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# DECENTRALIZED REAL-TIME VELOCITY FEEDBACK CONTROL OF STRUCTURES USING WIRELESS SENSORS

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## ABSTRACT

Substantial research studies have been conducted to advance structural control as a means of mitigating the dynamic response of civil structures. Recently, the structural engineering field has begun exploring low-cost wireless sensors for structural monitoring applications. Wireless sensors can be employed to reduce the labor and costs associated with installing extensive lengths of coaxial wires in today's structural control systems. In this study, the wireless sensors are designed to perform four major tasks in a control system: (a) collect real-time structural response data; (b) wirelessly transmit or receive the response data; (c) process data and compute control decisions; and (d) apply control signals to structural actuators. The demands of the control system to respond in real-time pose challenges for wireless sensing and control, due to communication delays between wireless sensors and possible data loss in some instances. This paper investigates the feasibility of employing decentralized and partially decentralized control strategies to reduce communication latency associated with wireless sensor networks. Control algorithms are embedded in a wireless sensor prototype designed for use in a structural control system. Both numerical simulation and experimental results show that decentralized wireless control is viable for future structural control systems.

Keywords: structural control, wireless communication, embedded computing, decentralized control, velocity feedback control

## INTRODUCTION

Over the past few decades, structural control technology has emerged as an effective method for mitigating structural responses and reducing structural damages during strong dynamic excitations (Soong and Spencer, 2002; Chu et al., 2005). Current structural control technology can be classified into three categories: (a) passive control (e.g. base isolation), (b) active control (e.g. active mass dampers), and (c) semi-active control (e.g. semi-active variable dampers). Passive control has the advantage of energy efficiency, and active control has the advantage of being adaptable to real-time excitations. As a hybrid between passive and active control, semi-active control effectively combines these two advantages. In a semi-active control system, sensors are installed in a structure to record real-time structural response data. Based on the response data, a controller executes an embedded algorithm in real-time to determine an optimal set of forces to mitigate the structure response. The

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controller then issues commands to the semi-active devices installed, which in turn apply desired forces to the structure. Examples of semi-active actuators include active variable stiffness (AVS) devices, semi-active hydraulic dampers (SHD), electrorheological (ER) dampers, and magnetorheological (MR) dampers. Because semi-active control devices function by dissipating structural vibration energy, the control system is inherently Bounded Input / Bounded Output (BIBO) stable.

In traditional semi-active or active control systems, coaxial wires are normally used to provide communication links between sensors, actuators and controllers. Installation cost of a wired communication channel can be as high as a few thousand dollars (Celebi, 2002). As structural size grows and the number of actuation and sensing nodes in the control system rises, the installation cost and time for wired sensing or control systems increase significantly (Solomon et al., 2000). To capitalize on future low-cost semi-active devices that may be installed in high density, wireless communication technology can be adopted to eradicate the coaxial wires in traditional control systems. Wireless communication channels can be used for feeding back real-time sensor data to the controllers and issuing control commands from the controllers to the actuators. In structural health monitoring, wireless communication has been shown sufficiently reliable for collecting structural sensor data (Straser and Kiremidjian, 1998; Lynch and Loh, 2005). The authors have recently explored the possibility of employing wireless communication technologies for feedback structural control, and developed a prototype real-time wireless sensing and control system for feedback structural control (Wang et al., 2006a). The system consists of multiple stand-alone wireless sensors and controllers that form an integrated wireless network through a common-use wireless communication channel. Utilizing modern embedded computing technology, distributed low-cost wireless controllers are closely associated with the structural actuators. Experimental tests have been successfully carried out to validate the feasibility of this system.

When replacing wired communication channels with wireless ones for feedback structural control, difficulties include coordination of the wireless nodes in a collaborative control network, degradation of real-time performance, and higher probability of data loss during transmission (Ploplys, 2004). Among different solutions to the degradation of the control system's real-time characteristics, one efficient remedy for this problem is the adoption of decentralized control strategies (Lynch and Law, 2002). In a decentralized control system, the sensing and control network is divided into multiple subsystems. Controllers are assigned to each subsystem and require only subsystem sensor data for control decisions. Therefore, reduced use of the communication channel is offered by a decentralized control architecture, which results in higher control sampling rates. Meanwhile, decentralized control requires relatively shorter communication ranges, enabling more reliable data transmissions. The drawback of decentralized control is that decentralized control architectures may only achieve sub-optimal control performance compared with the centralized architectures, because each subsystem has only the sensor data from that subsystem available to make control decisions.

