

# Design and Implementation of Active Control for Adjacent Buildings during the Earthquake on Benchmark Structure

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**ABSTRACT:** This paper presents an active control of adjacent buildings during earthquake on benchmark structure. The presented method uses accelerometer to measure the structures acceleration and its direction. Controller uses the data to make decision about mass displacement (in this case mass is inverse pendulum) and this will reduce the vibration and acts as a damper. For testing the proposed method, a benchmark structure with two building is used. The test results show the feasibility of this method for adjacent structures.

**KEYWORDS:** Active control, Earthquake, accelerometer, adjacent buildings.

## I. INTRODUCTION

More than 150 years ago, cities looked very different from the way they look today. A high-rise building is a tall building, as opposed to a low-rise building and is defined differently in terms of height depending on the jurisdiction. It is used as a residential, office building, or other functions including hotel, retail, or with multiple purposes combined. Because of increasing birth rate in last decades and lack of residential area in cities, number of tall buildings are increased. The materials used in such buildings are usually lightweight with very high flexibility. In the construction of high-rise structures, it should be noted that elevation is often accompanied by an increase in the softness and weakness of damping, which increases the sensitivity of the structure to dynamic forces such as wind, sea waves and earthquakes. Moreover, due to their high energy absorption, these structures are prone to high-amplitude vibrations even at low wind speeds [1]. To attenuate these vibrations, dampers are used as actuators. Dampers can be either passive or active. Passive damping is used to reduce vibrations of machining tools. The drawback with the passive damping system is that it is adjusted to damp out vibrations in one restricted frequency range. Active damping uses real time measurements to dampen the vibrations and is not tuned for one specific frequency range. Active dampers are more efficient and they have the ability to implement different control strategies. Gathering and processing data in active control is very important and it must be real time. Sensor selection and placement is one of the challenges in this field. In this paper there are two hardware and software part. Hardware part contains sensor, processor board and actuator. Software part contains the control algorithm and, in this work, it will implement on Matlab.

## II. RELATED WORK

Vibration may be caused by nearby traffic or subways, building mechanical systems, or simply normal human activity, such as walking across the floor. This vibration does not jeopardize the building's structural integrity. Yet, while the actual movement may be minimal, human perception of motion is significant. Vibration can be disturbing to building occupants. In 2010, the effectiveness of MR dampers for seismic response reduction is examined in a coupled building control scheme. Buildings were coupled with passive and active components. The buildings were three and six floor and they were connected with MR dampers [2]. Two semi-active control methods are proposed in a research to control the performance of a structure equipped with MRdampers. The first method is the Simple Adaptive Control method and the second one is the genetic-based fuzzy control method. In the SAC method, the response of the structure is optimized by forcing the controlled structure to behave like the model which is a system with desired behaviour. This method is a direct adaptive control method and does not require explicit system identification or observation. In the second approach, an intelligent controller using fuzzy logic and genetic algorithm is developed [3]. In another research, three types of control model of semi-active damper were evaluated to identify a suitable control model of adjacent buildings connected with semi-active damper. A hybrid model, that combines skyhook and ground hook control model, can be applied to control seismic response of adjacent buildings simultaneously. Hybrid control model is more efficient to control seismic response of adjacent building where building movements are limited. Hybrid control

model can be applied for the vibration control of the parallel buildings under strong wind and another excitation force [4]. In other work, two adjacent buildings are considered as lumped mass models connected to each other using discrete viscous dampers. A pseudo excitation formula is used to generate an earthquake load in a frequency domain. The optimization procedure consists of two parts including discrete and continuous optimizations. An outer-loop (discrete optimization algorithm) finds the best configuration of a limited number of dampers between two buildings; an inner-loop (continuous optimization algorithm) finds the optimal damper coefficients of the dampers [5]. Different vibration characteristics of neighbouring buildings result in structural pounding which may lead to harmful damages. In researches like this, special methods use for investigating optimum viscous damper capacity and number for prevention of one-sided structural pounding between two adjacent buildings under earthquake motion [6]. In another work, a comprehensive sensitivity analysis of two single degree of freedom impacting oscillators was carried out using Sobol' method. The overall conclusions of this analysis are that the frequency ratio is, in general, the most important parameter as far as maximum force and ductility demand are concerned [7]. In other researches, tuned mass dampers<sup>1</sup> were used. The effectiveness of sharing a TMD between two adjacent buildings for seismic response reduction is investigated in this study. Thus, two configurations of shared TMD were proposed, a classical shared TMD known in the literature and a hybrid shared MR-TMD proposed in this study [8]. In other experiments, PTMD2 is used. In a word, PTMD is an effective means in vibration control on structures. Although PTMD shows better efficiency comparing to traditional TMD, it needs to be very careful to design and calculate the detail parameters, especially for properties of viscoelastic layer and gaps between mass and limiters [9]. In other researches, simple adaptive control<sup>3</sup> methods are used to reduce vibration of structures. The effectiveness of the simple adaptive control method for mitigating the seismic responses of the coupled system was investigated in this study. The coupled system consists of two buildings with different heights connected by MR dampers or hydraulic actuators at three levels. The performance of SAC was compared with optimal control theory and Lyapunov stability theory-based algorithm [10].

### III. METHODOLOGY

The main purpose of this paper is to reduce the vibration of adjacent building and for achieving this goal, building vibration data must be gathered and send to a processor. After gathering data by a processor board, it will transfer to Matlab to apply to controller and the out put of controller will transfer to processor board to control the actuator. We use serial port for transferring data between Matlab and processor board. In this case, an Arduino UNO board is used as processor. Fig. 1, shows the Arduino UNO board.



