Indian Journal of Science and Technology, Vol 9(47), DOI: 10.17485/ijst/2016/v9i47/108438, December 2016 ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Active Vibration Suppression of UAV Camera Mounts

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Abstract

Objectives: Vibrations are propagated onto a UAV camera mount; this leads to improper images. We analyze the vibrations occurring in and come up with a solution to suppress them. **Methods/Analysis:** The vibrations occurring in a quadcopter are first measured by using a piezoelectric element, and then the existing algorithms for vibration suppression are compared. The data recorded is then imported in MATLAB and the NLMS algorithm is applied on it. Following this we generate a vibration, measure it and generate an anti-vibration to cancel it to prove the concept of vibration suppression. **Findings:** The best suited algorithm among the LMS, Fx-LMS and the NLMS algorithms is the NLMS algorithm because it has an estimate for the step factor and is stable. The main frequency of vibrations of the quadcopter camera mount is measured as 17.91Hz. The measured frequency from the generated vibrations of 25Hz is 23.17Hz. The vibrations after suppression are found to be lesser in intensity. **Application/Improvements:** The concept stated could find application in suppressing vibrations occurring in a quadcopter camera mount. A frequency tracking algorithm could be developed additionally to suppress vibrations of varying frequencies.

Keywords: Active Vibration Suppression, NLMS Algorithm, Phase Synchronization, UAV

1. Introduction

Vibrations occur everywhere around us and they are usually undesirable and must be reduced. The camera mount of an unmanned aerial vehicle used for surveillance by imaging techniques may suffer from the vibrations that are induced due to the rotors rotating at high speeds, this may cause the image obtained to be blurred or the object tracked to be lost. Passive vibration control techniques are not useful in this case because heavy systems cannot be mounted on the unmanned aerial vehicle and also the nature of these vibrations is found to be highly dynamic, therefore the system requires active vibration control methods. The proposed algorithm for vibration suppression is the normalized least mean squared algorithm. This algorithm basically consists of a primary path between the source of vibration and the desired signal. The error is obtained from the difference of the desired signal with the output signal. The error signal is given to the least mean square filter which modifies the coefficients of a finite impulse response filter to minimize the error obtained at the output.

2. Analysis of Industry Applications

Vibrations are bound to occur in most industries and the following describes the sources of vibration and the problems that they cause.

2.1 Aerospace

Vibrations are the cause for many failures especially in aerospace vehicles. Vibrations are the main reasons for failure of mechanical components and electronic systems such as navigation equipment. Among all aerospace vehicles, helicopters have the most moving parts and induce strong vibrations in the structures, cockpit and

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electronics. The aircraft engines also generate vibrations that can cause induced vibrations to the aircraft structure and electronics. Space vehicles and missiles suffer large vibrations especially during launch. In all aerospace vehicles navigation systems are extremely susceptible to vibration and can cause catastrophic failures.

2.2 Automotive

Vibrations due to the engine and varying terrain of the road get propagated along the chassis and cause vibrations to parts of the car like dashboard and door panels[1]. These vibrations can act as a source of noise of different frequencies and intensities, depending on the frequencies and intensities of vibration.

2.3 Factory Floor Equipment

Various heavy machinery in factories such as large motors induce vibrations in other factory equipment leading to improper functioning in a plant, so these vibrations must be minimized in order to achieve proper plant functioning.

2.4 Robotics

In robotic assembly, the positioning of the robotic arms has to be very precise and vibration of moving parts and joints in this arm can cause variation in position and lead to improper assembly and cause huge losses to the assembly plant.

2.5 Imaging

In imaging, while the shutter of the camera lens is closing during the capture of the image by the camera image sensors, any vibration will distort and blur the images. While many high end cameras have in-built features to prevent camera shake, they do not work well especially in low light conditions. It is important to implement other anti-vibration techniques external to the camera to prevent the vibrations from affecting the camera body. In small unmanned aircrafts, vibrations from the platform can result in loss of visual tracking ground targets and other low light surveillance applications.

3. Technology Background

This gives a basic overview of the various control strategies and algorithms behind vibration control

3.1 Techniques for Vibration Control

There are two basic techniques for vibration control techniques that are active vibration control and passive vibration control

3.1.1 Active Vibration Control

This method involves generation of an anti-vibration signal which is in phase and opposite in amplitude so that the superposition of the signals is almost a steady waveform with zero amplitude[2]. It may also involve prediction of future amplitude of the vibration signal if the nature of variation of the vibrations are dynamic in nature, this is precisely required in vibrations of UAV camera mount[3]. The disadvantage of this method is that amount of cost and effort required by this method is on the higher side.

