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Detection and Localisation of a Ground Based Impulsive Sound Source using Acoustic Sensors Onboard a Tactical Unmanned Aerial Vehicle

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ABSTRACT

Acoustic surveillance of the battlefield enables the detection, classification, localisation and tracking of sound sources of military interest including ground vehicles, air vehicles and weapon fire. An application of current interest is the detection and localisation of sources of ground-based indirect weapon fire (from mortars and artillery) using acoustic sensors onboard a tactical unmanned aerial vehicle. The acoustic self-noise environment onboard an aerial vehicle is dominated by propulsion engine noise with air flow noise contributing to a lesser extent. By applying suitable signal processing and pattern recognition methods, it is shown that a tactical unmanned aerial vehicle can provide an effective platform for locating sources of indirect weapon fire.

1.0 INTRODUCTION

Instrumenting a tactical unmanned aerial vehicle (TUAV) with microphones provides a highly mobile platform with the potential to acquire acoustic information from widely dispersed regions of the battlefield without exposing personnel to risk. This provides the opportunity to locate and classify targets such as vehicles, artillery, mortars and small arms whilst avoiding system performance limitations imposed by the operational environment such as screening by foliage, camouflage, fog, smoke or ground clutter which can occur with visual or radar detection. It can also provide wide area omnidirectional coverage with the acoustic surveillance information used to cue other sensors such as cameras with a limited field of view.

Offset against the mobility achieved by using a TUAV as a platform for the acoustic sensors is its high self-noise level which tends to mask the signals of interest. To demonstrate the feasibility of utilising a TUAV in this role, an experimental TUAV was instrumented with microphones and measurements made to quantify the characteristics and levels of the noise on the aircraft. A propane gas-fired bird scarer was used to provide an impulsive sound source against which self noise suppression algorithms could be evaluated. Also, the feasibility of the system for detecting sources of indirect weapon fire was demonstrated by mixing calibrated real data recorded during a previous weapon firing exercise with the self-noise data recorded on the TUAV.

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2.0 TUAV ACOUSTIC SELF NOISE AND IMPULSIVE SOUND SOURCE MEASUREMENTS

2.1 Self Noise Measurements: TUAV Static with the Engine Running

Two microphones were mounted flush with the upper surface of the wings of an experimental TUAV, with one on either side of the fuselage. The microphones were separated by 1.94 m. Self noise measurements were made both with the TUAV static with the engine running and with the TUAV in flight. This allowed the noise from the engine and the wind noise associated with the flow of air over the wing to be isolated. The acoustic self noise measured from the TUAV while static with the engine running was observed to consist of a sequence of impulses associated with the firing of the engine. These impulses were separated by about 25 ms in the time domain and the peak sound pressure level corresponded to about 116 dB re 20µPa.

The low-frequency (<1 kHz) spectrum of the self noise of the TUAV (which was static with the engine running) is represented by the red line in Fig. 1. The ambient noise represented by the green line is also shown in Fig. 1 for comparison purposes. The dominant feature of the TUAV self noise spectrum is a series of spectral lines. These spectral lines, which are a harmonic series of the cylinder firing rate, can be suppressed by the application of a suitable filtering method (blue line), which is discussed below in Section 3.

