COMPLETE DECENTRALIZED DISPLACEMENT CONTROL ALGORITHM

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ABSTRACT:

Damages caused on structures by seismic events could produce the lost of a great number of human lives. In some cases the building's contents can often be more expensive than the structure. It is desirable to maintain the structure in optimal conditions before, during and after a seismic event. This could be achieved if the structure's displacements are restricted. The controls algorithms have been greatly develop in the last years. Mainly they are classified in four forms of control: passive, active, semi active and hybrid. Most of the control forms have been applied on a centralized way; this means that all the information is sent to a central node where control algorithm is then calculated. The problem of this paradigm is the difficulty to scale its application. In this paper a completely decentralized control algorithm is analytically implemented. The algorithm considers that each one of the control systems take the best decision based solely in the information collected at its location. The semi active control is used because of following advantages over the active control: minimum consumption of energy, little or null possibility of destabilization, diminution of the possibility of data saturation, and reduces the response time in caparison to the centralized control.

KEYWORDS: semiactive control, smart sensors, decentralized algorithm.

1. INTRODUCTION

Several important cities are constructed near seismic areas located in the ring of fire. The seismic activity occurred in such places could incur in the lost of human lives and important economic losses for structural damages. A possible solution to reduce damage is to limit the displacement of the structure. This can be achieved using a more robust designed or implementing control device. The first option usually conduced in a more expensive structure. The second option has been used in countries like Japan, USA and China.

Structural control can be grouped in four types: passive, active, semi-active and hybrid. Studies had shown that active control reduces greatly the displacements of the structures; however power requirements and the possibility of destabilization could hinder its use. Passive control is the most economical; nevertheless its capabilities are limited. Hybrid control (mainly combination of passive and active) takes the best of the two systems. Semi-active control has some advantages over the active control such as: minimum consumption of energy and little or null possibility of destabilization. Nonetheless, the reduction of displacements over the structure is greater than active control but better than passive control.

Houser et al. reference a complete state of the art of the different types of structural control and energy dissipate devices. This work also presents some of the main applications.

One of the problems with the implementation of control (active or semi-active) is the requirement of interconnection of all of the sensors over the structure to a central node. This centralized scheme allows for a complete solution of the control algorithm. The setback of this methodology is the high of cost of installation therefore scalable impractical.

Decentralized paradigms offer a scalable solution. The cost of the decentralization is paid in the performance of the control. Lych presents two decentralized control methodologies: market-based control (MBC) and energy market-based control (EMBC). These control algorithms were inspired in the interaction of free-market buyers and sellers that leads to an optimal control solution. A 20-story structure is selected as an illustrative example to compare the performance of the MBC and EMBC and the centralized linear quadratic regulation (LQR) approaches.

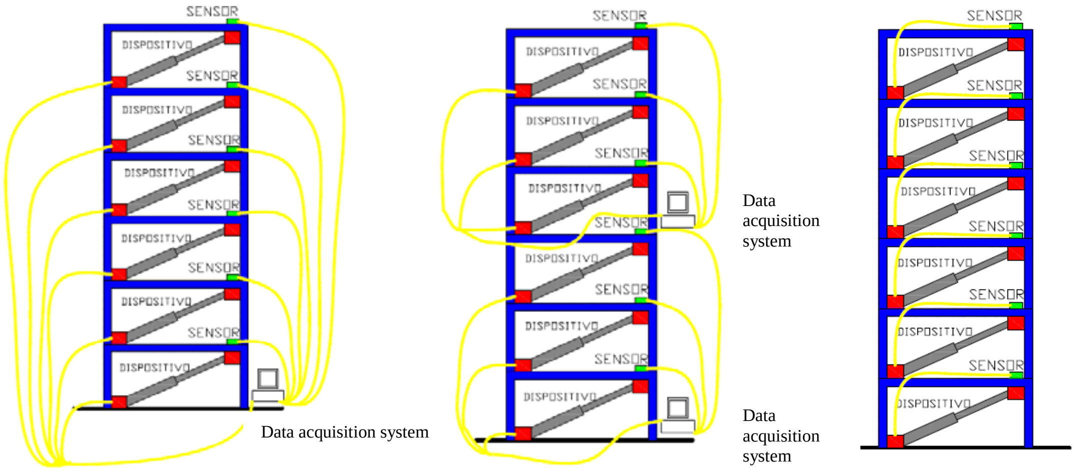
Loh and Chang present the smart control strategies for active or semi-active devices under seismic excitations using the concept of decentralized control algorithm. This algorithm control is based on the H2 control theory in which accelerometer feedback control used. The authors explore four different techniques: (a). Partially decentralized control, (b). Fully centralized control,(c) Half centralized control, (d) Fully decentralized control, (e) Partially decentralized control (coupled & uncoupled). The result over a 20-story structure is presented.

