Design and development of Active Vibration Isolation System for Free Space Optics Communication

Khairiah K. Turahim [a], Asan G. A. Muthalif [b] Syazwani A. Rahim [c],

Department of Mechatronics Engineering, International Islamic University Malaysia

Jalan Gombak, 53100, Kuala Lumpur, Malaysia

[a]khairiah.turahim@gmail.com, [b]asan@iium.edu.my, [c]syazwani_0103@yahoo.com

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Abstract. Free Space Optics (FSO) communication is a technology widely used today. It involves transmission of data from a transmitter to a receiver. In order to achieve successful data transmission, a continuous alignment between the transmitter and receiver telescope is needed. Misalignment could happen due to many factors. Vibration at the transmitter or the receiver is one of the factors that contribute to misalignment. In this work, active vibration isolation (AVI) system is designed and fabricated in order to improve the performance of the transmitter and receiver in an FSO link. First, a virtual prototype is designed. Then a real prototype is fabricated to implement AVI. The result after applying a controller to the AVI system shows 33.1% reduction in amplitude of displacement of the top plate, in other words reduction in amplitude of vibration.

Introduction

Free-space optics (FSO) communication is a technology that uses light to transmit data through free space. Free space acts as the transmission medium which can be air, outer space, and vacuum. An FSO communication link consists of a transmitter and a receiver. The transmitter has a laser diode and gives out laser beam to the receiver, and a photodetector in the receiver detects the laser beam.

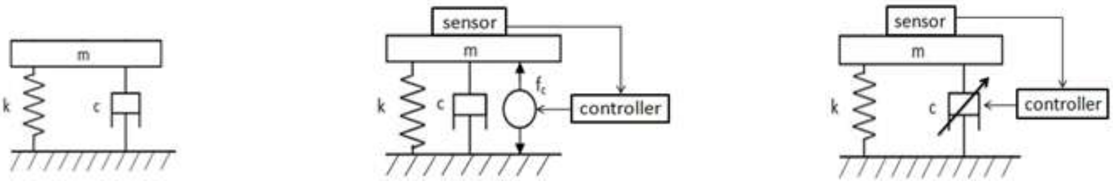
For an FSO link to successfully transmit data, it requires a continuous alignment between the transmitter and receiver [1]. Misalignment will occur due to movement of the transmitter and receiver from the common line of sight and will cause a decrease in the received signal which eventually increases the bit error probability (BEP) [2].

The mounting environment is amongst the factors that contribute to the misalignment of the FSO link. Usually, a transmitter and receiver are mounted on rooftops or on top of a high rise building. Several vibration sources can be found here which includes nearby equipment such as elevators and ventilation units. Furthermore, deformation of the mount due to temperature changes and uneven heating by the sun, human activities such as walking and shutting doors all contribute to misalignment. It is interesting to note that almost all the integrated motion is due to frequency content below 10 Hz [3].Hence, due to the issues discussed above, it is important to have an AVI system to isolate FSO transmission devices and improve their performance.

The rest of the paper is organized as follows. Section 2 gives an overview of active vibration isolation system and the development of its mathematical model. Section 3 describes virtual prototyping using SolidWorks and LabVIEW. Section 4 shows the fabrication of the system, followed by summary in Section 5.

Active Vibration Isolation

Vibration isolation is a common approach used to protect human, device, machine or structure from a vibration source. Vibration isolation systems can be categorized in various ways. One is to categorize them according to control schemes. There are three major control approaches to overcome vibration problem which are passive, active and semi-active [4]. Simple diagrams illustrating basic elements in these three types of vibration isolation systems are shown in Fig. 1.



(a) (b) (c)

Fig. 1: Schematic models showing basic elements in different types of vibration isolation systems: (a) passive, (b) active, and (c) semi-active system

Passive Vibration Isolation. The most commonly applied vibration control techniques are based on the use of passive technologies. The majority of these applications are based on passive damping using viscoelastic materials for vibration control.

Active Vibration Isolation. An active vibration isolation system consists of sensor, controller and actuator. Sensor will detect the motions of the system. Then the data are passed to controller which calculates the required external forces or displacement and send signals to control the actuators. Actuators will provide desired forces or displacements to the system.

Semi-active Vibration Isolation. A semi-active system combines features of a passive system and an active system. Semi-active control devices are essentially passive devices where properties can be adjusted in real time [5].