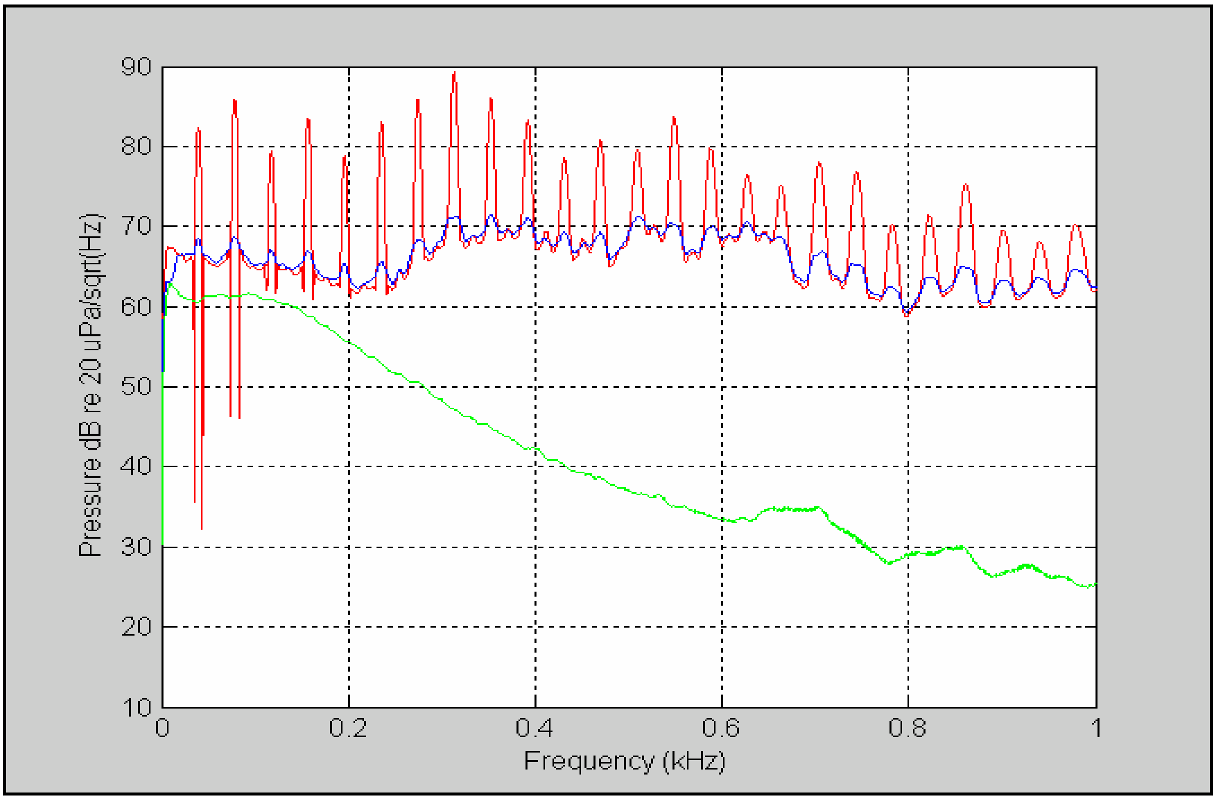

Figure 1: The low frequency spectra of the TUAV when static with the engine running (red), with the discrete spectral lines suppressed by filtering (blue) and the ambient noise with the engine stopped (green).

2.2 Self Noise Measurement: TUAV Flying

The spectrum of the TUAV when in flight is plotted in Fig. 2. A comparison with Fig. 1 indicates that the line levels remain about the same as in the static case but the underlying broadband (aerodynamic) noise is increased by 5-10 dB.

2.3 Impulsive Sound Source Signal

The signal was an acoustic impulse that was generated by the detonation of propane gas in a device commonly used to scare birds away from farm crops and airport runways. Using this device, an impulse is generated about every 27 s. The impulse was characteristic of an explosive sound, which consists of an initial compression followed by a rarefaction during the relaxation phase. The total duration of this local atmospheric disturbance was less than 20 ms and the peak sound pressure level of the source was about 146 dB re 20µPa at 1 m.