This study attempts to investigate the effects of communication latencies in centralized and decentralized control strategies. In this paper, a prototype wireless sensing and control system employed for this investigation is first introduced, following by a brief description to the centralized and decentralized output feedback control algorithms. Numerical simulation results show that the higher sampling rates in decentralized control may compensate the disadvantage that incomplete sensor data is available for control decisions. Large-scale shake table experiments are conducted on a 3-story steel frame test structure installed with MR dampers to compare the performance of different decentralized and centralized control schemes.

## A PROTOTYPE REAL-TIME WIRELESS SENSING AND CONTROL SYSTEM

To illustrate the architecture of the prototype wireless sensing and control system, Fig. 1(a) shows a 3-story structure controlled by three actuators. Wireless sensors and controllers are mounted on the structure for measuring structural response data and commanding the actuators in real-time. Besides the wireless sensing and control units that are essential for the operation of the control system, a

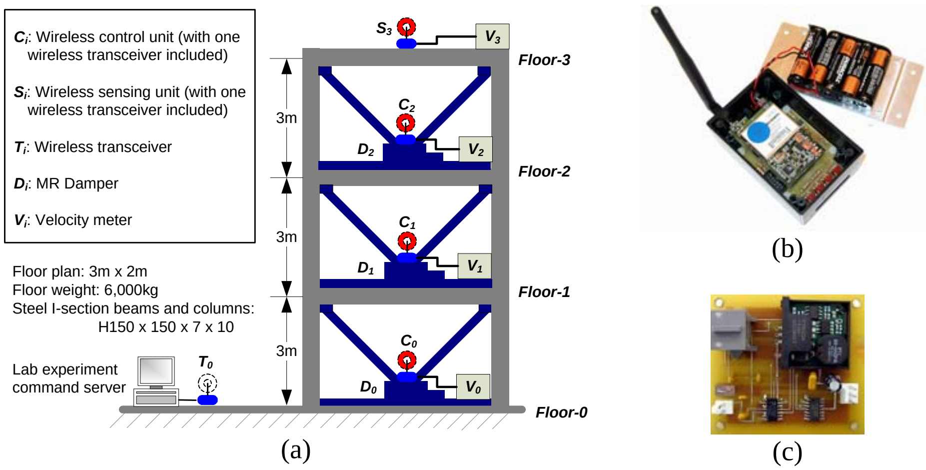



Figure 1. Overview to the prototype wireless sensing and control system: (a) a 3-story structure controlled by three actuators; (b) packaged wireless sensing and control unit ($10.2 \times 6.5 \times 4.0\text{cm}^3$); (c) printed circuit board of the signal generation module ($5.5 \times 6.0\text{cm}^2$).

remote data and command server with a wireless transceiver is included, as an optional element responsible for logging the flow of wireless data. During an experimental test, the command server first notifies the wireless sensing and control units to initiate automated operations. Once the start command is received, the wireless units that are responsible for collecting sensor data start acquiring and broadcasting data at a specified time interval. Accordingly, the wireless units responsible for commanding the actuators receive the sensor data, calculate desired control forces in real-time, and apply control commands at the specified time interval.

The wireless unit is designed in such a way that the unit can serve as either a sensing unit, or a control unit, or a unit for both sensing and control. This flexibility is supported by an integrated hardware design based upon a wireless sensing unit (Fig. 1b) previously proposed for wireless structural monitoring by Wang et al. (2006b). The three original functional modules included in the wireless sensing unit design are the sensor signal digitizer, the computational core, and the wireless transceiver. To extend the functionality of the wireless sensor for actuation, an off-board control signal generation module (Fig. 1c) is designed and fabricated. The control signal generation module consists of a single-channel 16-bit digital-to-analog converter and other support electronics. The module can output an analog voltage from -5V to 5V at rates as high as 100 kHz. Detailed design of the wireless sensing and control unit and the control signal generation module has been described by Wang et al. (2006a).

## CENTRALIZED AND DECENTRALIZED LINEAR OUTPUT FEEDBACK CONTROL ALGORITHMS CONSIDERING TIME-DELAY

This section reviews briefly the basic formulation of linear quadratic regulator (LQR) output feedback control. Strategies for handling communication time delays and constraints due to decentralized control are discussed. Numerical simulations are conducted to evaluate the effects of communication latency for centralized and decentralized control strategies.