Mathematical Model of the AVI system

A mathematical model is constructed according to the diagram in Fig. 2. It consists of a top plate, m_1 and a base plate m_2. The base plate rests on a table that can be modeled as a spring, k_2 and damper, c_2. The system will be excited by disturbance coming from the ground, and the disturbance will be transferred to base plate m_2 and top plate, m_1. k_1 and c_1 are the spring constant and damping coefficient of isolation system and f_c is force exerted by the actuator.

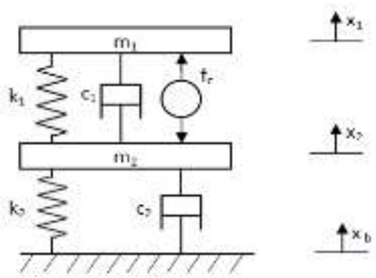


Fig. 2: Physical model of the Active Vibration Isolation System

By applying Newton's Second Law to m_1 and m_2, the equation of motion of m_1 and m_2 are

$$m_1\ddot{x}_1 = -k_1(x_1 - x_2) - c_1(\dot{x}_1 - \dot{x}_2) - f_c$$
$$m_2\ddot{x}_2 = k_1(x_1 - x_2) + c_1(\dot{x}_1 - \dot{x}_2) + f_c - k_2(x_2 - x_b) - c_2(\dot{x}_2 - \dot{x}_b) \tag{1}$$

Based on the equation of motion, the state space form becomes

$$\dot{x} = Ax + Bu \qquad y = Cx + Du \tag{2}$$

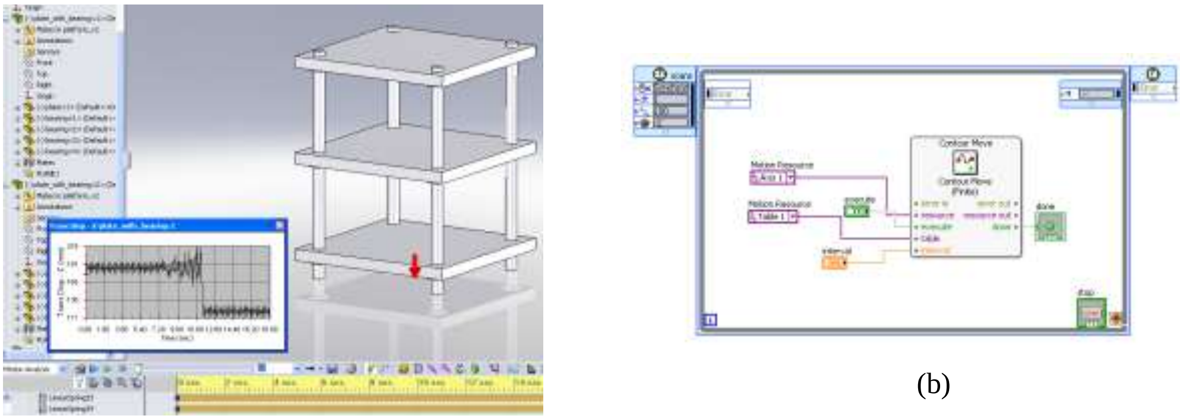
where the matrices of A, B, C and D are:

$$A = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ -\frac{k_1}{m_1} & \frac{k_1}{m_1} & -\frac{c_1}{m_1} & \frac{c_1}{m_1} \\ \frac{k_1}{m_2} & \frac{-(k_1+k_2)}{m_2} & \frac{c_1}{m_2} & \frac{-(c_1+c_2)}{m_2} \end{bmatrix}, \quad B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ -\frac{1}{m_1} & 0 & 0 \\ \frac{1}{m_2} & \frac{k_2}{m_2} & \frac{c_2}{m_2} \end{bmatrix} \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}, \quad D = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix} \tag{3}$$

Virtual Prototyping

Virtual prototyping is a technique used to build a prototype without the need for a physical model. When engineers discover the need for a change and ways to optimize their design, they can simply alter the virtual prototype itself. This eliminates time and money consuming physical prototypes [6].

Virtual Prototyping using SolidWorks-LabVIEW. A 3D model in SolidWorks as shown in Fig. 3(a) is designed according to the mathematical model diagram as shown in Fig. 2. This model is integrated with LabVIEW as shown in Fig. 3 (b) to perform virtual prototyping.