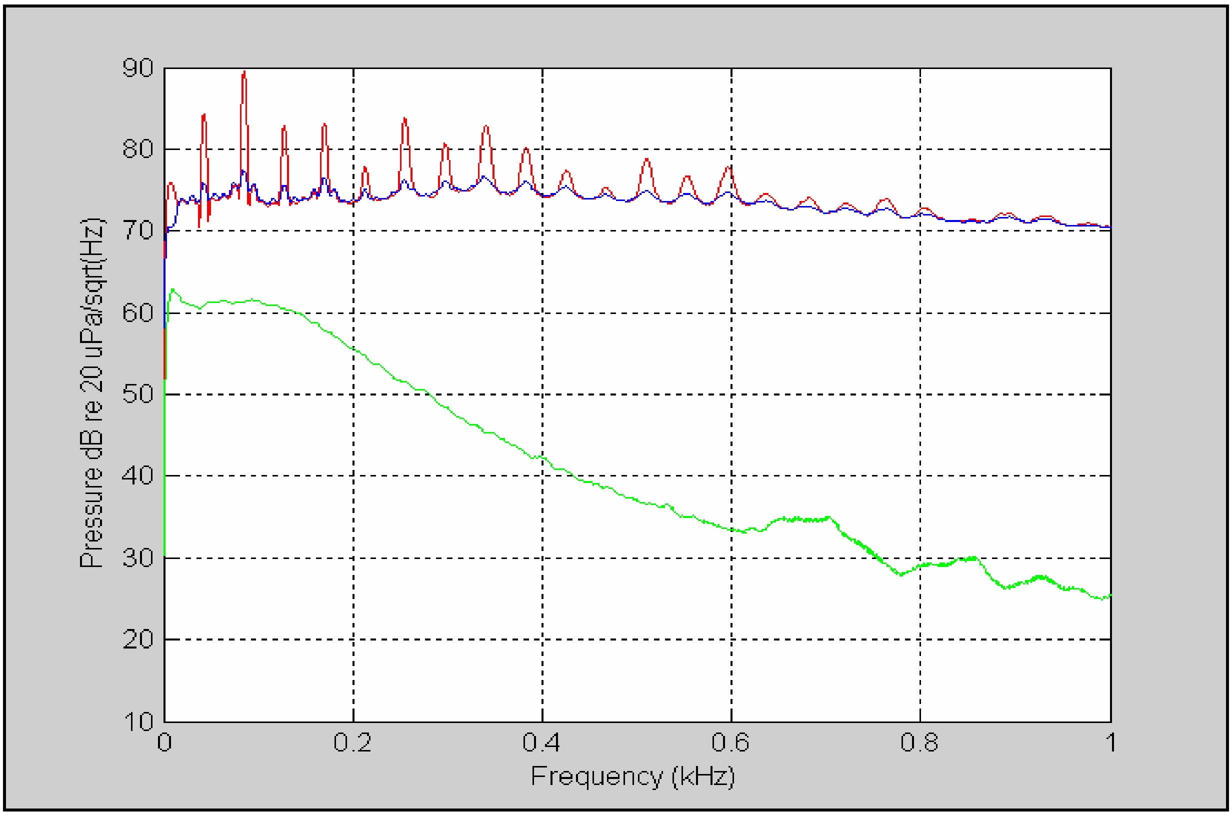

Figure 2: The low frequency spectra of the TUAV flying (red), with discrete spectral line suppression (blue) and the ambient noise with the engine stopped (green).

3.0 SIGNAL PROCESSING FOR DETECTION OF THE IMPULSIVE SOUND SOURCE

As the received signal level of the impulsive sound is well below the level of the self noise, it is necessary to utilise the characteristic differences in the properties of the signal from those of the noise so that the signal can be detected. One feature associated with a short impulse is that its spectrum is smooth relative to the noise, which has a series of strong frequency lines. This allows a filter to be applied which reduces the lines while having a minimum effect on the signal. In applying such a filter it is desirable that the lines are not completely nulled as this will result in sharp transitions in the frequency spectrum of the impulsive signal which will lead to ringing in the time domain.

Instead a filter is applied by first convolving the modulus of the spectrum with a square window with a gap in the centre matched to the width of the frequency lines. This produces a spectrum in which the level in the region of the lines is estimated from the level of the adjoining spectral regions. This spectrum is then increased by about 2 dB and a spectrum is extracted which is the minimum of the smoothed spectrum and the raw data. This has the effect of estimating the spectrum in the vicinity of the lines by the smoothed value of the surrounding spectrum while leaving the spectral levels of the lower amplitude regions unchanged. A filter is then formed from the ratio of the extracted spectra to the raw spectra. By applying this amplitude filter to the raw data a signal is obtained which preserves the phase information of the original signal but which suppresses strong lines without creating frequency nulls. This is the filter which is used to suppress the lines in the spectra represented by the blue lines in Figs 1 and 2.