### Formulation for Linear Output Feedback Control

The output feedback discrete-time LQR control solution can be briefly summarized as follows. For a lumped-mass structural model with $n$ degrees-of-freedom (DOF) and $m$ actuators, the system state-space equations considering $l$ time steps of delay can be stated as:

$$\mathbf{z_d}[k+1] = \mathbf{A_d}\mathbf{z_d}[k] + \mathbf{B_d}\mathbf{p_d}[k-l], \text{ where } \mathbf{z_d}[k] = \begin{Bmatrix} \mathbf{x_d}[k] \\ \dot{\mathbf{x}}_\mathbf{d}[k] \end{Bmatrix} \tag{1}$$

Here $\mathbf{z_d}[k]$ represents the $2n \times 1$ discrete-time state-space vector, $\mathbf{p_d}[k-l]$ is the delayed $m \times 1$ control force vector, $\mathbf{A_d}$ is the $2n \times 2n$ system matrix (containing the information about structural mass, stiffness and damping), and $\mathbf{B_d}$ is the $2n \times m$ actuator location matrix. The primary objective of the time-delay LQR problem is to minimize a cost function $J$ by selecting an optimal control force trajectory $\mathbf{p_d}$:

$$J\Big|_{\mathbf{p_d}} = \sum_{k=l}^{\infty}\left(\mathbf{z_d}^T[k]\mathbf{Q}\mathbf{z_d}[k] + \mathbf{p_d}^T[k-l]\mathbf{R}\mathbf{p_d}[k-l]\right), \text{ where } \mathbf{Q}_{2n\times 2n} \geq 0 \text{ and } \mathbf{R}_{m\times m} > 0 \tag{2}$$

In an output feedback control design, when control decisions are computed, only data in the system output vector $\mathbf{y_d}[k]$ are available. The output vector is defined by a $q \times 2n$ linear transformation, $\mathbf{D_d}$, to the state-space vector $\mathbf{z_d}[k]$:

$$\mathbf{y_d}[k] = \mathbf{D_d}\mathbf{z_d}[k] \tag{3}$$

For example, if only the relative velocities on all floors (but not the relative displacements) are measurable, $\mathbf{D_d}$ can be defined as:

$$\mathbf{D_{d\_cen}} = \begin{bmatrix} \mathbf{0}_{n\times n} & \mathbf{I}_{n\times n} \end{bmatrix} \tag{4}$$

In another example, if inter-story velocities between adjacent floors are measurable, the following output matrix $\mathbf{D_d}$ can be used:

$$\mathbf{D_{d\_dec}} = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{bmatrix} \tag{5}$$

The $m \times q$ optimal gain matrix $\mathbf{G_d}$ is designed to provide the linear output feedback control force:

$$\mathbf{p_d}[k] = \mathbf{G_d}\mathbf{y_d}[k] \tag{6}$$

Chung et al. (1995) proposed a solution to the above output feedback control problem considering time delay ($l$ time steps). An equivalent system to the original difference equations (Eq. 1) can be obtained by properly defining the augmented matrices and vectors (denoted here with over bars) as:

$$\bar{\mathbf{z}}_\mathbf{d}[k+1] = \bar{\mathbf{A}}_\mathbf{d}\bar{\mathbf{z}}_\mathbf{d}[k] + \bar{\mathbf{B}}_\mathbf{d}\bar{\mathbf{p}}_\mathbf{d}[k] \tag{7}$$

As a result, the following nonlinear coupled matrix equations can be obtained:

$$\left(\bar{\mathbf{A}}_\mathbf{d} + \bar{\mathbf{B}}_\mathbf{d}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\right)^T \mathbf{H}\left(\bar{\mathbf{A}}_\mathbf{d} + \bar{\mathbf{B}}_\mathbf{d}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\right) - \mathbf{H} + \left(\bar{\mathbf{Q}} + \bar{\mathbf{D}}_\mathbf{d}^T\mathbf{G_d}^T\mathbf{R}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\right) = \mathbf{0} \tag{8a}$$

$$\left(\bar{\mathbf{A}}_\mathbf{d} + \bar{\mathbf{B}}_\mathbf{d}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\right)\mathbf{L}\left(\bar{\mathbf{A}}_\mathbf{d} + \bar{\mathbf{B}}_\mathbf{d}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\right)^T - \mathbf{L} + \bar{\mathbf{Z}}_{\mathbf{d}l} = \mathbf{0} \tag{8b}$$

$$2\bar{\mathbf{B}}_\mathbf{d}^T\mathbf{H}\left(\bar{\mathbf{A}}_\mathbf{d} + \bar{\mathbf{B}}_\mathbf{d}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\right)\mathbf{L}\bar{\mathbf{D}}_\mathbf{d}^T + 2\mathbf{R}\mathbf{G_d}\bar{\mathbf{D}}_\mathbf{d}\mathbf{L}\bar{\mathbf{D}}_\mathbf{d}^T = \mathbf{0} \tag{8c}$$

