Vibration Control System Based Upon Filters For Aircraft Applications

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Abstract: In aircraft, vibration arises from several sources, such as sound waves, engine noise, and airflow. Vibrations arising from these sources must be suppressed to avoid problems like discomfort in the cockpit and cabin, cracks or failures in landing gear, ride comfort, and component failure in the aircraft. In this research, a vibration control system is developed by using a 801S shock vibration sensor and an Arduino Uno board. The proposed vibration control system is able to suppress vibration in the range of 0-100 Hz, 0-300 Hz, and 0-499 Hz frequencies by using digital FIR and IIR filters developed using an Arduino Uno board. High-pass filters for suppressing these vibration frequencies are designed using the MATLAB FDA tool, and their coefficients are also obtained for implementing FIR and IIR filters on the Arduino Uno board. The on-chip LED of the Arduino Uno board turns high if a set threshold value is greater than the filter (FIR/IIR) output value. Experimental results indicate that the proposed system is able to successfully suppress the vibration of the range of 0-100 Hz, 0-300 Hz, and 0-499 Hz.

Keywords: Vibration Sensor, Arduino Uno, Matlab, FIR , IIR

I. Introduction

In modern aircraft operations, vibration control is a critical issue: structural components, avionics, and passenger comfort are all affected by unwanted vibrations caused by engines, airflow turbulence, and mechanical interactions [1]. These vibrations can lead to accelerated fatigue, structural damage, sensor error, and decreased system reliability. A vibration control system contains mechanical, electronic, and computational components to detect, analyse, and reduce unwanted vibrations. A typical vibration control system uses sensors, controllers, and actuators to control unwanted vibrations. Vibration is in the frequency range of 10-500 hertz (Hz); 10-2,000 Hz or 10-3,000 Hz [2] may be encountered in aircraft, missiles, and tanks. In this research, a vibration control system based upon filters for aircraft applications is developed by using an Arduino Uno board and a 801S shock vibration sensor. Implemented digital filters detect vibration signals and attenuate them around certain problematic frequencies. In effect, they act like a "vibration suppressor" that reduces the amplitude of harmful frequencies without needing heavy mechanical dampers. The high-frequency vibration test is performed for the purpose of determining the effect of vibration on components. In our implementation, we designed and implemented FIR (Finite Impulse Response) and IIR (Infinite Impulse Response) digital filters created by giving specific cut off frequencies—101 Hz, 301 Hz, and 500 Hz—using MATLAB FDA tool, which represent test points for typical vibration ranges in aircraft structures. The sensor (801S vibration shock sensor) is connected via male-to-female jumper wires to an Arduino microcontroller, which is powered by a 9V battery (using a proper battery connector). The sensor measures the vibration and produces digital output. The produced digital output of the vibration sensor passes as an input to the high-pass FIR/IIR filters, and if a set threshold value is greater than the filtered output value of the FIR/IIR filter, then the on-chip LED of the Arduino Uno turns ON.

In the proposed system, high-pass FIR and IIR filters are designed and implemented on the Arduino Uno board. FIR filters are non-recursive and inherently stable and can be designed for precise linear phase; they guarantee that the output does not feed back into the filter processing. In contrast, IIR filters include recursion and are more computationally efficient (fewer coefficients), but they need careful design to maintain stability. Research shows that IIR filters are more sensitive to finite-precision effects than FIR filters, so careful coefficient quantization and filter order selection are important [3]. In digital vibration control, applying digital filters after sampling allows more precise tuning and flexibility than analog filters, and they are less affected by temperature drift or component tolerances.