Most of the energy in the impulsive signal lies below 4 kHz, so further suppression of the noise is achieved through the application a low pass filter to reject the noise above this frequency. The next stage of the signal processing chain involves threshold detection. However, there remain impulses in the self noise which will lead to many false alarms with this type of detector. For example, over an observation period of 12.5 minutes (750 s) with the impulsive sound source 140 m from the TUAV (which was stationary with the engine running), there were approximately 700 false detections made by the threshold detector, along with 25 valid detections of the impulsive signal.

Further discrimination against the self noise impulses is required and this may be achieved by correlating the measured signal with a replica of the source. A pattern recognition method is then used to identify the shape of the impulse. This is done by detecting each of the individual pulses and normalising their amplitude to a peak value of unity. A discriminator is then formed based on the root-mean-square difference between a replica of the impulse and the detected impulse. When this discriminator is applied to the acoustic data, the false alarms are reduced by a factor of about 10. If the impulse is truly an acoustic signal it will be received on both of the microphones. As the time for an acoustic signal to propagate between the two microphones has a maximum of about 5.6 ms for an endfire signal the impulses may be rejected as acoustic signals if they are not received on both microphones within this time interval. As use of the discriminator reduced the period between impulses not rejected as self noise to about 10 seconds, there is less than a 0.1% chance that two self noise impulses will arrive with the time separation characteristic of an acoustic signal. When this criterion is applied to the detected impulses, all of the false alarms are rejected while detecting 25 of the 27 (over 90%) of the impulses from the sound source. Over the 750 s observation period, these impulsive signals were observed to be uniformly spaced in time with an interval of about 27 seconds which corresponds to the repetition period at which the sound source fires. The two missed detections occurred at 430 s and 720 s. Using the differential time-of-arrival of the signal at the two spatially-separated sensors enables the bearing of the signal source to be estimated. The bearing estimates were observed to be consistent over all of the impulsive signals varying within 3 degrees about a value of 38 degrees.

With the TUAV in flight, these same techniques successfully reject 100% of the impulses from the self noise. With the TUAV flying at an altitude of 300 m and following a racetrack course, it was observed that for much of the time the distance to the source was such that the signal was below the level which it could be detected. The processing did detect two impulses however both of which were very strongly matched to the signal. One pair of these impulses is plotted in Fig. 3. These impulses are slightly higher than those measured on the ground. The bearings for the two impulses are about 4 degrees suggesting that for both of these detections, the TUAV is close to being overhead the sound source at a range of about 300 m.