The above equations are then solved for an optimal output feedback gain matrix $\mathbf{G_d}$, the Lagrangian matrix, $\mathbf{L}$, and the Hamiltonian matrix, $\mathbf{H}$. Detailed derivations have been discussed by Chung et al.

(1995). In our implementations, an iterative algorithm put forth by Lunze (1990) is modified to solve the above matrix equations (Wang et al., 2006c). The iterative algorithm can also be applied to compute an optimal control solution for a decentralized system simply by constraining the structure of $\mathbf{G_d}$ to be consistent with the decentralized architecture. The following equation illustrates the patterns of two decentralized output feedback gain matrices for a simple 3-story lumped-mass structure:

$$\mathbf{G_{d\_dec}}_1 = \begin{bmatrix} * & 0 & 0 \\ 0 & * & 0 \\ 0 & 0 & * \end{bmatrix}, \quad \mathbf{G_{d\_dec}}_2 = \begin{bmatrix} * & * & 0 \\ 0 & * & * \\ 0 & * & * \end{bmatrix} \tag{9}$$

The pattern in $\mathbf{G_{d\_dec}}_1$ specifies that when computing control decisions, the actuator on each floor only needs the entry in the output vector $\mathbf{y_d}$ that corresponds to that floor. The pattern in $\mathbf{G_{d\_dec}}_2$ specifies the control decisions also require information from a neighboring floor.

**Simulation Results using Centralized and Decentralized Control Strategies**

Numerical simulations have been conducted to assess the performance of decentralized and centralized control strategies considering time delays due to communication latency. Numerical model for the 3-story half-scale laboratory structure illustrated in Fig. 1(a) is used for the simulation. For simplicity, one ideal structural actuator, which is capable of producing any desired force under the maximum limit of 20kN, is deployed between every two adjacent floors. Three control architectures are employed: (1) decentralized, (2) partially decentralized, and (3) centralized control. Different patterns of the gain matrices, $\mathbf{G_d}$, and the output matrices, $\mathbf{D_d}$, for these three control architectures are summarized in Table 1. As defined by these matrices, three centralized and decentralized velocity feedback patterns are adopted. An LQR weighting matrix **Q** minimizing inter-story drifts over time and a diagonal weighting matrix **R** are used when designing the optimal gain matrices for all the simulations presented herein. Various combinations of centralization degrees and sampling time steps ranging from 0.005s to 0.1s (at a resolution of 0.005s) are simulated.

To assess the performance of each control scheme, three ground motion records are used for the simulation: the El Centro (1940), the Kobe (1995), and the Chichi (1999) earthquake records. Performance indices proposed by Spencer et al. (1998) are adopted. In particular, two representative performance indices employed here are:

$$PI_1 = \max_{\substack{\text{El Centro}\\ \text{Kobe}\\ \text{Chichi}}} \left\{ \frac{\max_{t,i} d_i(t)}{\max_{t,i} \hat{d}_i(t)} \right\}, \quad PI_2 = \max_{\substack{\text{El Centro}\\ \text{Kobe}\\ \text{Chichi}}} \left\{ \frac{J_{LQR}}{\hat{J}_{LQR}} \right\} \tag{10}$$

where $PI_1$ and $PI_2$ are the performance indices corresponding to inter-story drifts and LQR control measure, respectively. In Eq. (10), $d_i(t)$ represents the inter-story drift between floor $i$ ($i$ = 1, 2, 3) and its lower floor at time $t$, and $\max_{t,i} d_i(t)$ is the maximum inter-story drift over the entire time history and among all three floors. The maximum inter-story drift is normalized by its counterpart $\max_{t,i} \hat{d}_i(t)$, the maximum response of the uncontrolled structure. The largest normalized ratio among the simulations for the three different earthquake records is defined as the performance index $PI_1$.