II. Related Work

Most of the researchers have been working on controlling vibrations in structural components. Sushma Tiparaddi et al. [4] developed an adaptive filter using FPGA to suppress vibration up to 500 Hz frequency. The proposed system based on the XILINX 3E FPGA is successfully tested, and it can be used for structural applications. Pawan Kumar Bissa et al. [5] use bonded linear actuators and sensors to suppress vibrations in a rigid aluminum cantilever beam. The proposed system uses a PID control algorithm, an accelerometer sensor (MPU6050), and a linear actuator to control vibrations induced by an eccentric mass motor exciter. In this system, ANSYS software is used for modelling, harmonic, and structural analysis; the Arduino Uno board is used for controlling PID functions and interfacing with the MPU6050 sensor. Basel Salaas et al. [6] developed a hybrid vibration control system for buildings. The proposed hybrid control system is used to control seismic responses in buildings. It also effectively reduces the structural response under seismic excitations. Authors in paper [7] developed an active vibration isolation system for suppressing external vibrations. In this work an active vibration control system is compared with a passive vibration isolation system, a PD-controlled active vibration isolation system, and a robust-controlled active vibration isolation system.

III. Proposed Vibration Control System

A flowchart diagram of the proposed vibration control system is shown in Fig. 1. The digital vibration sensor (801S) is interfaced with an Arduino Uno board for detecting vibration in the frequency range of 0-499 Hz. High-pass FIR and IIR digital filters of different cut-off frequencies (101 Hz, 301 Hz, and 500 Hz) are designed using Matlab software and implemented on the Arduino Uno board. If the cut off frequency of the designed FIR/IIR filter is 101 Hz, then this filter suppresses the vibration in the frequency range of 0-100 Hz, and if the set threshold value is greater than the filter output value, then the on-chip Arduino Uno board LED turns ON; otherwise, it is OFF. Similarly, the proposed vibration control system works for other cut-off frequencies of the high-pass FIR/IIR filters.

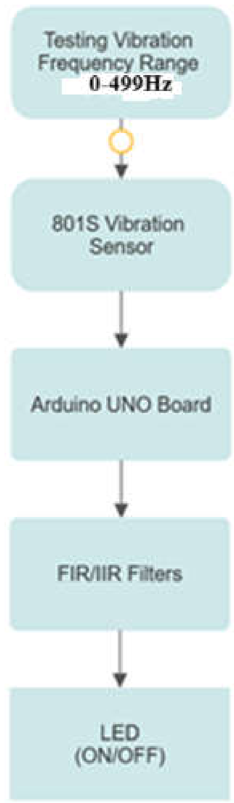

Fig.1 : Workflow of Vibration Control System Based Upon filters

Table. I: Components description

Arduino UNO board	ATmega328P microcontroller board that reads the sensor's digital output and controls the indicator logic.
9Volt Battery	Portable supply that powers the Uno through VIN/barrel jack within the recommended 7–12 V input range.
801S Vibration Shock Sensor	Detect the mechanical vibrations and shocks and acts like a sensitive switch that closes when a sufficient vibration occurs. It has three pins: VCC (3.3V or 5V), GND, and Digital Output Pin.
Jumper Wires	Solder-free wires with pins used to interconnect the sensor, board, and breadboard during prototyping.
LED	A semi-conductor device that produces light when an electrical current passes through it.

3.1 Designing of FIR and IIR Filters

Circuit diagrams for the 1st and 3rd order high-pass FIR [8] filters are shown in Fig. 2(a)) and 2(b), respectively. Circuit diagrams for the 1st and 2nd order High Pass IIR [8] filters are shown in Fig. 3(a)) and 3(b), respectively. In these circuits, x(n) represents digital input, DFF represents a delay element, + represents an adder element, x represents a multiplier element, and y(n) represents filter digital output.

