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Seismic Structural Health Monitoring (SSHM) and Computer Vision

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EXTENDED ABSTRACT

The seismic response of a structure during an earthquake is a short nonrepetitive signal from a nonlinear system, even if no damage has occurred. In instrumented buildings, the seismic response is typically obtained using a limited number of sensors, such as accelerometers, seismometers, displacement sensors (strain gages, potentiometers, LVDT), and more recently, video cameras. In Seismic Structural Health Monitoring (SSHM), response time series and their derivatives, such as interstory drifts, maximum accelerations, CAV, Arias Intensity, and base shear, among others, are combined with modal identification parameters (mainly period and mode shape) to estimate the potential level of damage.

The typical application of SSHM goes beyond being just a monitoring system where data is obtained, stored locally or transmitted, without online analysis or immediate information to stakeholders following an earthquake. SSHM precisely addresses these aspects: continuous monitoring, autonomous and online analysis of recorded data (locally or remotely), automatic deviation detection, and automatic information dissemination to users, considering their knowledge and responsibilities.

For many years, several institutions have installed seismic monitoring systems in buildings. Notable examples include the California Strong Motion Instrumentation Program (CSMIP) in the Department of Conservation's California Geological Survey and the Building Research Institute in Japan. However, the primary objective has been to record the response for later analysis. Although there are examples of systems that capture the response of buildings and estimate drift and accelerations for potential structural and nonstructural damage, such applications are limited when compared to the existing infrastructure. The question arises: why don't we have widespread adoption of this technology in buildings in high seismic countries? There are several reasons, but in my opinion, the key aspects are as follows:

1. Civil engineers have limited knowledge of sensors, signal processing, and analysis. There is generally a scarcity of knowledgeable technicians and professionals outside academia, capable of effectively managing or utilizing the information provided by SSHM.
2. The initial and maintenance costs are additional factors that were not considered in the typical design. In some cases, building owners fail to comprehend the need for an additional system to detect damage, assuming that the building was designed according to the codes and earthquakes are rare occurrences. They do not perceive the benefits but rather see the yearly bill for a system dedicated to an extreme event that may never happen or, if it does occur, may not mitigate the damage. We should also consider that some buildings have multiple owners making decisions more difficult.
3. The consequences of the information obtained are not always understood. How will the owner benefit from it? Could it be used against the owner? Who can manage this information? In general, users do not grasp the significance of the data obtained.
4. Technological limitations also pose a challenge. System robustness requires a large number of sensors, redundancy in communications and sensors, how to know and capture all damage scenarios? including nonstructural damage, which can be dangerous and costly but is not always part of the SSHM information system. Structures are nonlinear, and not all changes are due to damage, so incipient damage can go undetected, see other in (Cawley, 2018)

In bridge the instrumentation is still limited. One way to enhance the system's robustness is to incorporate video cameras in addition to the traditional structural instrumentation. Video cameras are already widely used for traffic control, security, and surveillance purposes. Videos from this extensive network can be utilized to estimate the response of structures. Excellent

results have been obtained in laboratory environments, where response data from sensors is compared with estimations using standard computer vision techniques, (Dong & Catbas, 2021; Khuc & Catbas, 2017; Yang et al., 2017). Initial on-site applications are already present, mainly for bridges, for example (Brownjohn et al., 2017). While some of these applications are demonstrative for research purposes, they have already demonstrated their benefits and limitations. The key advantages include the ease of installation, relatively low cost of basic systems, wide field of view allowing monitoring of large structural response areas, measurement of static and residual displacements without the long period distortion observed in integrated acceleration records, the ability to estimate accelerations, and full applicability for parametric and non-parametric system identification techniques.

However, similar to traditional systems, video camera systems also have drawbacks: a shortage of knowledgeable technical professionals, limited software packages for video processing, damage detection, and location and quantification, as well as limitations related to occlusions or lighting sensitivities. These drawbacks can be overcome but often result in increased costs, although they generally remain lower than those associated with traditional systems.

CONCLUSIONS

Based on my experience, the simplicity and robustness of computer vision technology confirm its role as a key component in SSHM. We see clear advantages in the field particularly on the use of CNN for bridge monitoring and the expansion of graduate courses on SHM.

Keywords: Computer Vision, structural damage, SSHM, modal parameters

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