Table 1. Different decentralization patterns for the control simulations and experiments.

| **Degree of Centralization** | (1) Decentralized | (2) Partially Decentralized | (3) Centralized |
|---|---|---|---|
| **Gain Matrix Constraint** | $\mathbf{G_{d\_dec}}_1$ in Eq. (9) | $\mathbf{G_{d\_dec}}_2$ in Eq. (9) | N/A |
| **Output Matrix** | $\mathbf{D_{d\_dec}}$ in Eq. (5) | $\mathbf{D_{d\_dec}}$ in Eq. (5) | $\mathbf{D_{d\_cen}}$ in Eq. (4) |

Similarly the performance index $PI_2$ is defined for the LQR control index $J_{LQR}$, as given in Eq. (2). When computing the LQR index over time, a uniform time step of 0.005s is used to collect the structural response data points, regardless of the sampling time step of the control scheme.

Values of the two control performance indices are plotted in Fig. 2 for different combinations of centralization degrees and sampling time steps. The plots shown in Fig. 2(a) and 2(b) illustrate that centralization degree and sampling step have important effects to control performance. Generally speaking, control performance is better for higher degrees of centralization and shorter sampling time. To better review the simulation results, the performance indices for the three different control schemes are re-plotted as a function of sampling time in Fig. 2(c) and 2(d). As shown in Fig. 2(c), if a partially decentralized control system can achieve 0.04s sampling step and a centralized system can only achieve 0.08s due to additional communication latency, the partially decentralized system can result in lower maximum inter-story drift. Similar trend is observed in Fig. 2(d), although for a given sampling time step, the performance index $PI_2$ for the centralized case is always lower than the indices for the two decentralized cases.

## EXPERIMETAL VALIDATION TESTS USING A REAL-TIME WIRELESS STRUCTURAL SENSING AND CONTROL SYSTEM

To study the potential use of the wireless sensing and control system for decentralized structural control, validation tests are conducted at the National Center for Research on Earthquake Engineering (NCREE) in Taipei, Taiwan. Both a baseline wired control system and a wireless sensing and control system are employed to implement the real-time feedback control of a 3-story steel frame instrumented with three MR dampers.

