Motion Parameter Estimation of Low Flying UAV using Acoustic Sensor

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Abstract - *The field of acoustics is emerging as a significant supplementary modality that should be investigated and utilized in the development of intelligence and surveillance systems. These systems often depend on technology that is rooted in the singularity of electromagnetic fields.Acoustic sensors are preferred because of their affordability, robustness, and small size. They are also passive. Furthermore, sound energy can go beyond a line of sight. The current scenario can be used to the detection and localization of sound sources utilizing Unmanned Aerial Vehicle (UAV) and ground-based Acoustic Sensors. An acoustic sensor placed on the ground detected the target's immediate frequency.An Acoustic Sensor above the ground generates Doppler altered frequency time records to determine flight characteristics. The Acoustical Doppler Effect causes the instantaneous frequency perceived to fluctuate on a straight-line trajectory with constant velocity.The Nelder-Mead technique is used to estimate the low flying UAV's motion characteristics based on the instantaneous frequency model.*
Keywords: *UAV, Acoustics, Doppler effect, Nelder – Mead.*

I INTRODUCTION

In order to provide direction and early warning, unattended ground detectors are commonly placed in isolated locations. Base instrumentation and aircraft (helicopters, jets, and propeller-driven aircraft) are sources of interest for land-based guiding systems. Due to the high acoustic dynamism emitted by automobile and airplane engines and propulsion systems, it is possible to identify these sources using unresistant acoustic detectors placed close to the ground [2]. By equating the received location of the acoustic signal with a predetermined or adaptively suppressed threshold, it is possible to automatically detect the existence of an auditory source. Reusing data from acoustic detectors is also possible for tracking, localization, and source division. A collection of flight parameters precisely specifies the flight path of an airplane traveling at a constant speed and altitude [1]. The ability to estimate part or all of the aircraft flight characteristics while using tolerant acoustic techniques is made possible by the retardation effect, which occurs when the source's velocity is comparable to the speed at which sound propagates through a medium. The estimating process uses the Nelder-Mead simplex method [5], a derivative-free, non-constrained optimization technique, to find its solution. The method used here is an iterative procedure that involves applying the algorithm to optimize the estimated instantaneous frequency and adjusting the optimizing parameters at the conclusion of each iteration [3], [4]. Because acoustic parameter estimate of aircraft motion is passive, undetectable, and unmaskable, it provides a trustworthy method of aircraft parameter estimation. It discovers that border security and alertness have a great deal of potential for locating hostile aircraft [13].

II INSTANTANEOUS FREQUENCY ESTIMATION USING DOPPLER SHIFT

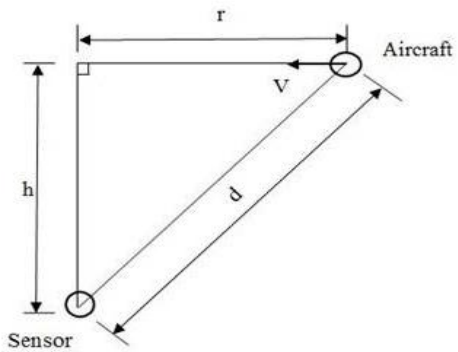

Figure 1 Geometrical Configuration for an UAV & Acoustic Sensor

Figure 1 represets the geometrical configuration representation for an UAV and the acoustic sensor used for the instantaneous frequency estimation. The estimating process uses the Nelder-Mead simplex method [5], a derivative-free, non-constrained optimization technique, to find its solution. The method used here is an iterative procedure that involves applying the algorithm to optimize the estimated instantaneous frequency and adjusting the optimizing parameters at the conclusion of each iteration [3], [4]. Because acoustic parameter estimate of aircraft motion is passive, undetectable, and unmaskable, it provides a trustworthy method of aircraft parameter estimation. It discovers that border security and alertness have a great deal of potential for locating hostile aircraft [13].

$$t = \tau + \frac{d}{c} \tag{1}$$

where d /c is the time delay [15] needed for sound to travel between the UAV and the sensor, which are separated by d, at a constant speed of c. The tilt range or distance is provided by

$$d = (h^2 + r^2)^{1/2} \tag{2}$$

$$d = (h^2 + v^2(\tau - t_c)^2)^{1/2} \tag{3}$$

If we replace Equation (3) with Equation (1) and rewrite the equation using τ, we obtain

$$\tau = \frac{c^2 t - v^2 t_c - [h^2(c^2 - v^2) + v^2 c^2 (t - t_c)^2]^{1/2}}{c^2 - v^2} \tag{4}$$

