ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

MEMS-based Feedback Controller

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03/24/2023

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1. Introduction

1.1 Problem:

Seismic activity is a major problem in many parts of the world, especially in earthquake-prone regions. The effects of seismic activity on buildings and infrastructure can be severe, leading to damage, equipment failure, and even collapse. This can result in significant financial losses, as well as serious safety risks for people in and around the affected structures.

To address this problem, various methods have been developed to try and mitigate the risks of seismic activity. One of the most common methods is to design buildings and infrastructure to be earthquake resistant. This involves using materials and construction methods that can withstand the ground shaking that occurs during an earthquake. However, even earthquake-resistant buildings can suffer damage or fail in severe earthquakes, especially if they are not designed to withstand the maximum expected levels of ground shaking.

Another method that has been developed to mitigate the risks of seismic activity is structural control. This involves using various devices and systems to control the vibrations of structures during earthquakes. One of the most common types of structural control systems is known as passive control, which uses devices like dampers and isolators to reduce the effects of seismic activity on structures. However, passive control systems are limited in their ability to adapt to changing conditions during an earthquake and may not be effective in all situations.

Active control systems, on the other hand, are designed to actively control the vibrations of structures during an earthquake. These systems use sensors to measure the vibrations of the structure and feedback controllers to adjust the input to the shake table or other control devices. Active control systems are generally more effective than passive control systems, but they can be more complex and expensive to implement.

Our goal is to design a MEMS-based accelerometer which is a type of sensor that can be used to measure the vibrations of structures during an earthquake. These sensors are small, lightweight, and can be placed in multiple locations throughout a structure to provide a detailed picture of its response to seismic activity. MEMS-based accelerometers have become increasingly popular in recent years due to their high accuracy, low cost, and ease of use.

1.2 Solution:

In order to develop a feedback controller that accurately and efficiently controls the vibration of the building model in response to seismic activity, a number of factors need to be considered. These include the type and sensitivity of the sensors used to measure the vibration of the building model, the design and implementation of the control algorithm, and the type of control system used to actively suppress the vibrations.

MEMS-based accelerometers are an attractive choice for measuring the vibration of the building model, as they offer high sensitivity and low power consumption, making them well-suited to remote and battery-powered applications. Additionally, MEMS-based sensors are small and lightweight, allowing them to be easily integrated into the structure of the building model without significantly altering its properties.

The control algorithm used in the feedback controller must be carefully designed to ensure that it accurately and efficiently responds to the measured vibrations. This involves selecting appropriate control parameters, such as gain and phase margins, and tuning the control loop to minimize the impact of noise and other sources of error. In addition, the control algorithm must be robust to changes in the properties of the building model, such as changes in mass or stiffness, to ensure that it remains effective over time.

The Active Mass Driver (AMD) control system is a popular choice for controlling the vibrations of civil engineering structures in earthquake-prone areas. The system consists of a mass attached to the structure via an actuator, which can be controlled to actively suppress vibrations in the structure. The control algorithm used in the AMD system is typically based on a combination of feedback and feedforward control, which allows it to respond quickly to changes in the vibration of the building model.

Overall, the development of a MEMS-based feedback controller for mitigating the effects of seismic activity on civil engineering structures involves a complex interplay of factors, including the selection of appropriate sensors, the design and implementation of the control algorithm, and the choice of control system. By carefully considering each of these factors, it is possible to develop a feedback controller that is effective in reducing the risk of damage or failure due to seismic activity, thereby improving the safety and performance of civil engineering structures.

1.3 Visual Aid:

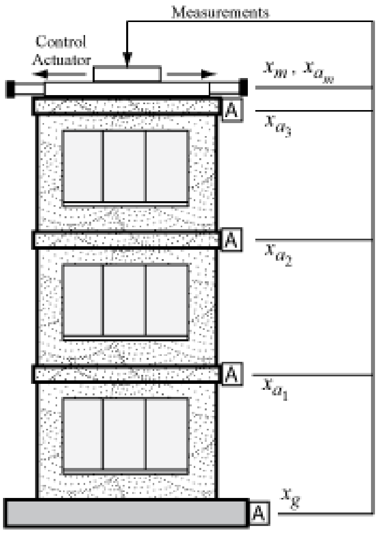

Fig.1. Visual Aid of MEMS-based Feedback Controller **[1]**

1.4 High-Level requirements list:

Reliability: The feedback controller must be reliable and have a high level of availability, with minimal downtime and maintenance requirements. Feedback controller can detect seismic excitation correctly, and overall weight is no more than 10% of the floor mass.

Accuracy：It can make reaction to a slight vibration and must be able to effectively reduce the vibrations and seismic responses of the structure to within specified limits.