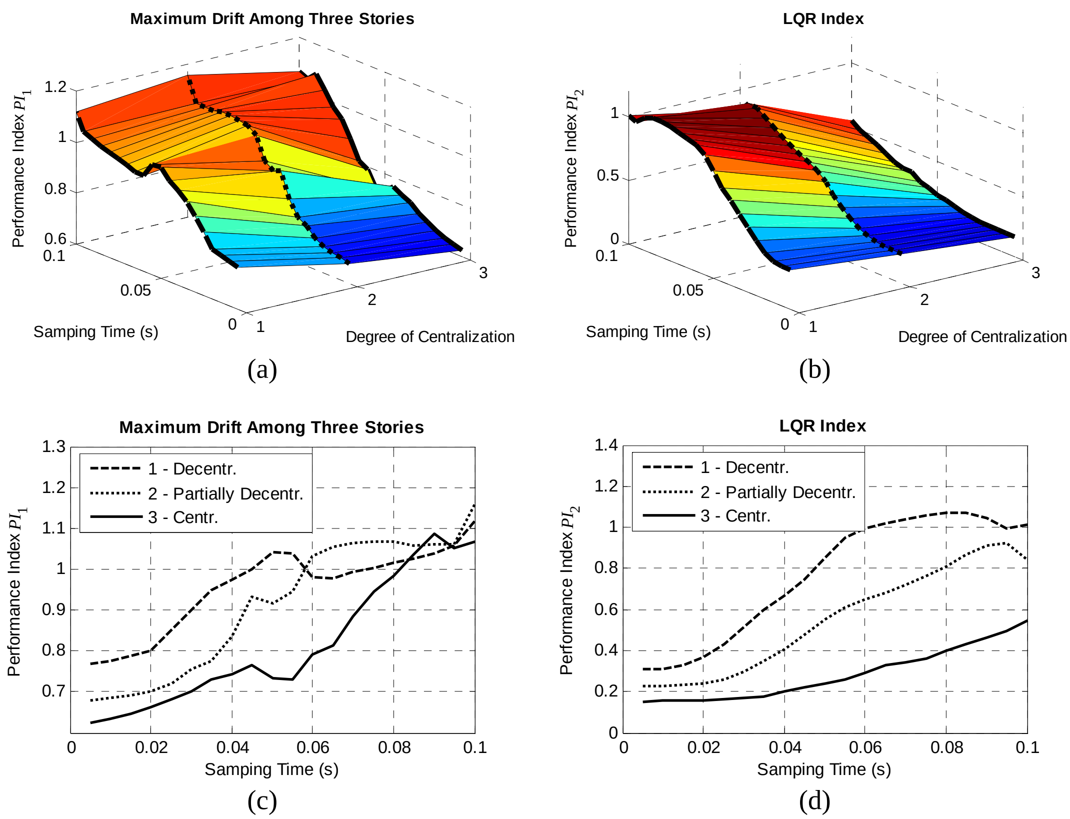


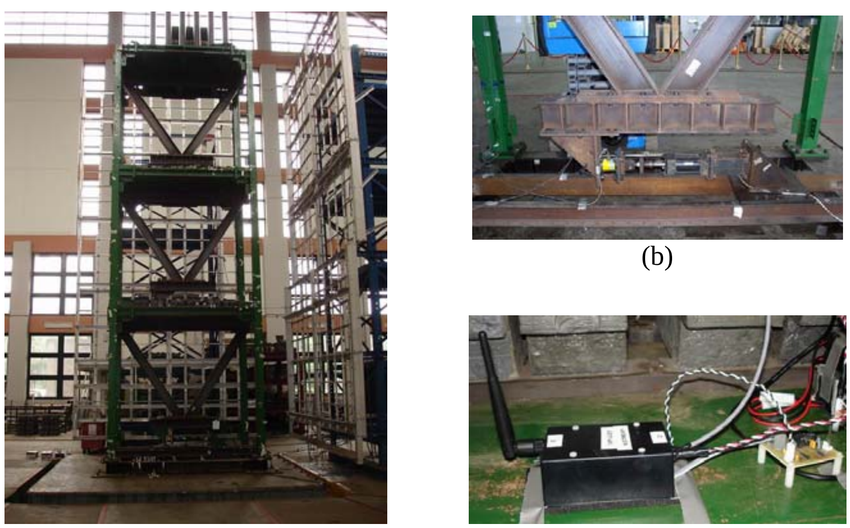

Figure 2. Simulation results illustrating control performance indexes for different sampling time steps and centralization degrees: (a) 3D plot for performance index $PI_1$; (b) 3D plot for performance index $PI_2$; (c) Condensed 2D plot for $PI_1$; (d) Condensed 2D plot for $PI_2$.

## Validation Test Setup

A three-story steel frame structure is designed and constructed by researchers affiliated with NCREE (Fig. 3a). The dimensions of the structure are provided as shown in Fig. 1(a). The three-story structure is mounted on a 5m × 5m 6-DOF shake table. The shake table can generate ground excitations with frequencies spanning from 0.1Hz to 50Hz. For this study, only longitudinal excitations are used. Along this direction, the shake table can excite the structure with a maximum acceleration of 9.8m/s$^2$. The excitation has a maximum stroke and force of ±0.25m and 220kN, respectively. The test structure is heavily instrumented with accelerometers, velocity meters, and linear variable displacement transducers (LVDT) installed on each floor of the structure to measure the dynamic response. These sensors are interfaced to a high-precision wire-based data acquisition (DAQ) system native to the NCREE facility; the DAQ system is set to a sampling rate of 200 Hz. A separate set of wireless sensors are installed as part of the wireless control system.

For this experimental study, three 20 kN MR dampers are installed with V-braces on each story of the steel structure (Fig. 3b). The damping coefficients of the MR dampers can be changed by issuing a command voltage between 0V to 1.2V. This command voltage determines the electric current of the electromagnetic coil in the MR damper, which in turn, generates a magnetic field that sets the viscous damping properties of the MR damper. Calibration tests are first conducted on the MR dampers before mounting them to the structure so that modified Bouc-Wen damper models can be formulated for each damper (Lin et al., 2005). In the real-time feedback control tests, hysteresis model parameters for the MR dampers are an integral element in the calculation of damper actuation voltages. Fig. 3(c) illustrates a wireless control unit and an off-board control signal generation module that work together to command an MR damper.