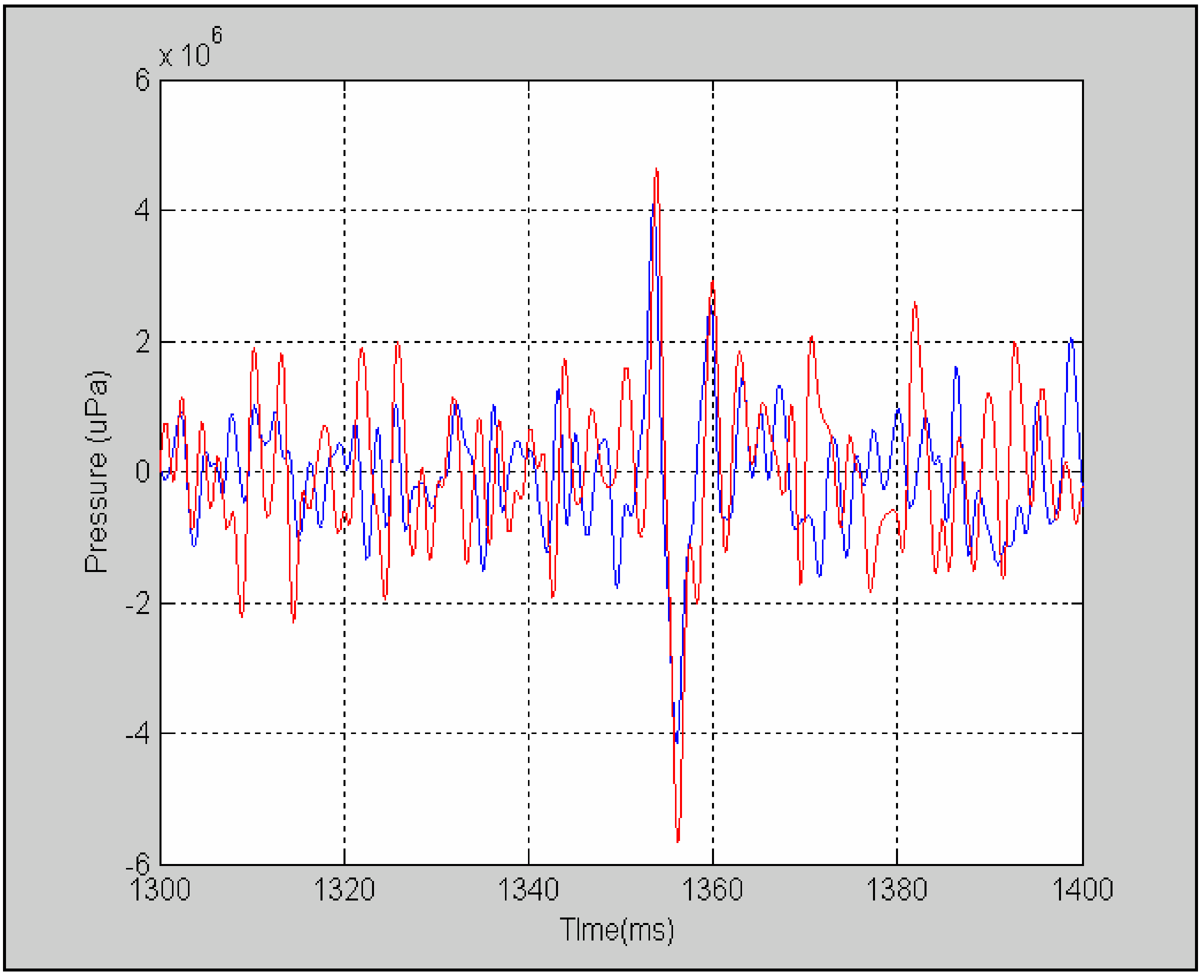

Figure 3: The impulses received on the left (blue) and right (red) microphones for an impulsive sound classified as being from the sound source with the TUAV in flight.

3.0 DETECTION OF INDIRECT WEAPON FIRE

Calibrated acoustic data for artillery and mortar fire were accessed using DSTO's Battlefield Acoustics Data Base. These data were used previously to test and evaluate a ground-based sound ranging method for locating sources of indirect weapon fire during live firing exercises[1]. The acoustic data that were selected had been recorded at two nodes each using three microphones at ranges of 3 km and 5.5 km from a 105 mm gun. The acoustic signal from the firing of the gun was added to the TUAV self noise. The time series data are plotted in Fig. 4. Due to the high level of the TUAV self noise, the signal is not readily observable (it is located close to the centre of the time series plot at time 0.75 s). However, detection of the signal requires spectral line suppression of the self noise. Figure 5 demonstrates the effectiveness of the spectral line suppression method as it reveals the presence of the signal. Similar results were obtained using the data for all of the gun firings (about 200 events). The method was also successfully tested using real data from a previous mortar firing exercise.