The frequency that the sensor immediately received is provided by

$$f_t = f_o \frac{d\tau}{dt} \tag{5}$$

$$f_t = \frac{f_o c^2}{c^2 - v^2}\left[1 - \frac{v^2(t - t_c)}{[h^2(c^2 - v^2) + v^2 c^2 (t - t_c)^2]^{1/2}}\right] \tag{6}$$

where v is the vehicle speed, f_o is the source frequency, c is the sound speed, and t_c is the time at the closest point of approach (CPA) [10], [14]. Equation (6) is the necessary model for Doppler Effect-based acoustic vehicle detection. Using a Nelder-Mead simplex method, parameters at the CPA, such as v, f_o, t_c and d, can be retrieved.

III ALGORITHM IMPLEMENTATION

A. Introduction

Using the Nelder Mead simplex method to Doppler shift acoustic signals received from the UAV at a ground-based sensor, one may estimate the motion parameters of the aircraft, such as its velocity, frequency spectrum, time, and altitude at the closest point of approach to the sensor. Since auditory signals are never completely obscured, this provides a dependable means of tracking stealth mode low flying aircraft. Doppler-shifted reverberations are generated at the sensor and are contingent upon the relative velocity between the UAV and the sensor [8], [9]. We are able to get sound frequencies that are only reliant on the UAV's motion because the sensor is stationary. The Nelder-Mead simplex approach can be used to minimize the mean square error [7] and get estimates of v, t_c, and d at the CPA.

$$\sum_{t=1}^{T}[F(t) - f(t)]^2 \quad (7)$$

This is the t^{th} measured frequency, or f (t), obtained from the spectrogram plot of the acoustic signal recorded at the sensor, at discrete time t (t = 1,... T. Equation (6) is used to determine the instantaneous frequency F(t), which is based on the values of [v, f_o, t_c, d] that are derived from the present recapitulation. The Nelder Mead simplex estimation function f_{min}search () is used in MATLAB to implement the procedure and improve the given objective function. f_{min}search () begins from an initial estimate and finds the minimum of a scalar function of several variables. The term "unconstrained nonlinear optimization" describes this.

B. Nelder-Mead Simplex Method

One of the most well-known methods for multidimensional unconstrained optimization without outcomes is the Nelder-Mead or simplex search algorithm. This approach is ideal for problems involving non-smooth functions because it does not require any evidence of plagiarism [12]. It is frequently used to resolve arithmetic problems with parameter approximation and other situations where the function values are erratic or noisy. A collection of n+1 points, x_0, xn, $\in R_n$, which are regarded as the vertices of a working simplex S, and the associated set of function values at the vertices, $f_j = f(x_j)$, for j=0, n, are the starting points of a simplex-based direct search method [5]. It is required that the first working simplex S be non-degenerate, meaning that the points x_0,..., x_n cannot be located in the same hyper plane. After that, the working simplex S is modified in a series of steps with the goal of lowering the function values at its vertices. Each time a step is performed, the transformation is ascertained by computing one or more test points and their corresponding function values, then contrasting these values with the vertices' values. Each time a step is performed, the transformation is ascertained by computing one or more test points and their corresponding function values, then contrasting these values with the vertices' values. When the working simplex S gets small enough or, if f is continuous, when the function values f_j are sufficiently near together, this process comes to an end. Many other direct search techniques need even more function evaluations each step than the Nelder-Mead algorithm, which usually only needs one or two at most [11]. Here, the process is to generate the initial functioning simplex first, then run a termination test.

IV RESULTS AND DISCUSSION

A. Acoustic Data Analysis

Total interval of flight	=	115.6733 seconds
Sampling frequency	=	12000 Hz
Total sum of samples	=	1388080
Considered period	=	20-60 seconds

B. Observation

The resulting sensor data were processed in overlapping blocks, each with 8192 samples and a 50% overlap between two subsequent data blocks. The data were sampled at a frequency of 12 kHz. The vehicle transit FFT study for the observed extent is shown in Figure 2.