(a) (b)

Fig. 3: (a) SolidWorks 3D CAD model, (b) Contour move in LabVIEW Softmotion Module

Fabrication of Active Vibration Isolation system

The active vibration isolation system was fabricated which consists of two parts; an active vibration isolation test rig which is developed according to the SolidWorks 3D CAD model in Fig. 3(a) and an excitation mechanism.

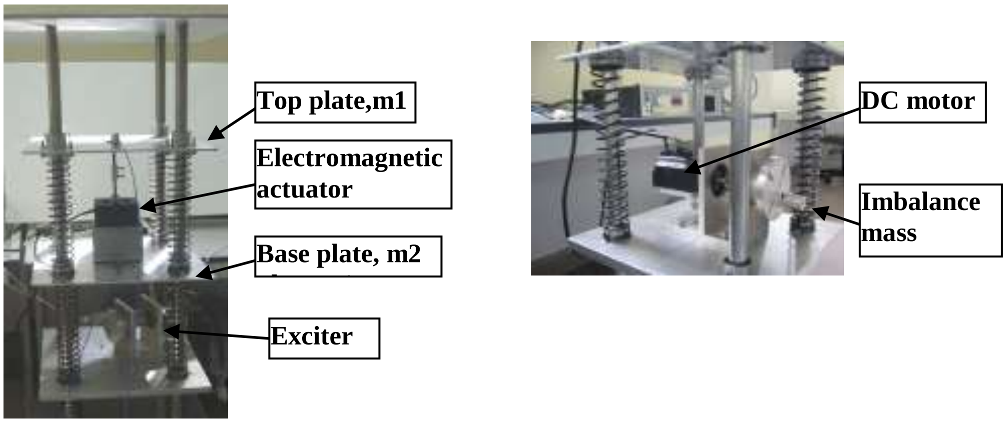
Active Vibration Isolation test rig. The test rig shown in Fig. 4(a) consists of three square aluminium plates that act as m1, top plate, m2, base plate and ground. Four stainless steel rods are placed at each corner to hold the three plates, linear bearings are fixed into the three square aluminium plates so that they are free to move up and down, and springs are put in between the three plates to support and provide an equal distance between them. The three plates are free to move once it is excited by the excitation mechanism.

Excitation Mechanism. The excitation mechanism shown in figure 4(b) is used to excite the test rig. It consists of a DC motor and imbalance mass on a disk.

The main purpose of this project is to reduce vibration at the top plate, where the transmitter or receiver will be placed. To achieve this, an actuator is placed between the top plate, m1 and base plate, m2. Accelerometer is fixed to the top plate, m1 to provide readings for its level of vibration. Accelerometer reading from the top plate will be sent to controller to calculate appropriate output signal for the actuator to cancel the motion and maintain displacement of m1 to near zero. This process repeats continuously for the active vibration isolation system.

Experimental verification

The active vibration isolation system was tested using simple gain feedback controller with a step input excitation of 9Hz. The displacement of m1 is reduced by 33.1% compared to without controller as shown in Fig. 5



(a) (b)

Fig. 4: (a)Hardware setup of active vibration isolation system, (b) Excitation mechanism

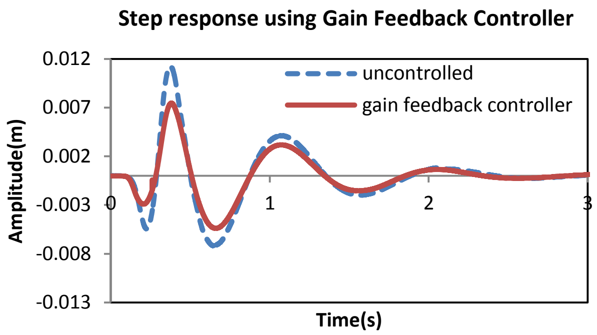


Fig. 5: Step response using gain feedback controller

Summary

Active vibration isolation system can be used successfully to improve FSO transmission. A simple feedback controller has shown to reduce vibration of the top plate, where transmitter or receiver is placed by 33.1 % for a step input. The proposed system can be used successfully to reduce vibration below 10 Hz. The design of an AVI system using virtual prototype in SolidWorks and LabVIEW is also shown in this paper.

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