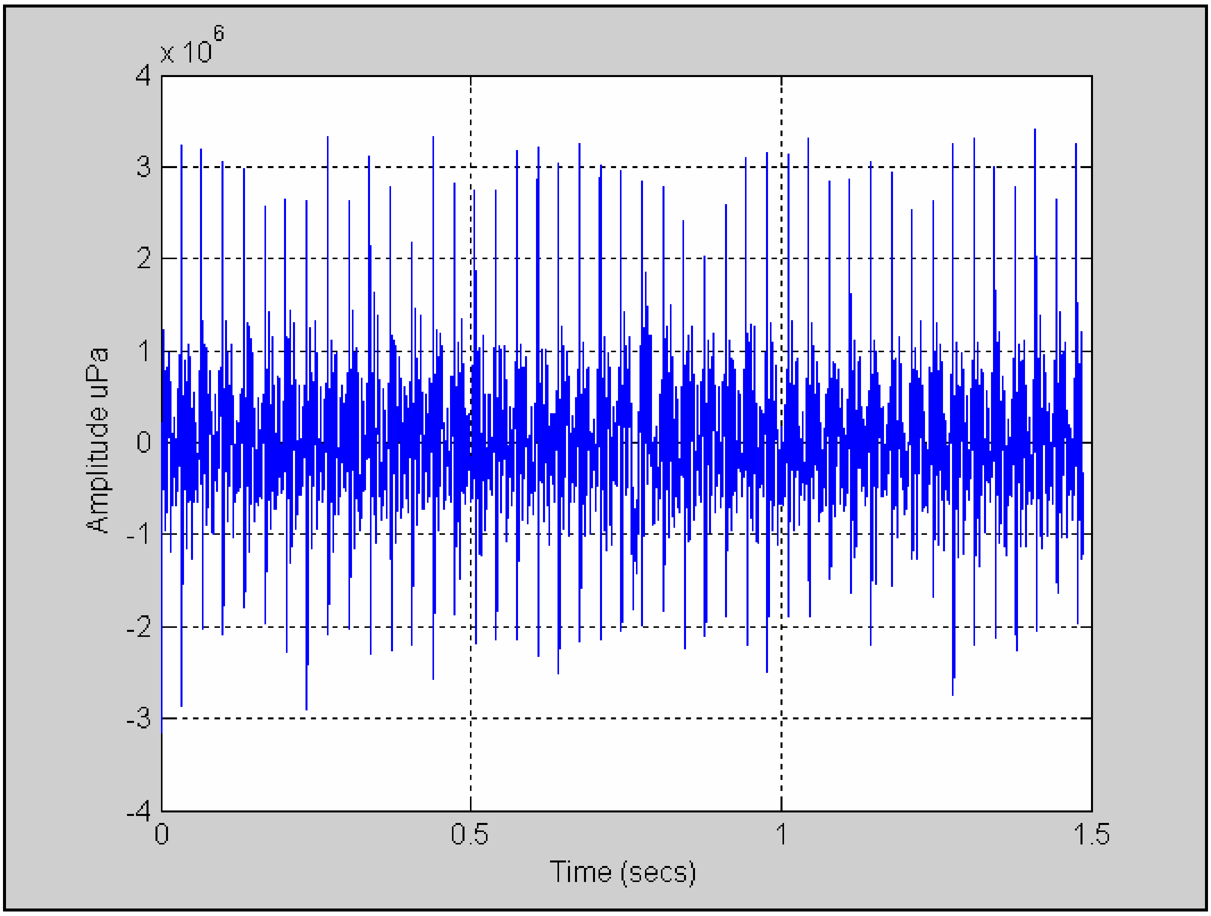

Figure 4: Time series of the TUAV self noise with the impulsive signal from the firing of a 105mm gun (the signal is near the centre of the display but it is not readily observable due to the high level of self noise).