3.1.2 Passive Vibration Control

There are mechanical methods to suppress the vibration, which involve design using spring and hydraulic/ pneumatic dampers. There are no electronics and these techniques rely on mechanical methods to absorb the shock. These methods add mass to the system and it would be inappropriate in applications where weight is a constraint, such as small unmanned aircrafts for surveillance applications. The cost and design requirements for this method are on the lower side.

3.2 Types of Control Strategies

3.2.1 Feedforward

In this type of control strategy, the system responds to the gives control action without actually knowing the output but from a feed forward estimate. It is as shown in [Figure 1].

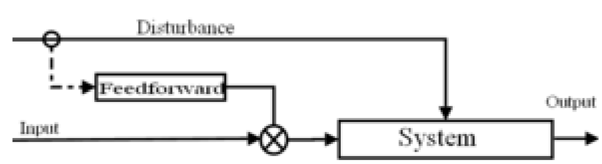

Figure 1. Feedforward control system.

3.2.2 Feedback

In this type of control system, the control action of the system is generated from a feedback path from the output of the system. It is shown in [Figure 2].

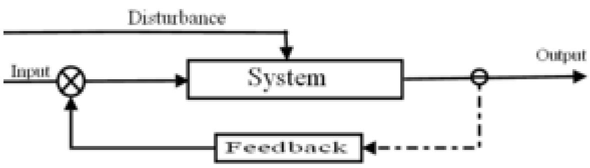

Figure 2. Feedback control system.

3.2.3 Combination of Feedback and Feedforward

This type of control algorithm has both feed forward

And feedback paths and makes use of both of these paths for the control action. It is shown in [Figure 3]. The filtered x-lms algorithm makes use of this kind of a technique for control.

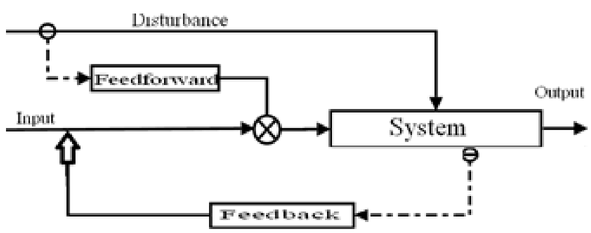

Figure 3. Combination of feed forward and feedback control.

3.3 Control Algorithms

3.3.1 Least Mean Squared Algorithm

3.3.1.1 Filtering Process

Y(n) =X(n)*W(n) -(1)

The output Y(n) is a linear combination of the vibration input value from sensor and the weight estimate from a finite impulse response filter.

3.3.1.2 Error

Here, there exists a primary path between the input signal and desired signal. The path from the input signal through primary Path results in the desired signal. The error is calculated as the difference between the desired and the output signal.

D(n)-y(n)=e(n) -(2)

3.3.1.3 Adaptation

Mean square error function is given by

$f(w)=E((e(n))^2)$ -(3)

The above mean square error is minimized by the weight update equation given by

$W(n+1)=w(n)+ \mu e(n)x(n)$ –(4)

Where w(n) is the weight update matrix, u is the convergence step factor, e(n) is the error, x(n) is value from sensor and y(n) is the output.

3.3.2 Filtered X-LMS Algorithm

Practically, there exists a secondary path transfer function between the output from the filter to the difference block with the desired signal[4] ,this affects the amplitude and phase of the output generated by the adaptive filter ,we don't want this to occur so, in order to compensate for this we introduce an additional secondary path of same transfer function from the input source to the LMS filter so, in effect the input x is directly filtered by the LMS filter, hence it is given the name filtered x-least mean squared algorithm. The block diagram for Fx-LMS algorithm as shown in [Figure 4]. The error signal e(n) is given as:

e(n)=d(n)-s(n)*y(n) –(5)
y(n) is given as w(n)*x(n) -(6)
e(n)=d(n)-S(z)*(w(n)*x(n)) -(7)

where, s(n) is impulse response of secondary response S(z) and w(n) is the vector of filter coefficients

The objective of this filter, like the lms filter is to minimize the mean squared error.

The coefficients of w(n) are updated as per the equation

$w(n+1)=w(n)+ \mu\Delta(E(n))/2$ -(8)

where, $\Delta(E(n))$ is the instantaneous mean square error at a very small time interval Δ.

But, we have $\Delta(E(n))= \Delta(e(n)*e(n))= \Delta(e(n))*e(n)$ -(9)
From eqn-(1), we have $\Delta(e(n))=d(n)-s(n)*y(n)$ -(10)

At very small time interval Δ, d(n)=0

Substituting in (5), we get Δ(e(n))=-s(n)*y(n)=x'(n) -(11)

Where x' (n) is the input x (n) through identical alternate filter S'(z) of secondary path estimate

So, we get: Δ(E(n))=-2x'(n)*e(n) -(12)
Substituting this in (3), we get w(n+1)=w(n)- μx'(n)e(n) -(13)

Thus we get a filter update equation that is independent of the mean square error. Unfortunately, even though it has the advantage as mentioned now, both the LMS and Fx-lms algorithms do not give equation for step factor μ, therefore it causes instability. This is resolved in normalized LMS algorithm.