For the wireless system, a total of four wireless sensors are installed, following the deployment shown in Fig. 1(a). Each wireless sensor is interfaced to a Tokyo Sokushin VSE15-D velocity meter to measure the absolute velocity response for each floor of the structure as well as the base. The sensitivity of this velocity meter is 10V/(m/s) with a measurement limit of ±1 m/s. The three wireless sensors on the first three levels of the structure ($C_0$, $C_1$, and $C_2$) are also responsible for commanding the MR dampers. Besides the wireless control system, a traditional wire-based control system is installed in the structure for comparative tests. Centralized and decentralized velocity feedback control schemes described earlier (Table 1) are used for both the wired and the wireless control



(a) (b) (c)

Figure 3. Laboratory setup: (a) the 3-story test structure mounted on the shake table; (b) the MR damper installed between the 1st floor and the base floor of the structure; (c) a wireless control unit and an off-board control signal generation module.

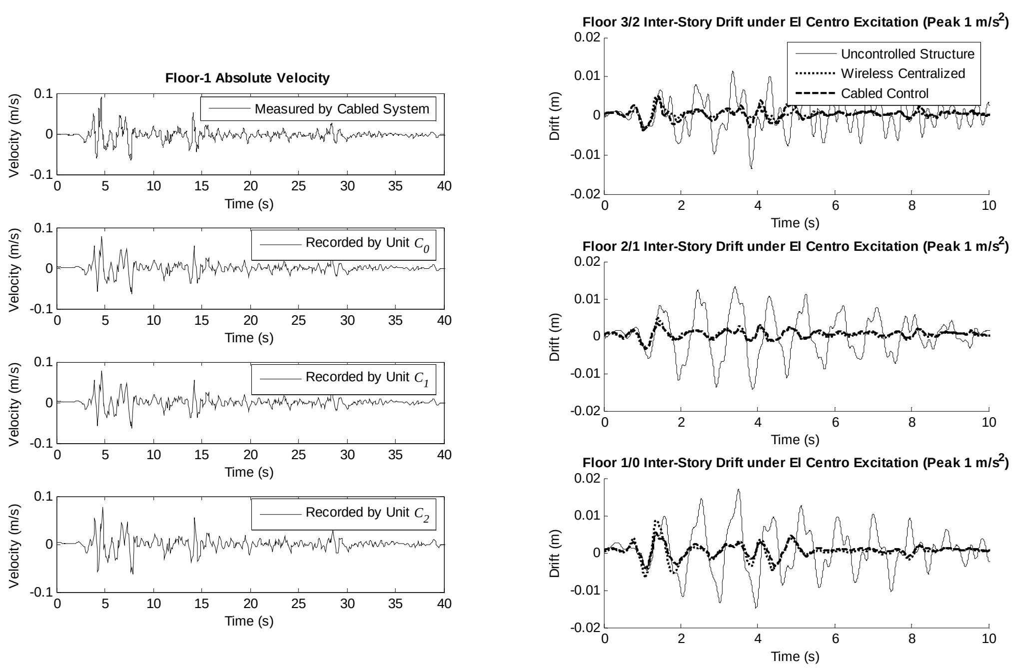
Table 2. Different decentralization patterns and sampling steps for the wireless and wire-based control experiments (degrees of centralization are defined as shown in Table 1).

| | **Wireless System** | | | **Wired System** |
|---|---|---|---|---|
| **Degree of Centralization** | 1 | 2 | 3 | 3 |
| **Sampling Step/Rate** | 0.02s / 50Hz | 0.06s / 16.67Hz | 0.08s / 12.5Hz | 0.005s / 200Hz |

systems. As shown in Table 2, different decentralization patterns and sampling steps are tested. For the test structure, the wire-based system can achieve a sampling rate of 200Hz, or a time step of 0.005s. Mostly decided by the communication latency of the 24XStream wireless transceivers, the wireless system can achieve a sampling rate of 12.5Hz (or a time step of 0.08s) for the centralized control scheme. This sampling rate is due to each wireless sensor waiting in turn to communicate its data to the network (about 0.02s for each transmission). An advantage of the decentralized architecture is that fewer communication steps are needed, thereby reducing the time for wireless communication.