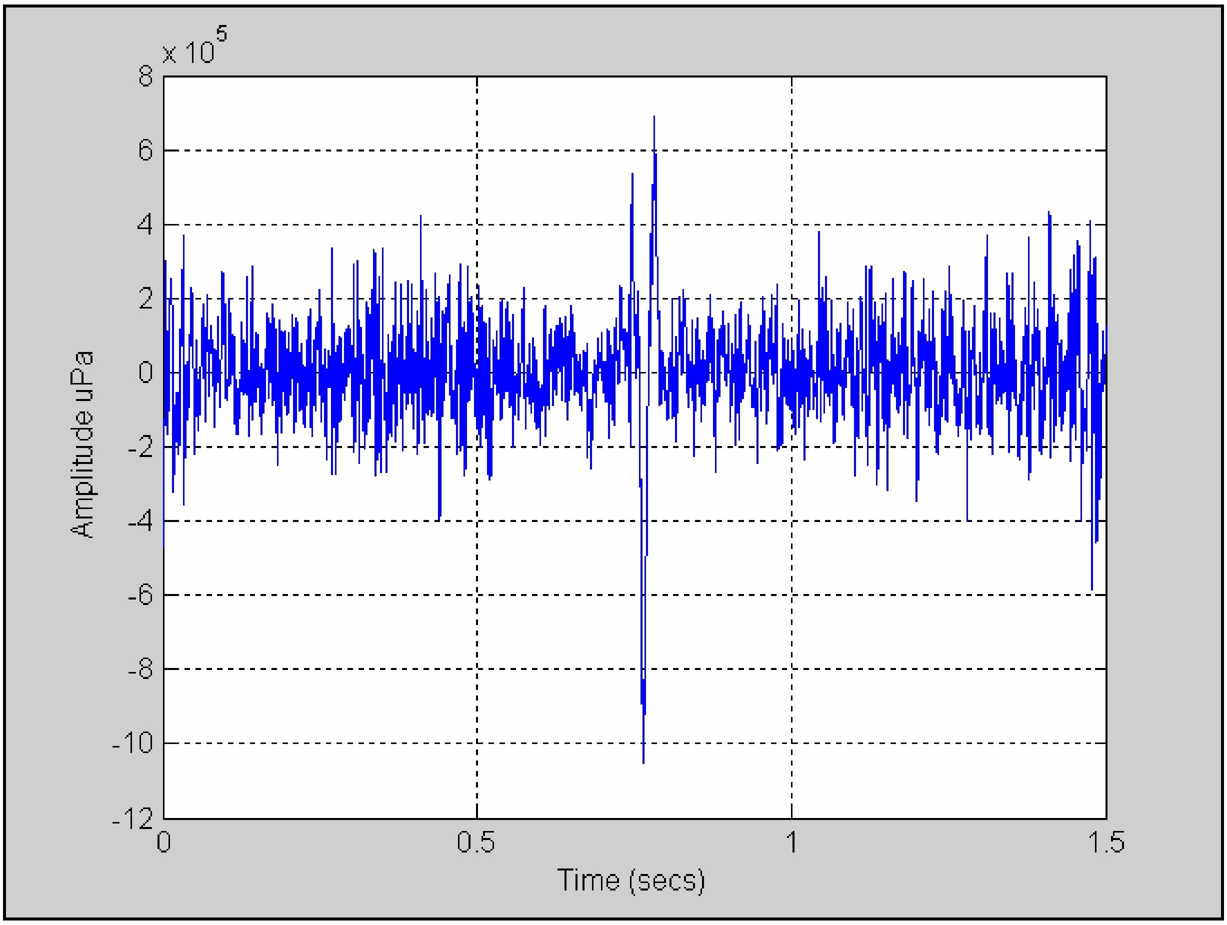

Figure 5: Time series of the TUAV self noise with the impulsive signal from the firing of a 105 mm gun observable after suppression of the self-noise spectral lines.

4. FUTURE PROGRAM AND CONCLUSIONS

A novel acoustic sensor has been designed to reduce the aerodynamic flow noise when the TUAV is in flight and its performance is to be evaluated in a proposed field experiment. Even if the wind noise were eliminated, the self noise of a TUAV that is powered by a gasoline engine would remain extremely high. Despite this, the application of signal processing and pattern recognition techniques has allowed very high detection probabilities to be achieved against an impulsive sound source with no false alarms out to a range of 300 m. While the impulsive signal source used in the present experiment was loud, the source levels of acoustic impulsive events generated by indirect fire weapons such as mortars and artillery are significantly higher. Thus while the detection ranges achievable will be much less than for ground based sensors deployed in quiet locations, the location of the sensors on a forward deployed platform will provide operationally useful ranges for some scenarios.

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