Selectivity: Maximum acceleration of floor response is no more than 0.01 g under various seismic excitations.

Safety: The feedback controller must be designed to ensure the safety of the structure and its occupants, and to prevent any potential hazards that may arise from its o

2. Design

2.1 Block Diagram

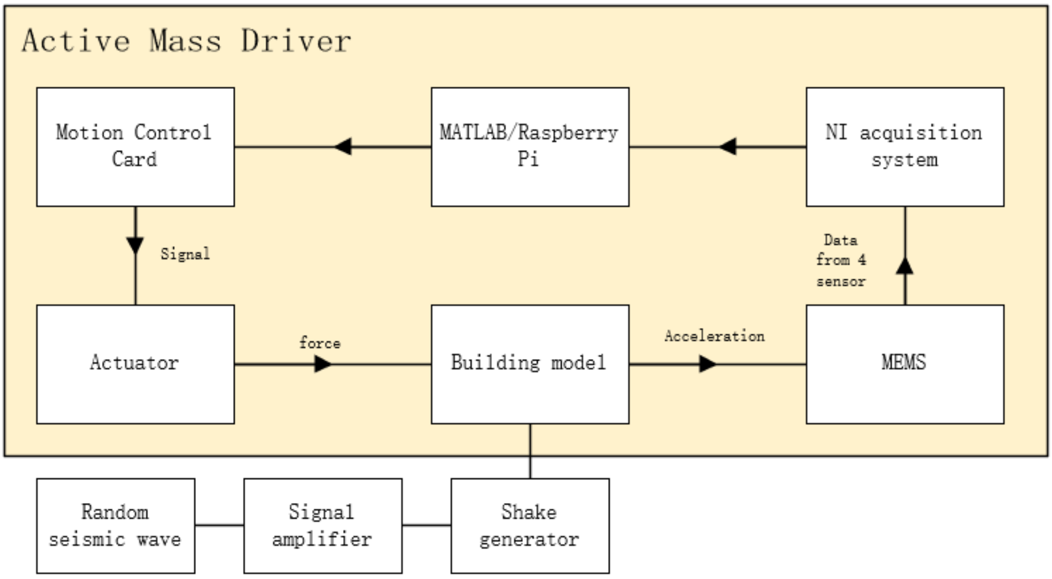

Fig.2. Block Diagram of MEMS-based Feedback Controller

2.2 Subsystem Overview

2.2.1 Shake Generator

Fig.3&4. Amplifier and Shaker

Simulate a random seismic wave using lab's computer, amplify the wave through an amplifier and then transmit it to the shaker.

2.2.2 Three-story building model

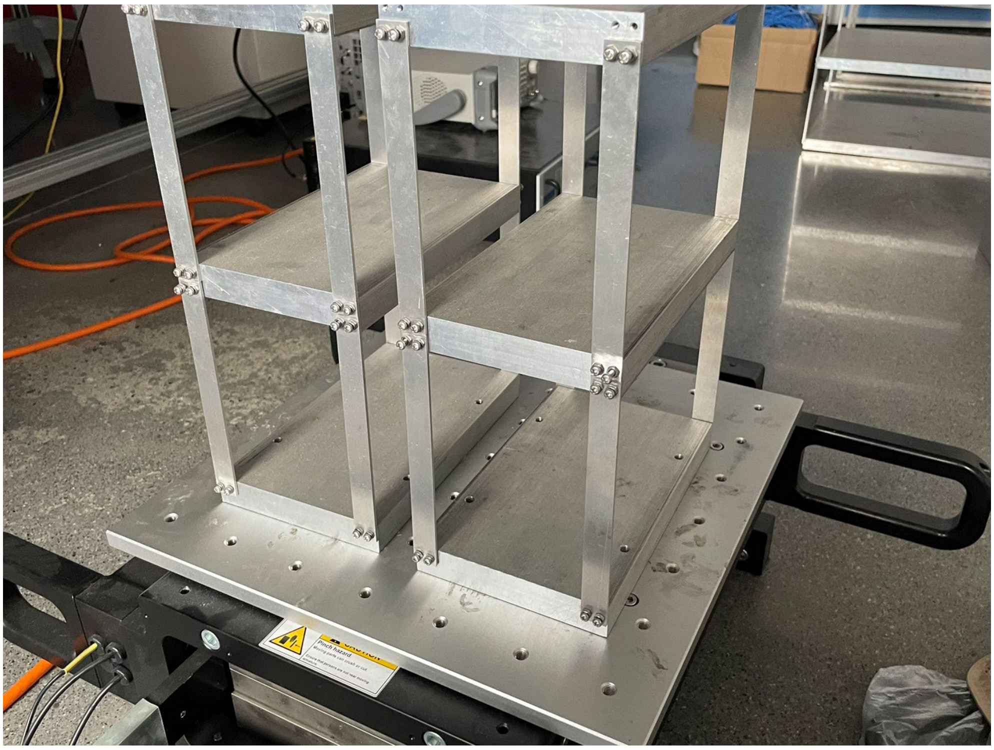

Fig.5. Three steel plate

There are two models, one is as a control group for the experiment.

