a week time where it records all aircraft. The system is in a high technology readiness level. Because the procedure has some post process steps, it can be used by experts. The procedure for using an electro-optical camera that is used to determine what aircraft was measured is in a lower technology readiness level, but may be desirable.

10. ACKNOWLEDGEMENT

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11. REFERENCES

[1] J.W. Wind, W.F. Druyvesteyn, H-E. de Bree and A. Liñares Garcia, Ground-based source localization in the presence of unknown surface impedance, July 2, 2010

[2] Hans-Elias de Bree, Jelmer Wind, Subramaniam Sadasivan, Broad banded acoustic vector sensors for outdoor monitoring propeller driven aircraft, DAGA 2010

[3] Antonio Liñares, Erik Druyvesteyn, Jelmer Wind, Hans-Elias de Bree, Determination of the location of a sound source in 3D based on acoustic vector sensors on the ground, NOISE-CON 2010

[4] Hans-Elias de Bree, Jelmer Wind, Pascal de Theije, Detection, localization and tracking of aircraft using acoustic vector sensors, Internoise 2011