The objective of this paper is to explore the performance a complete decentralized control algorithm using semi-active dampers. This is applied in the five-story steel structure Kajima Shizuoka Building (Kurata et al.). In the near future simulations for the 20-story SAC building will be presented.

2. DECENTRALIZED AND CENTRALIZED CONTROL

Structural control is effective to improve the behavior of the civil structures. It is difficult and expensive to implement a control system in tall structures when the algorithm solution is calculated in only one point, that is, the number and longitude of the cables required could be large. To over come this, the problem is divided in sub-problems in which there are more than one point where the algorithm control is calculated. A final possibility is that each device has its own autonomy; therefore control algorithm solely for its location is calculated. Based on the above information a new classification for control algorithm based in the number of points where the algorithm is calculate is:

- Centralized (figure 1a)
- Partially centralized (figure 1b)
- Complete decentralized (figure 1c)



(a) (b) (c)

Figure 1: (a) Centralized, (b) Partially centralized and (c) Complete decentralized.

3. DESCRIPTION OF THE STRUCTURES

3.1 Kajima Shizuoka Building

The Kajima Shizuoka Building is a five-story regular structure located at Shizuoka City in Japan. The floor dimension is 24 x 11.8 meters, and height is 18.95 meters. It has collocated eight Semi-active Hydraulic Damper (SHD) systems in the short direction, on floor levels 1 to 4. The fifth floor does not have any SHD. The connection with the structure is made with steel braces. Also, elasto-plastic steel dampers are collocated at short and long direction of the building (figure 2).

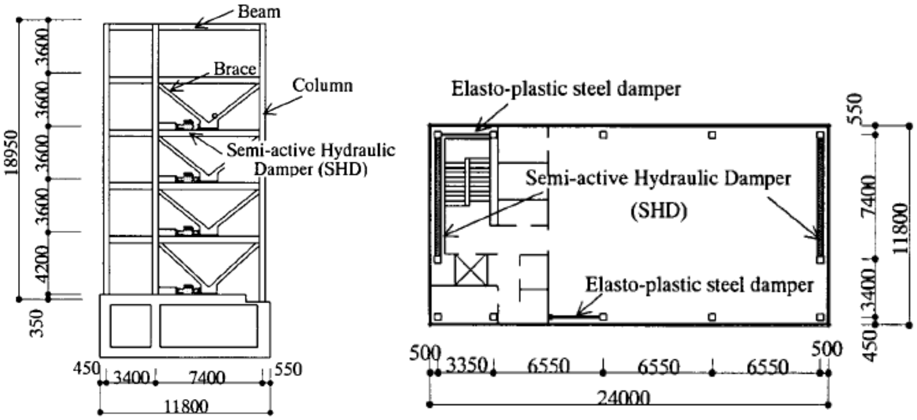


Figure 2. Shizuoka Building (Kurata et al).

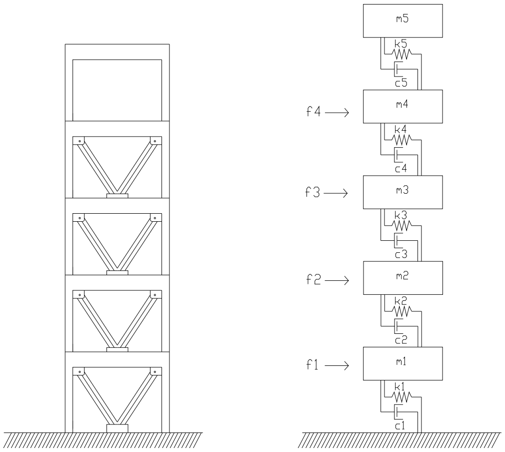


Figure 3. Simplified model (Kurata et al).