MATLAB FDA tool [9] outputs for filters coefficients at a cut off frequency of 101 Hz for FIR filters of 1st and 3rd order are shown in Figs. 4(a) and 4(b), respectively. MATLAB FDA tool [9] outputs for filter coefficients at a cut off frequency of 301 Hz for an FIR filter of order 3rd order are shown in Fig. 5(a), and at a cutoff frequency of 500 Hz for an FIR filter of order 3rd order are shown in Fig. 5(b). MATLAB FDA tool [9] outputs for filter coefficients at a cutoff frequency of 101 Hz for the IIR filter of the 1st order are shown in Fig. 6(a), and filter coefficients at a cutoff frequency of 301 Hz for the IIR filter of the 1st order are shown in Fig. 6(b). MATLAB FDA tool [9] outputs for filter coefficients at a cutoff frequency of 500 Hz for the 1st-order IIR filter are shown in Fig. 7(a), and filter coefficients at a cutoff frequency of 101 Hz for the 2nd-order IIR filter are shown in Fig. 7(b). MATLAB FDA tool [9] outputs for filter coefficients at cutoff frequencies of 301 Hz and 500 Hz for the IIR filter of the 2nd order are shown in Figs. 8(a) and 8(b), respectively.

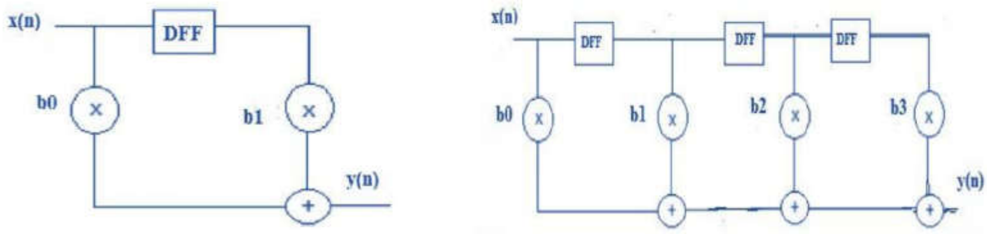

Fig.2 (a) : Circuit diagram of 1st order FIR Filter(b):Circuit diagram of 3rd order FIR Filter

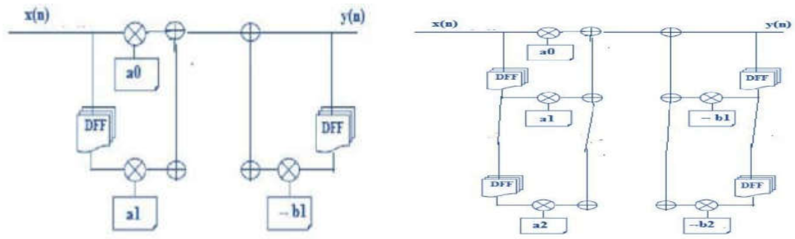

Fig.3 (a):Circuit diagram of 1st order IIR Filter (b).Circuit diagram of 2nd order IIR Filter

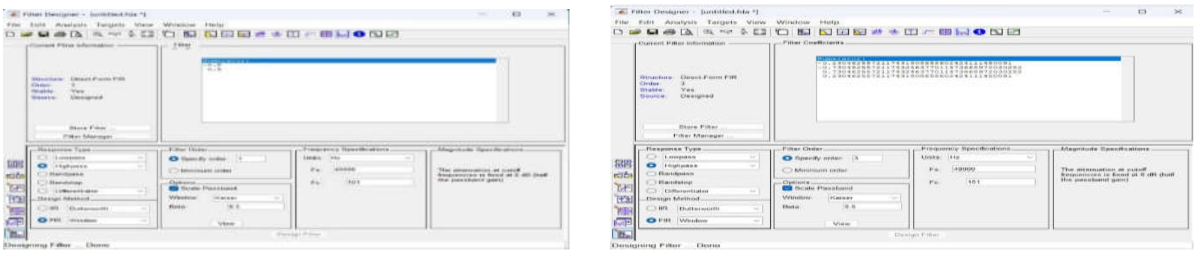

Fig.4(a) FIR 1st order filter coeffiecents at cut off frequency of value 101 Hz.(b) FIR 3rd order filter coefficents at cut off frequency of value 101Hz.