Fig. 1 Arduino UNO

Arduino is an open-source electronics platform based on easy-to-use hardware and software. Over the years Arduino has been the brain of thousands of projects, from everyday objects to complex scientific instruments. A worldwide community of makers - students, hobbyists, artists, programmers, and professionals - has gathered around this open-source platform, their contributions have added up to an incredible amount of accessible knowledge that can be of great help to novices and experts alike. The best advantage of Arduino boards is the ability to connect to Matlab. Arduino and Matlab release a support package for boards that they can program by Matlab functions and blocks. By adding Arduino support package to Matlab, we can monitor the data of different sensors and use Matlab functions for processing them. Fig. 2, shows the Simulink blocks for Arduino.

<sup>1</sup>Tuned Mass Dampers: TMD

<sup>2</sup>Pounding Tuned Mass Damper

<sup>3</sup>SAC: Simple Adaptive Control

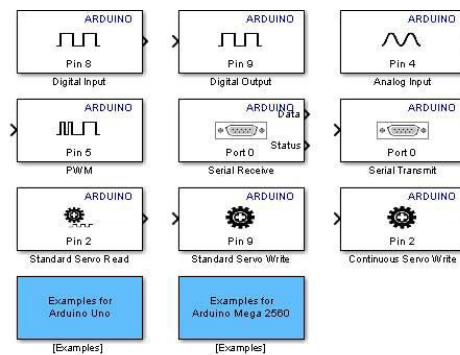


Fig. 2, Arduino Simulink blocks

For sensing the vibration, an accelerometer is used. ADXL345 is a 3-axis accelerometer with high-resolution (13-bit) measurement at up to  $\pm 16$  g. Digital output data is formatted as 16-bit two complement and is accessible through either an SPI (3- or 4-wire) or I2C digital interface. The ADXL345 is well suited for mobile device applications. It measures the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion or shock. Its high resolution (4 mg/LSB) enables measurement of inclination changes less than  $1.0^\circ$ . Fig. 3, shows the ADXL345 module.



Fig. 3, ADXL345 module

For actuator part, two servo motors are used. Servo motor is placed on top of each structure and a mass attached to it. Fig. 4, shows the used servo motor.



Fig. 4, Servo motor

ADXL345 attaches on the structures and measures the vibration. Fig. 5 shows the benchmark structure.

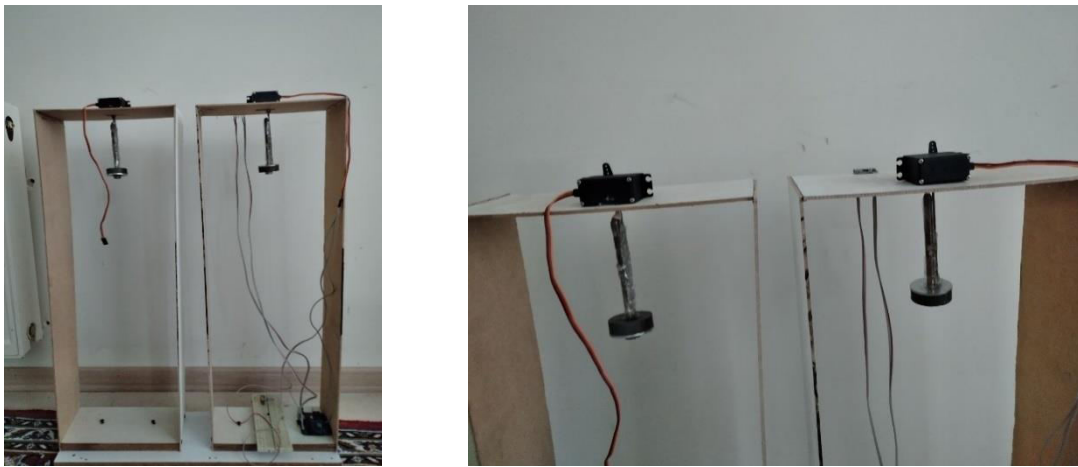


Fig. 5, Benchmark structure

By receiving the sensor data, Matlab make decision and control the servo motor angle and the speed of changing angle. If the variation in accelerometer data was big, the servo motor shaft angle will go to max or min angle with high speed and if accelerometers data was change slowly, servo motor variation is slow too. After a big and fast change in servo motor angle, by getting feedback from sensor, Matlab will make decision whether it change the servo motor fast or slow and by managing that, it avoids self-vibration because of pendulum movement. Fig. 6, show the pendulum movement.



Fig. 6, Pendulum movement

#### IV. EXPERIMENTAL RESULTS

By connecting sensor to Arduino board and send data t Matlab, and shake the table, sensor output data will change and oscillates. By implementing the controller, we see a damping output and the vibration of structure is reduced. Fig. 7, show the damping output of sensor by presence of controller.

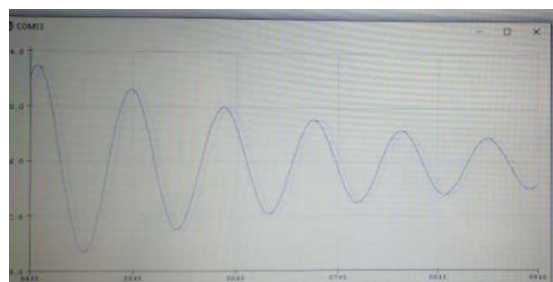


Fig. 7, structure vibration with controller

## V. CONCLUSION

We have implemented an active control for adjacent building on a benchmark structure. An accelerometer used for detecting vibration and displacement. Data from sensor goes to a microcontroller board and then it sends the data to Matlab by serial port. Sensor data goes to a controller and the output of the controller goes to processor via serial port and it controls the pendulum angle to reduce the vibration and displacement. According to the results, it reduces the vibration and it had acceptable effect.

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