The characteristics of the SHD are shown in table I [1]

Table 3.1. Specification for SHD

Maximum damping force	1000 kN
Relief load	800-900 kN
Maximum pressure	30 Mpa
Maximum displacement	+-60mm
Stiffness(with bracket)	>400 kN/mm
Maximum damping coefficient	>200 kN*sec/mm
Minimum camping coefficient	< 1kNsec/mm
Maximum velocity	250mm/sec
Diameter	390 mm
Weight	1300 kg

3.2 SAC building

The structure was design for the SAC Steel project according with the actual code that prevails at South California. The first mode is not the dominant for this building. The structure is build based on steel frames. It has 36 devices located in the positions observed in the figure 4, with variation in height. These were modeled in the same way that the Shizuoka building. Same SHD were used for this building than the Shizuoka Building.

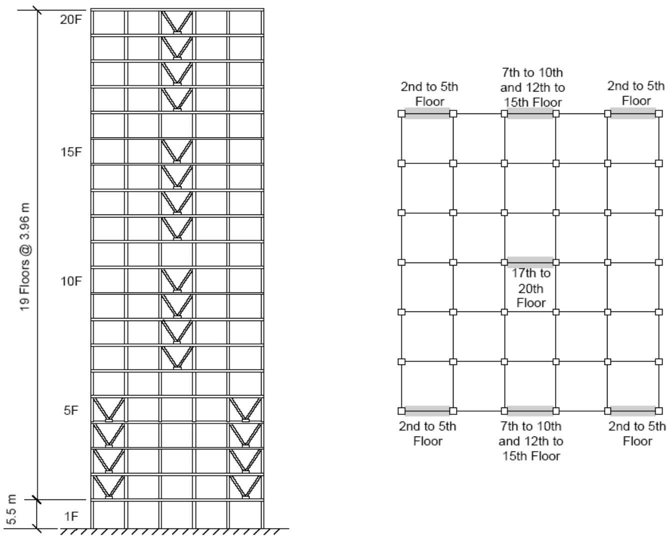


Figure 4 Benchmark structure and the location of the devices (Lynch 2002).

3.3 Earthquakes used

In this paper 4 earthquakes are used: Centro (1940 NS), Taft (1952 NS) y Hachihone (1968 NS). These records were used with the objective to have a reference with the models developed by other authors. The earthquakes have a record length of 53, 54 y 119 seconds respectively, and with a sample time of 0.02 seconds. Additionally, a normalization of a maximum velocity of 50m/s was done as the same as Kurata et al.

4. CONTROL ALGORITHMS

Two types of algorithms were considered in this paper: centralized and decentralized. In the first one, active and semiactive control algorithms are used. In the second one only semiactive control is implemented. Active control algorithm in a decentralized scheme was also investigated, however no decrease in the displacement was found therefore is not presented. Both control algorithms were based on a relative displacement and velocity feedback based on the Linear Quadratic Regulator (LQR). After several combinations were tested, both feedback (displacement and velocity) were equally weight. The control gain was fixed on 0.03 following the results of Kurata et al.

4.1 Centralized active control algorithm

A schematic of centralized control algorithm is presented in figure 5.