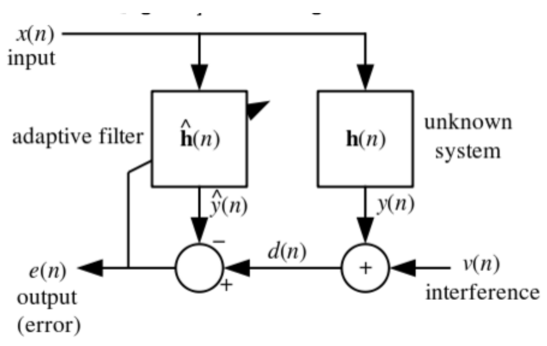

Figure 4. Fx-LMS algorithm.

3.3.3 Normalized LMS Algorithm

This method solves the problem of the step factor instability by providing equation for μ[5]. The output is normalized to input in this case. The filter weights are taken to be zero initially.

The equation for error is given by:

e(n)=d(n)-w(n)x(n) –(14)

The weight update equation for this algorithm is given by:

w(n+1)=w(n)+(μe(n)x(n)/(x(n)*x(n))) –(15)

The optimum value of the step factor is given as:

μopt=E[(y(n)-ŷ(n))^2] /E[e(n)^2] –(16)

Where ŷ(n) is the estimated value of y(n)

4. Solution

The solution proposed is to measure the vibrations and apply the NLMS algorithm on them and analyze the observations

4.1 Measurement of Vibrations of a Quadcopters Camera Mount

Here, the vibrations produced in a quadcopter's camera mount is measured using piezoelectric elements, the vibration produces proportional voltage out of piezoelectric elements which are read by the ADC of an Arduino board. The plotted vibrations measured are shown in [Figure 5].

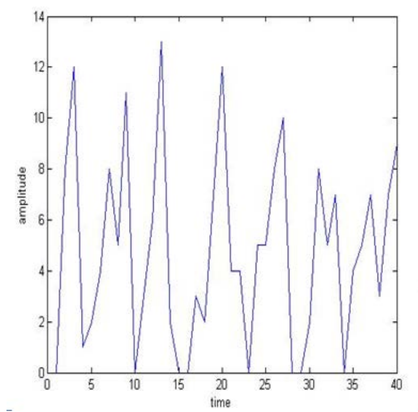

Figure 5. Measured vibrations from quadcopter.

4.1.1 FFT of Measured Vibrations

FFT is applied on the input data in mat lab and the peak frequency is found to be 17.91Hz. It is as shown in [Figure 6].

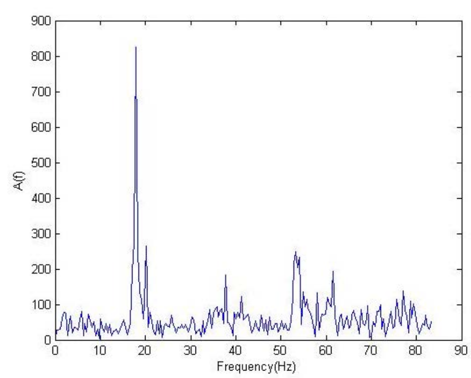

Figure 6. FFT of measured vibrations from quadcopter.

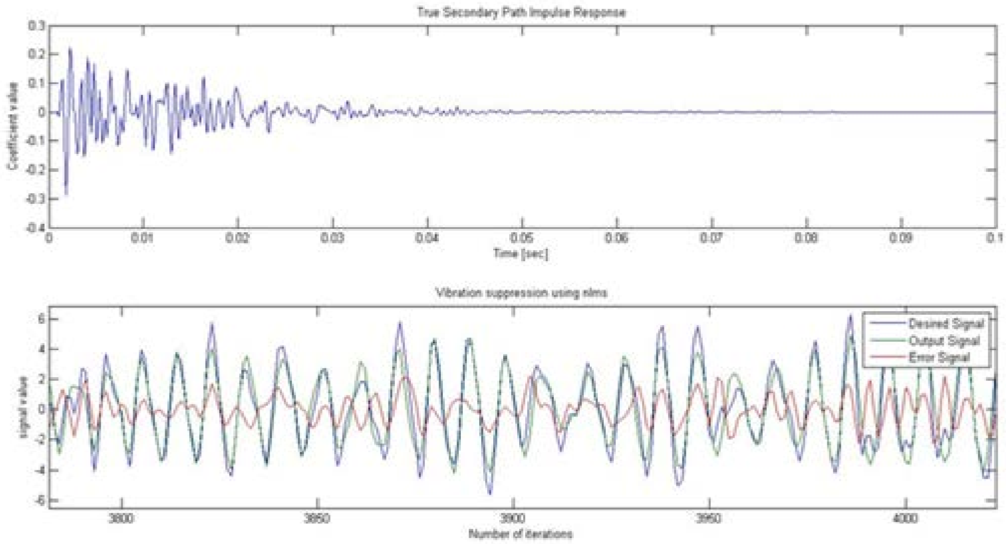

Figure 7. Results of NLMS algorithm on measured vibrations.