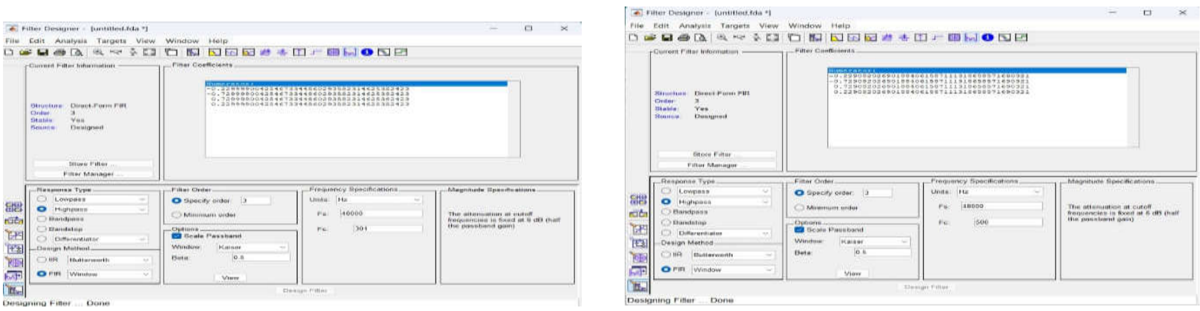

Fig.5(a) FIR 3rd order filter coeffiecents at cut off frequency of value 301 Hz.(b) FIR 3rd order filter coefficents at cut off frequency of value 500Hz.

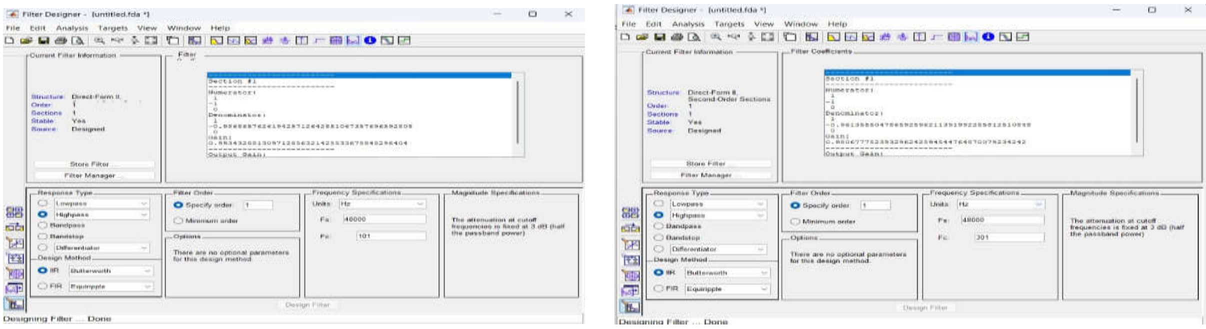

Fig.6(a) IIR 1st order filter coeffiecents at cut off frequency of value 101 Hz.(b) IIR 1st order filter coefficents at cut off frequency of value 301Hz.