2.2.3 MEMS

Fig.5. MEMS

Sensors placed at the four corners of the frame to measure the acceleration of the frame structure during shaking.

2.2.4 NI Acquisition System

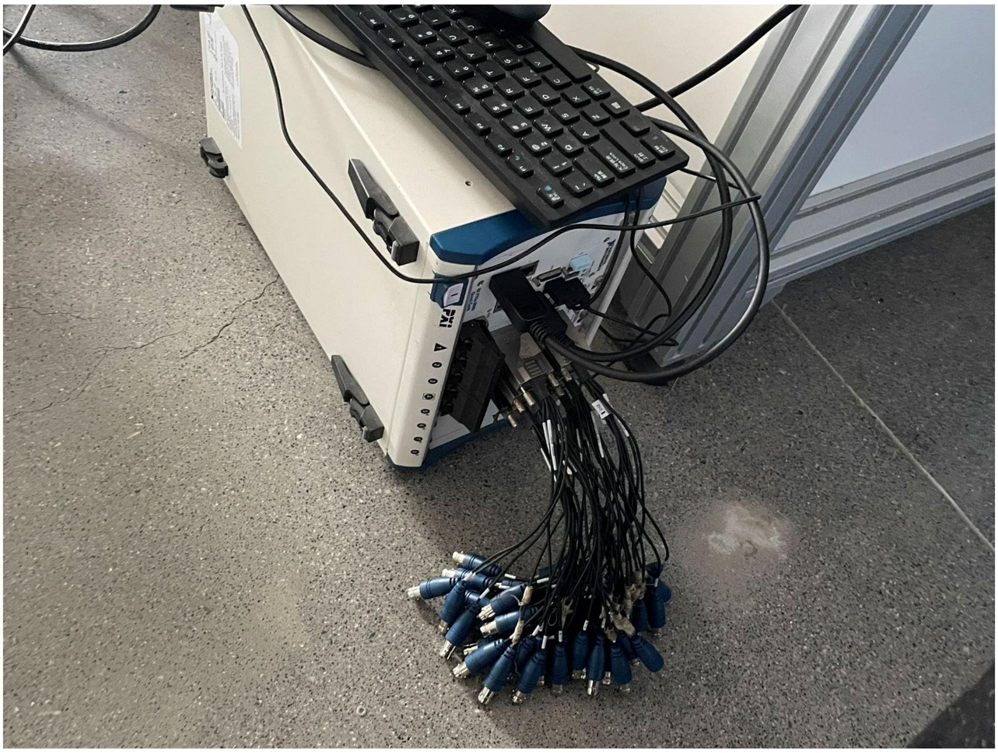

Fig.6. NI Acquisition System collect signals from sensors

Our current setup has four sensors connected to connectors numbered 13, 14, 15, and 16. However, if you want to capture more accurate and representative data, you may consider placing additional sensors. It's important to note that adding more sensors may come with more complex calculation. To avoid unnecessary troubles, we decide to optimize the placement of the sensors to strategically position them at the top of the building, where the vibrations are expected to be the greatest.

2.2.5 Motion Control Card & Pulse Generator

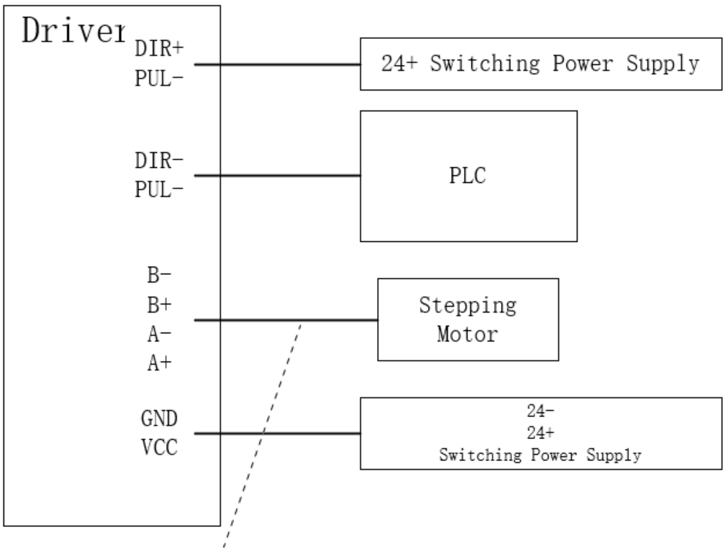

Fig.7. Circuit Schematics for Pulse Generator in Actuator.