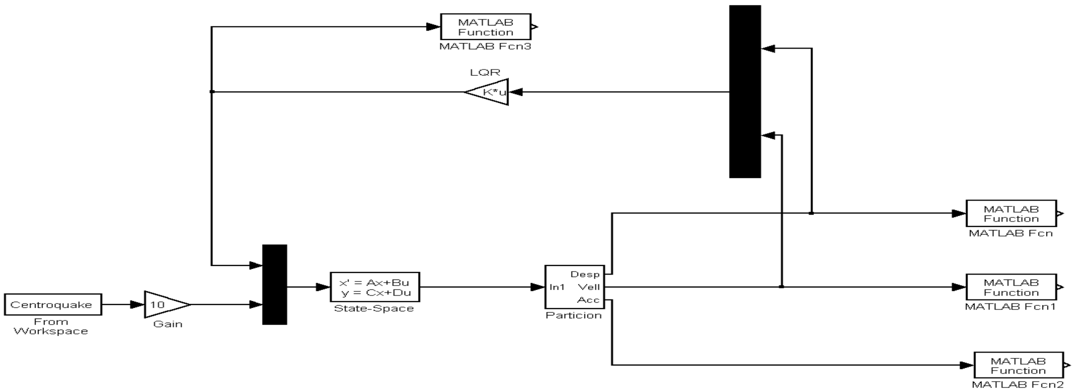


Figure 5. Centralized algorithm based on LQR control.

4.2 Centralized semiactive control algorithm

Jansen and Dyke studied several control algorithms applied to semi-active dampers. Results showed that, among others, the Clipped-Optimal Control (COC) algorithm is suitable for semi-active dampers.

The rules for the damping force f_s in semiactive algorithm are expressed in the following equations:

$$f_{si} = \begin{cases} f_{\max} sign(v_i) \xrightarrow{if} (fd_i * v_i) > 0, |fd_i| > f_{\max} & (1) \\ c_{\max} * v_i \xrightarrow{if} |fd_i / v_i| > c_{\max},\ fd_i \le f_{\max} & (2) \\ ci(t) * v_i \xrightarrow{if} |fd_i / v_i| \le c_{\max},\ fd_i \le f_{\max} & (3) \\ 0 \xrightarrow{if} fd_i * vi \le 0 & (4) \end{cases}$$

Where fd_i, is the damping force command, v_i is the velocity of the SHD, c_{max} is the maximum damping coefficient and f_{max} is the maximum damping force. The equation 1 define the possibility of apply any force and no to exceed the device maximum capacity. Equation 2 allows assigning a force in function of the velocity after checking that is less that the maximum. Equation 3 limits the maximum damping force that can be applied to the system. Finally, equation 4 define that the force and velocity are in oppose directions then none force can be applied. In addition of equations 1 through 4, equations 5, 6 and 7 are used to define the final force to be applied.

$$f_i = \begin{cases} f_{si} \xrightarrow{if} (f_{si}) > 0,\ f_{si} \le f_{lqr} & (5) \\ f_{lqr} \xrightarrow{if} (f_{si}) > 0,\ f_{si} > f_{lqr} & (6) \\ 0 \xrightarrow{if} f_i = 0 & (7) \end{cases}$$

Where f_i, is the final damping force command and f_{lqr} is the optimal force command according with the LQR law. The description of control flow is presented in figure 6.

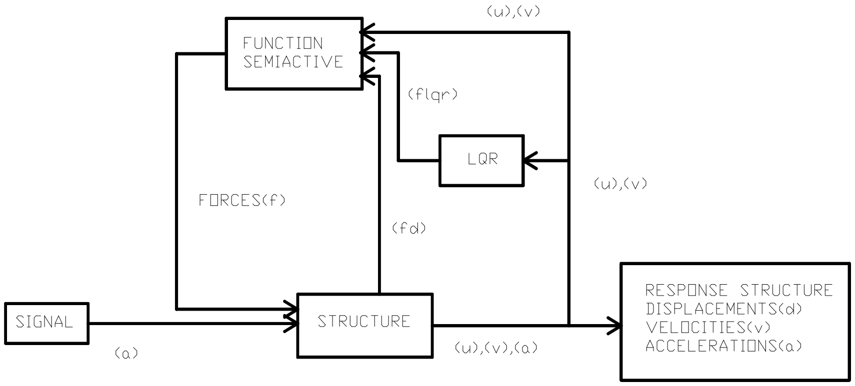


Figure 6. Control scheme.

4.1 Decentralized semiactive control algorithm

To consider the decentralized algorithm it was assumed that at each actuator level a smart sensor is available. Smart sensors have the properties of having a microprocessor on board, capable to perform the control algorithm. Moreover, the smart sensor has wireless communication (Spencer et al.).

Kurino et al (2003), developed an oil device that allows to control the damping coefficient. This damper called “HiDAX”, based its operation in the opening and closing of valves. The system allows to dissipate a great quantity of energy (up to two times more energy than a passive system). The algorithm works only in two modes on and off.