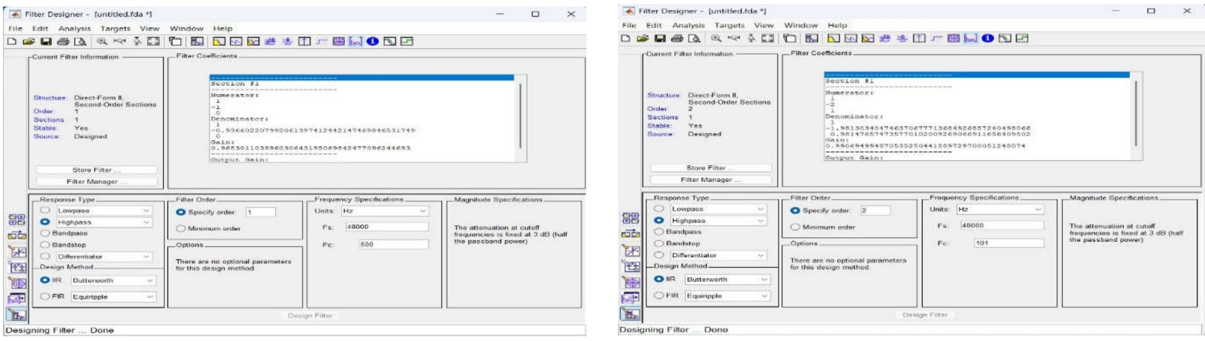

Fig.7(a) IIR 1st order filter coeffiecents at cut off frequency of value 500 Hz.(b) IIR 2nd order filter coefficents at cut off frequency of value 101Hz.

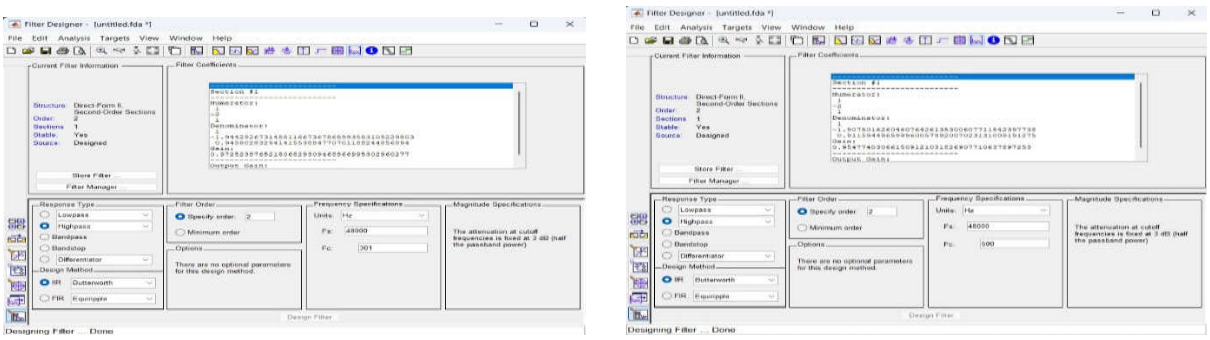

Fig.8(a) IIR 2nd order filter coeffiecents at cut off frequency of value 301 Hz.(b) IIR 2nd order filter coefficents at cut off frequency of value 500Hz.

IV. Experimental Results

An experimental set up diagram of the proposed vibration control system for interfacing of the Arduino Uno board (using a cable) with the digital vibration sensor(801S)) is shown in Fig. 9. An experimental setup diagram of the proposed vibration control system with a 9VV battery is shown in Fig. 10. In the proposed vibration control system, the vibration sensor digital output is fed as input (x(n)) to the FIR/IIR filters. As an Arduino uno board operates at 16MHz clock frequency, so to design a DFF element in FIR/IIR filter, delayMicroseconds(0.0625) function is used. For example, if you want to design a FIR filter of 1st order (Fig. 2(a)), then the filter input (x(n))) is passed after a delay of 0.0625 microseconds (using DFF) and multiplied with coefficient b1, and then it is added with the product of coefficient b0 with x(n) to generate filter output y(n).