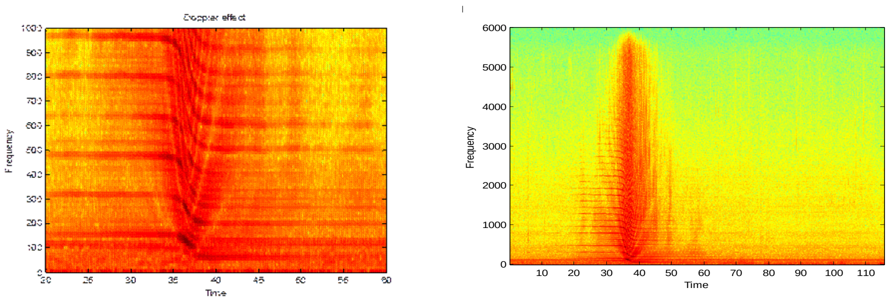

Figure 2 Doppler Effect (Bottom) & Scale Altered Chart (Top)

After sampling the data, the spectrogram analysis was completed. This study demonstrates the potential for transient and harmonic pattern detection of the vehicle due to the Doppler effect, as seen in Figure 2. Figure 2 also provides the appropriate scale-modified graph. The Doppler Effect causes the maximum and minimum frequency points on the scale-modified graph to occur. The precise transit time of a vehicle over the sensor was determined by analyzing the elevation and slant range revisions displayed in Figures 3 and 4. This came to 36.39 seconds.

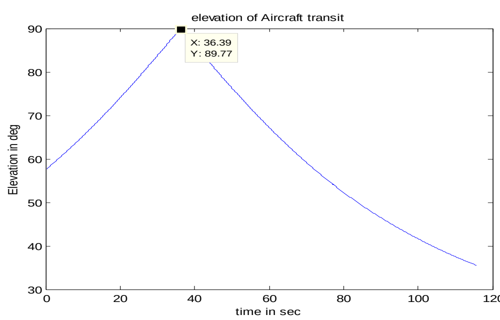

Figure 3 Elevation Plot for Vehicle Transit

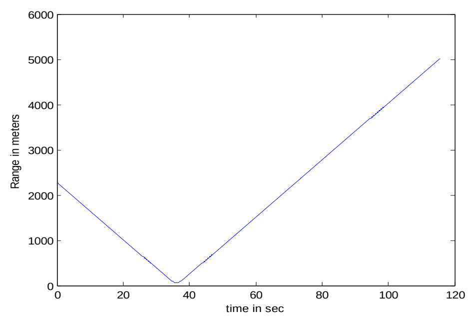

Figure 4 Range Plot for Aircraft Transit

The algorithm was used to minimize the sum square error between the estimated and measured instantaneous frequencies at discrete time instants. The desired parameter values were determined by identifying the values of the parameters that minimize the sum square error. Given that the f_{min} search function provided the frequency error, the optimal parameter values can be found by using the difference between the estimated and calculated frequencies as the objective function and the values of the parameters that converge this error value to zero. As an unconstrained minimization procedure, f_{min}search() causes the function's final value to converge to a negative value. Since a negative frequency difference value is undesirable, this had to be prevented. In order to solve this issue, the goal function was determined to be the frequency error's absolute value, which, when optimized with the f_{min}search algorithm, converged to a zero-error value.

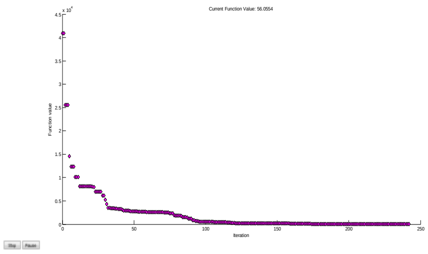

Figure 5 Plot of Optimization of Function Value

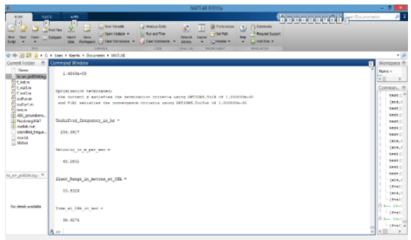

Figure 6 Screen Shot of Optimized Parameters Output

Screenshots of the MATLAB implementation illustrating the minimization procedure and the ideal parameter values are displayed in Figures 5 and 6. We tallied the trial results in Table 1 for a clear comparison.

Table 1 Comparison of Simulated and Reference Values

Parameters	Estimated values	Real values
Aircraft velocity(m/s)	63.28	65
Slant Range at CPA (in meters)	53.93	60
Source frequency (in Hz)	254.3917	Unavailable
Time at CPA (sec)	39.92	36

V CONCLUSION

Real-time data was used in this work to estimate the parameters of a low-flying UAV based on its acoustic signature. Using MATLAB, the Nelder-Mead algorithm was utilized to estimate the desired parameters of UAV motion. With the use of readily available real-time data, the outputs were validated and quite accurate convergence was achieved to these values.

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