4.2 Simulation of NLMS Algorithm for Vibration Control

The input data obtained previously is used as input for mat lab's adapt filt. nlms function and the input, desired and error signals are shown. The output signal is very close to the desired signal which is modeled from input and if the output signal is given to a piezoelectric element it will reduce the vibration to the value of error shown in red. It is as seen in [Figure 7].

5. Vibration Suppression of Vibrations Generated by Piezoelectric Element due to Square Wave of a Constant Frequency

Here, the setup consists of two boards one to generate the vibrations and another to measure and cancel the vibrations. A square wave of frequency 25hz is generated by an Arduino Uno through the output of the PWM pins, the output from this is fed to a piezoelectric element. The generating piezoelectric element is joined to a cancelling piezoelectric element such that the negative metallic ends are facing each other, another piezoelectric element is placed on the generator to measure the vibrations. The measuring and cancelling piezoelectric elements are connected to the ADC and PWM pins on another board, the arduino Due. The setup is as shown in [Figure 8].

The cancelling vibration is generated applying a square pulse of same frequency to the cancelling piezoelectric element. The phase of the cancelling signal is synched with the original signal by observing the amplitude of the measured vibrations. If the measured vibrations are increasing it is the the positive edge of the square wave and if it is decreasing it is the negative edge of the square wave. Based on this we apply a suitable square pulse to the cancelling piezoelectric element which in in phase with the square wave generated. The nature of vibrations before and after cancellation are as shown in [Figure 9]. Before the above stated can be done the frequency of the vibrations has to be measured, for this we take the FFT of the measured vibrations and observe the frequency for which we get maximum amplitude, this frequency denotes the main harmonic of vibration as shown. The main frequency is found to be 23.17hz, which is approximately the frequency of generated vibrations that is 25hz. The FFT is as seen in [Figure 10].

Figure 8. Test setup consists of Arduinouno on the left, due on the right, a single generating piezoelectric element is sandwiched between the sensing and cancelling piezoelectric elements.

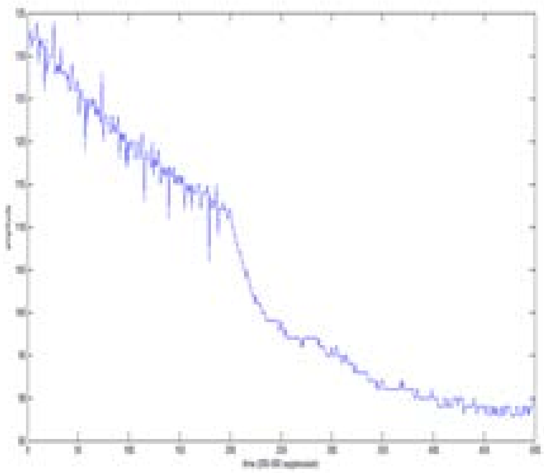

Figure 9. Measured vibrations before and after suppression 200-500 after suppression.

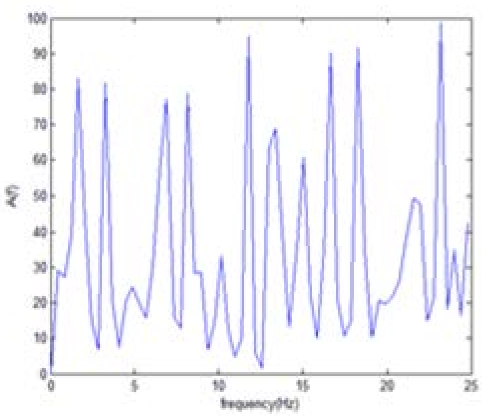

Figure 10. FFT of measured vibrations main frequency is 23.17Hz.

6. Conclusion

The nature and source of various vibrations has been discussed and the various algorithms have been compared and the NLMS algorithm is found to be the most suitable for the stated application. There is a reduction observed in the measured vibrations after suppression.

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Abbreviations:

UAV-Unmanned Aerial Vehicle
LMS-Least Mean Squared
NLMS-Normalized least mean squared
Fx-LMS-Filtered-X-Least Mean Squared
E ( )-Expectation of