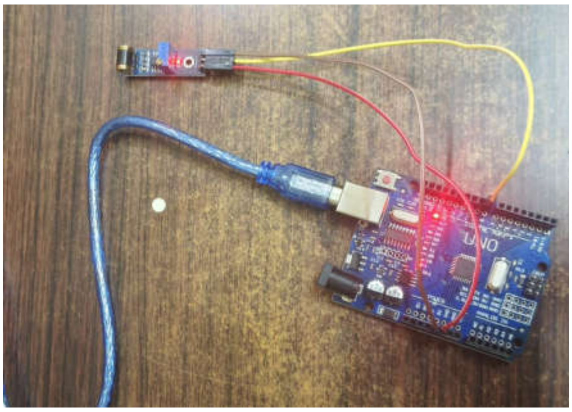

Fig.9: Experimental set up diagram of the Proposed Vibration Control System

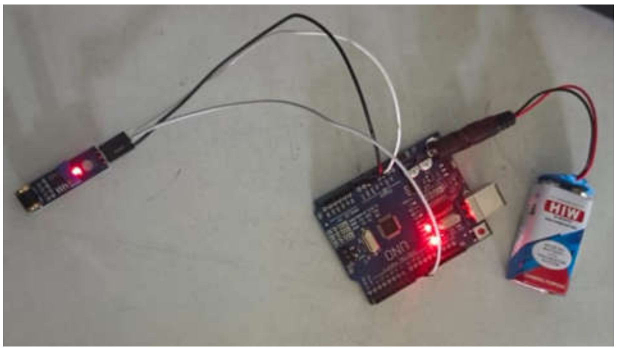

Fig.10 : Experimental Set Up diagram of the Proposed Vibration Control System using a 9V battery

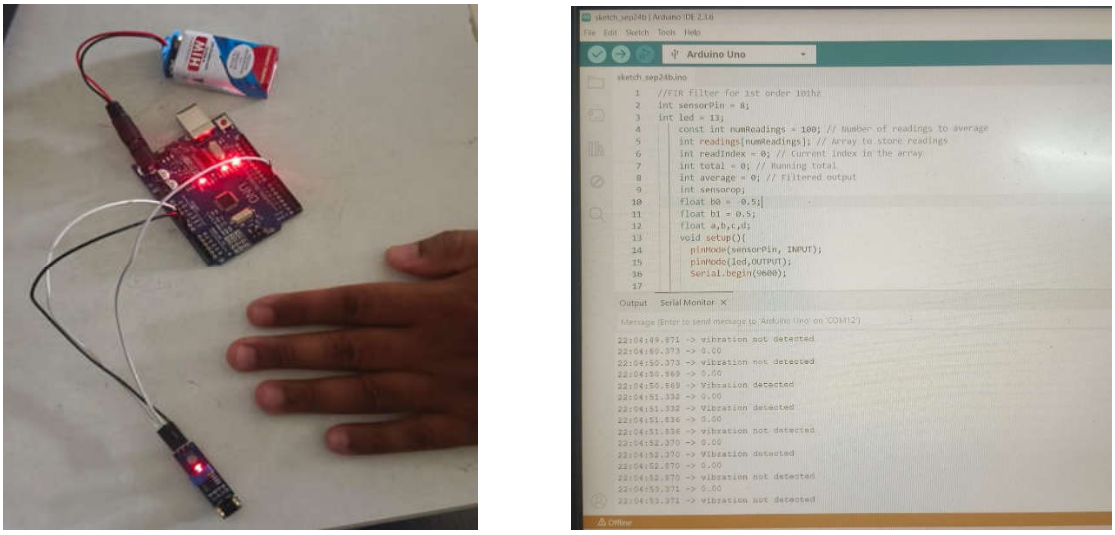

Fig.11 : Experimental output for the proposed vibration control system designed with FIR filter 1st order at cut off frequency 101Hz

Experimental output for the proposed vibration control system designed with a first-order FIR filter at a cutoff frequency of value 101 Hz is shown in Fig. 11. In this figure, detecting manual vibrations from hand movement using a vibration sensor along with the filter output value is shown. As vibration frequency is greater than 101 Hz, the on-chip LED of Arduino Uno turns ON as shown in this figure.

V. Conclusion

By using an Arduino Uno board and an 801S shock vibration sensor, a vibration control system is developed in this paper. The proposed vibration system is tested for a frequency range of 0-499 Hz. High-pass FIR and IIR filters were designed using the MATLAB tool and implemented on an Arduino Uno board for suppressing unwanted vibrations. MATLAB FDA tool outputs for finding filter coefficients are shown. Experimental output for interfacing the vibration sensor and Arduino Uno board is shown. The proposed vibration control system is able to suppress unwanted vibrations, and it can be used for aircraft applications.

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