Based on Kurino’s work an algorithm with a modified scheme is presented.

$$Fr = \begin{cases} \mathrm{N} * \mathrm{contp1} \rightarrow vi > 0 \mid vi = 0 \mid \mathrm{N} * \mathrm{contp1} < 1000 \\ -\mathrm{N} * \mathrm{contn1} \rightarrow vi < 0 \mid -\mathrm{N} * \mathrm{contn1} < -1000 \\ 1000 \rightarrow \mathrm{N} * \mathrm{contp1} > 1000 \\ -1000 \rightarrow -\mathrm{N} * \mathrm{contn1} < -1000 \end{cases}$$

(8)
(9)
(10)
(11)
(12)

$$F = \begin{cases} Fr \rightarrow \mathrm{Fr} \leq \mid (vi * C\,\mathrm{max}) \mid \\ vi * C\,\mathrm{max}_i \rightarrow \mid \mathrm{Fr} \mid > \mid (vi * C\,\mathrm{max}) \mid \end{cases} \qquad (13)$$

Where v_i is the velocity at each level in which the device is located, F_r is the proposed force for the system, F is the final force applied to the system that is limited according with the characteristics of the device, C_{max} is the maximum damping coefficient according with the damper specifications, *N*, *contp* and *contn* are the parameters that define the slope in which the force is increase (N, contp and contn are reinitialized to 1 when the system changes of sign). A schematic of the rules describe above are presented in the figure 7.

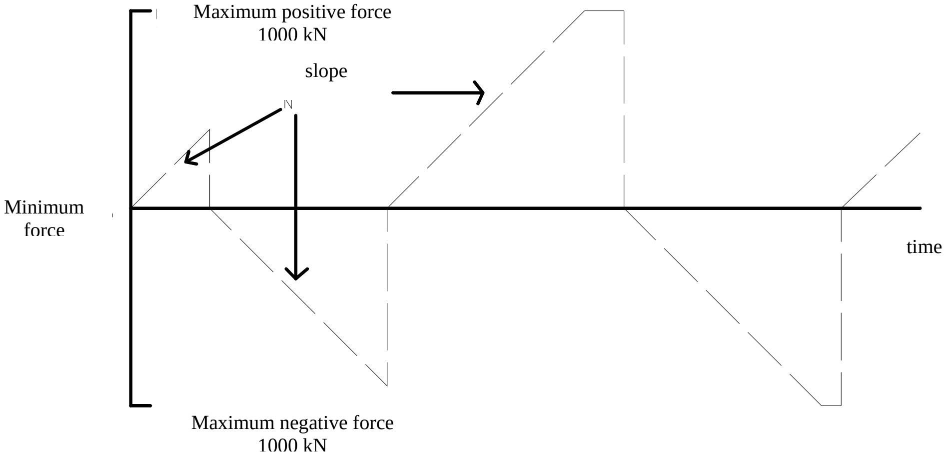


Figure 7. Control scheme.

Based on the proposed algorithm a set of different slopes are used. These are described in table 1.

Table 7.1 Slopes used with the decentralized control algorithm with semiactive devices.

Sample time (s)	N (kN)	slope (kN/s)
0.001	1	1000
0.001	0.1	100
0.001	0.05	50
0.001	0.01	10
0.001	0.001	1

5. RESULTS

After applying the algorithm described above the following results are obtained. For reasons of space only the results of the Centro earthquake is presented.

