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TOWARDS DEPLOYABLE, AUTONOMOUS, VIBRATION CONTROL SYSTEMS FOR LIGHTWEIGHT FOOTBRIDGES

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Structural control devices enable realizing innovative designs for lightweight footbridges by suppressing excessive vibrations that arise from the reduced self-weight. Currently, most control devices are permanent installations, tuned to a particular structural property and hence specific to a particular implementation. In some cases, the need for vibration mitigation is not permanent, but rather of a temporary nature arising under predictable peak-loading events such as large crowds or wind storms. On the other hand, advances in materials and construction methods has paved the way for temporary footbridges designed specifically for short term applications such as marathons or disaster response. These examples motivate the development of an innovative control system suitable for temporary yet immediate use on a range of footbridges.

This paper presents the concept of a deployable, autonomous control system (DACS) targeting specific applications where immediate, short-term vibration mitigation is desired. The proposed DACS (Fig. 1) consists of an electromagnetic mass damper (EMD) mounted on an unmanned ground vehicle (UGV) equipped with vision sensors. The actively controlled EMD provides the necessary control bandwidth for a range of structures while the UGV and vision sensors facilitate direct implementation on existing footbridges with the necessary mobility to autonomously position the device.

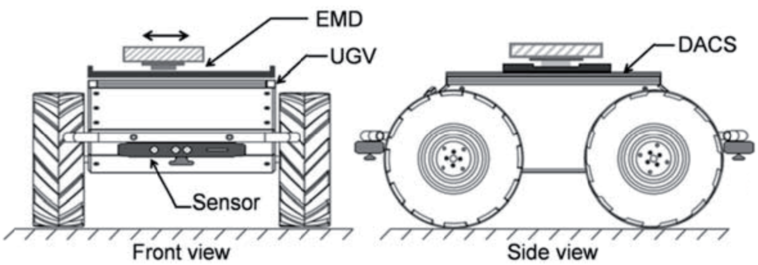

Fig. 1. Schematic of DACS

In most active control systems, the desired control force is used directly as the command signal to the actuator; However, for the proposed DACS, the force generated by the EMD is filtered through the dynamics of the UGV prior to being applied to the structure. As such, an experimentally identified transfer function model of the UGV is used within the control loop to compensate for the UGV dynamics. The EMD operates under position feedback due to the readily available motor encoder outputs and noise robustness with digital command signals. The challenge associated with position feedback is developing the necessary relationship between desired force and command position. To overcome this, a linear transfer function model that includes the effects of both motor dynamics and feedback control is identified experimentally. The overall controller for the DACS (Fig. 2) consists of a linear quadratic Gaussian (LQG) feedback algorithm in series with the identified model to compensate for UGV dynamics and the EMD model for position-feedback control.

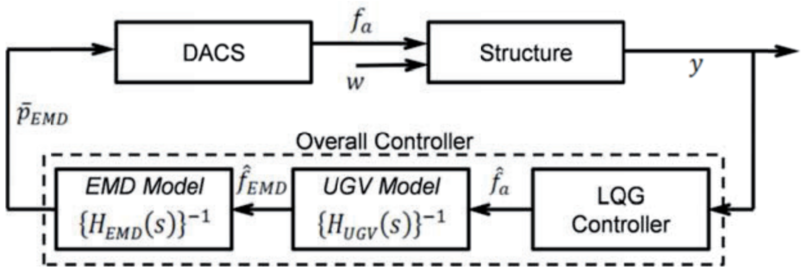

Fig. 2. Block diagram of active controller for DACS

Utilizing a mobile robot for structural control offers autonomous positioning of the control device at a desired location on the footbridge. Achieving this level of autonomy requires two of the most central tasks in autonomous robotics: localization and mapping. When navigating an unknown environment such as a footbridge, the UGV must build a map of the environment while concurrently using the same map to localize itself. This is a fundamental problem in mobile robotics and is addressed using SLAM, an acronym for simultaneous localization and mapping. An extended Kalman filter based solution, known as EKF-SLAM is implemented on the UGV using an open source robotic platform. The solution is tailored specifically for footbridges with sparse and/or repeated features and addresses central issues including data association and loop closure by adopting uniquely identifiable tags. After a satisfactory map has been created using EKF-SLAM, the algorithm can be reduced to an EKF-based localization algorithm for autonomous positioning of the DACS within the map.

The performance of the EKF-SLAM solution is assessed using a full-scale aluminum footbridge. Unique tags placed at the panel points on both sides of the bridge serve as the landmarks to be located in the map. The DACS is placed at one end of the bridge and a proportional-derivative (PD) steering controller is used to track the center-line of the map as it is being created. In general, the estimated landmark locations correspond well to the actual tag locations, particularly in the longitudinal direction. The lateral component of the footbridge is idealized as a multi-degree-of-freedom (MDOF) system and real-time hybrid simulation (RTHS) is used to experimentally validate the efficiently of the DACS in controlling different modes of vibration. RTHS is a dynamic testing method consisting of coupled experimental and analytical substructures. The DACS represents the experimental substructure and is tested physically while the remainder of the system is modelled numerically. This testing method facilitates the ability to simultaneously assess the performance of the EKF-based localization method for repositioning the UGV and ability to control different modes of vibration. The analytical model is excited such that different modes resonate and consequently force the DACS to reposition itself between the midspan and quarter-span. The experimental results confirm the ability of the proposed system to effectively control large amplitude motion in lightweight footbridges and reposition itself for controlling different modes.