## Experimental Results

To ensure that appropriate control decisions are computed by the wireless control units, one necessary condition is that the real-time velocity data used by the control units are reliable. Rarely experiencing data losses during the experiments, our prototype wireless sensor network proves to be robust. In case data loss happens, the wireless control unit is currently designed to simply use a previous data sample. To illustrate the reliability of the velocity data collected and transmitted by the wireless units, Fig. 4(a) presents the floor-1 time history data during a centralized wireless control test, as collected separately by the cabled DAQ system and recorded by the three wireless control units. The ground excitation is the El Centro (1940) NS earthquake record scaled to a peak ground acceleration of 1m/s$^2$. During the test, unit $C_1$ measures the data from the associated velocity meter directly, stores the data in its own memory bank, and transfers the data wirelessly to unit $C_0$ and $C_2$. After the test run is completed, data




(a) (b)

Figure 4. Experimental time histories for: (a) cabled and wireless sensor data; (b) inter-story drifts of the structure with and without control.

from all the three control units are sequentially streamed to the experiment command server, where the results are plotted as shown in Fig. 4(a). These plots illustrate strong agreements among data recorded by the three wireless control units and by the cabled system using a separate set of velocity meters and data acquisition system. This result illustrates that the velocity data is not only reliably measured by unit $C_0$, but also properly transmitted to other wireless control units in real-time.

The time histories of the inter-story drifts from the same centralized wireless control test is plotted in Fig. 4(b), together with the drifts of a centralized wired control test and a dynamic test when the structure is not instrumented with any control system. Same ground excitations are used for all the three cases shown in Fig. 4(b). The results show that both the wireless and wired control systems achieve considerable gain in limiting inter-story drifts. Running at a much shorter sampling time step, the wired centralized control system achieves slightly better control performance than the wireless centralized system in terms of mitigating inter-story drifts.

To further study different decentralized schemes with different communication latencies, Fig. 5 illustrates the peak inter-story drifts and floor accelerations for the original uncontrolled structure and the structure controlled by the four different wireless and wired control schemes, as defined in Table 2. Compared with the uncontrolled structure, all wireless and wired control schemes achieve significant reduction with respect to maximum inter-story drifts and absolute accelerations. Among the four control cases, the wired centralized control scheme shows better performance in achieving the least peak drifts and second least overall peak accelerations. This result is rather expected, because the wired system has the advantages of lower communication latency and utilizes complete sensor data from all floors. The wireless schemes, although running at longer sampling steps, achieve control performance comparable to the wired system. The fully decentralized wireless control scheme (case #1), results in uniformed peak inter-story drifts and the least peak floor accelerations. This illustrates that in the decentralized wireless control cases, the higher sampling rate (from lower communication latency) can potentially compensate the loss of data from ignoring the sensor data from faraway floors.

## CONCLUSIONS

This paper investigates the feasibility and effectiveness of decentralized wireless control strategies in civil structures. We first introduce the theoretical background for an optimal output feedback structural control design using centralized and decentralized communication patterns. Both numerical simulations and experimental tests are then performed to examine the tradeoff between the “degree” of centralization and communication latencies. The simulated and experimental results show that decentralized wireless control strategies may provide equivalent or even superior control performance, given that their centralized counterparts suffer longer sampling steps due to wireless communication latencies. Laboratory experiments also successfully validate the reliability of the prototype wireless

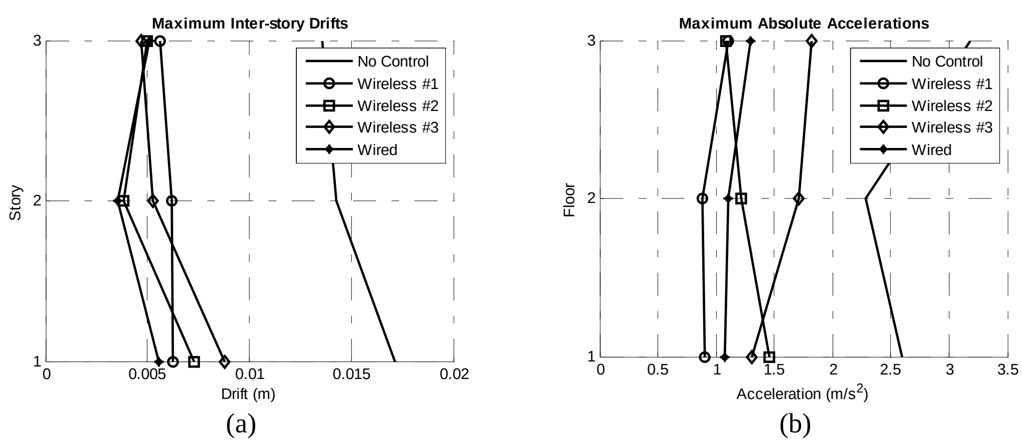



Figure 5. Experimental results of different control schemes using the El Centro excitation scaled to a peak acceleration of $1 m/s^2$: (a) peak inter-story drifts; (b) peak accelerations.

structural sensing and control system.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