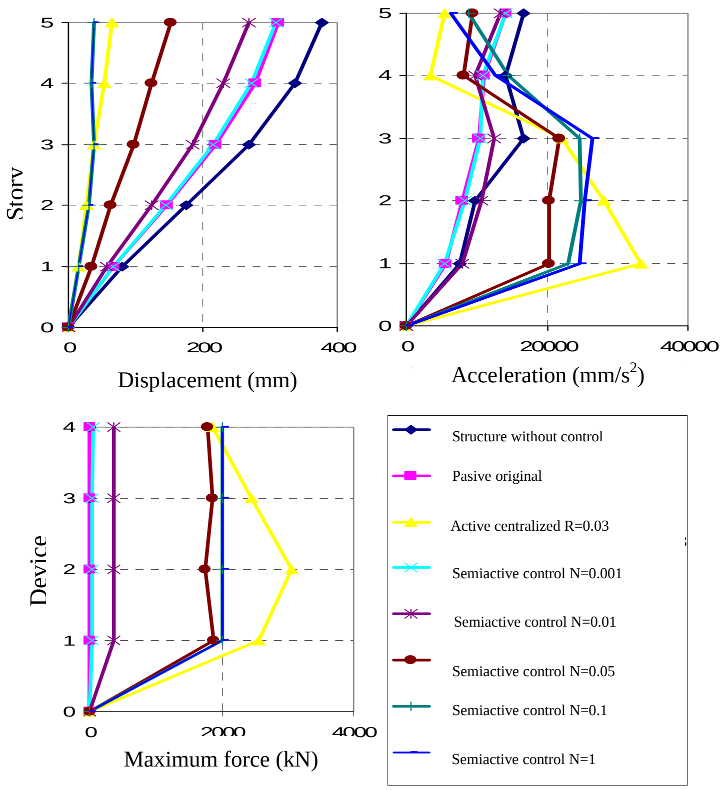
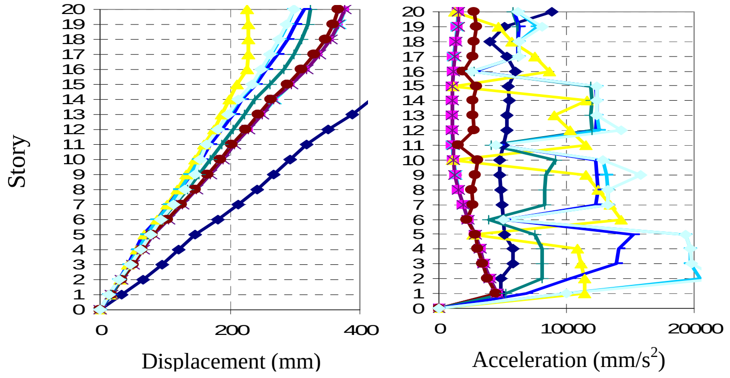


Figure 8. Displacements, accelerations and maximum forces for the 5 story building. Centro-NS.



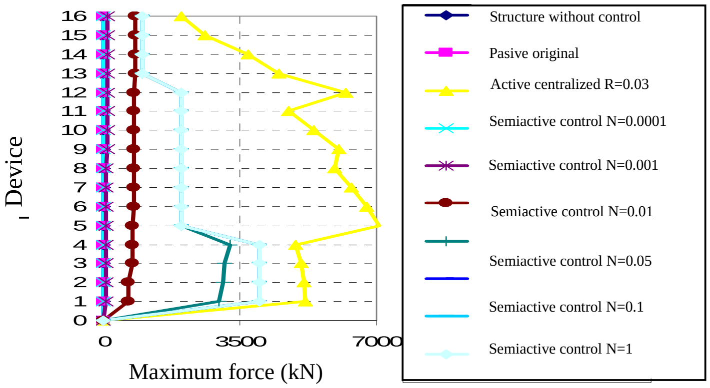


Figure 9. Displacements, accelerations and maximum forces for the 20 floor building. Centro-NS.

6. CONCLUSIONS

From the results observed in the analytical implementation the following conclusions can be drawn.

Active centralized control algorithm reduces the inter-story displacement of the structure; however an increase of the acceleration is observed. Also, the magnitude of the forces needed to be applied to the structure constitutes an important energy effort.

Semiactive decentralized control produce a larger inter-story displacement than the active control. The effect of a large damping slope increases the acceleration present in the structure. This outcome is product of the immediate reaction of the damper velocity movement of the building (an increase of stiffness). Lower values of slope make the structure more flexible and increase the inter-story displacement; nevertheless the acceleration imposed is reduced. The amount of power effort is limited as specify by the proposed control algorithm.

Decentralized control algorithms can achieve reasonable performance with respect of active centralized controls. The main advantage of the decentralized scheme is a reduction in the installation and operation cost.

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