2.2.6 Actuator

Fig.8. Actuator

It appears that the motor’s one turn causes the mass in the middle to move by 4mm. This level of precision in movement provides us with the ability to control the location, velocity, and acceleration of the actuator very precisely.

2.3.1 Calculation and Simulation

In order to analyze the relationship between the state of our model, ground acceleration, scalar control input, and model response, we need to use the state-space equation for calculations. By doing so, we can determine the amount of force required by the actuator to counteract the shaking from the ground.

Since simulating this process can be complex, we have decided to use our three-story building model for simulation. By optimizing the algorithm in MATLAB and adjusting the actuator, we aim to find the optimal solution to stabilize the model. Through this simulation, we can identify the best approach to make the model steady.

2.4.1 Flow chart for software

So far, our group can not predict what will happen with actuator. Telling actuator what to do directly by our intuition is one of our solutions. The main advantage of this method is that it has a very short time delay, so actuator can make response synchronously.

If this simple method doesn't work very well, we may consider a complex algorithm from website. But accordingly, it has a lot of parameters and will cost more time to calculate. When delay is too high, the actuator's response will not keep pace with vibration.

Another solution is advised by TA, using a neural network to predict the best response of the actuator is a promising approach that can improve the accuracy and efficiency of the actuator's performance. However, it's important to note that collecting and labeling data for training the neural network can be time-consuming and requires careful attention to ensure the data is representative of the actual operating conditions of the actuator.

3. Cost and Schedule

3.1 Cost Analysis

MEMS, three-story building model and other equipment are provided by sponsor, so we just need:

Actuator: ￥230

Arduino and Raspberry Pi: ￥700

Others: ￥570

Total: ￥1500

The total development cost is ￥1500.

3.2 Schedule

3/24	make building model and actuator
4/1	Program Arduino
4/8	algorithm in MATLAB
4/15	simulaiton
4/22	make the servo meter's Rotational Speed-voltage graph
4/29	make the servo meter's Rotational Speed-the mass block's acceleration graph
5/7	design the software to control the actuator used by simulink
4/22-final presentation	bugfix any problems caused in the transition between pcb and the actuator

4. Ethics and Safety

Ethics and safety are a crucial part of product planning.

For Ethics:

1. we have carefully read the relevant code of ethics of IEEE **[3]** and must ensure that MEMS will not violate the rules. All product-related data must be true, which is related to the privacy of users. Invading the privacy of others is strictly prohibited.

2. The feedback controller relies on data from sensors, which must be protected from unauthorized access or misuse. The data collected from the MEMS-based accelerometer must be securely transmitted and stored to prevent any compromise of privacy or security. The controller must also be designed with robust security features to prevent unauthorized access to the system.

3. It is essential to ensure that the feedback controller is transparent and accountable in its operations. This includes ensuring that the controller's actions are clearly visible, understandable, and auditable. There should be a mechanism in place to monitor the performance of the controller, identify any issues that arise, and take corrective action as necessary.

4. The development of the feedback controller must also consider the environmental impact of the system. The materials used in the MEMS-based accelerometer and AMD control system should be environmentally friendly, and the system's power consumption should be minimized. The system's life cycle should also be considered, including its end-of-life disposal.

For safety:

1. the reliability and safety of the MEMS-based accelerometer and the AMD control system are of utmost importance. The controller must be designed to operate within safe limits, and the MEMS-based accelerometer must be accurately calibrated and tested for reliability. Failure to ensure reliability and safety can lead to catastrophic consequences, including loss of life and property damage.

2. the production of products needs a long time of welding work. We need to follow the laboratory rules to improve the accuracy of products and avoid scalding of operators.

3. MEMS technology needs to be controlled by electricity. We should be careful about electric shock accidents caused by touching the wire connecting the sensor during the experiment.

Reference

[1] B. F. Spencer Jr., S. J. Dyke, and H. S. Deoskar, "Benchmark problems in structural control: Part I-active mass driver system," Earthquake Engng. Struct. Dyn., vol. 27, pp. 1127-1139, 1998. [Accessed: 24- Mar- 2023].

[2] G. J. Balas, "Synthesis of controllers for the active mass driver system in the presence of uncertainty," in Proceedings of the 1997 ASCE Structures Congress, Portland, OR, USA, 13-16 Apr. 1997, pp. 1087-1090. [Accessed: 24- Mar- 2023].

[3] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 24- Mar- 2023].