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A method of dual-sensor signal fusion for DSP-based wide-range vibration detection and control

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ABSTRACT

This paper presents a unique dual-sensor signal fusion technology for DSP (digital signal processor)-based wide range vibration detection and active vibration control (AVC), which aims to suppress wide range vibration disturbances up to sub-micron level. In this method, two accelerometer sensors with different measurement ranges and sensitivities are used to detect the vibration disturbances as coarse and fine sensors respectively, and feed the signals simultaneously to a DSP controller. Each sensor is responsible for detecting accelerations in a specific range. By proper incorporation of signals from the two sensors, it is possible to achieve a wide detection range of vibrations at low cost. Simulation study shows that in an AVC system with the proposed dual-sensor signal fusion approach as the vibration detection component, significant improvement can be achieved comparing with traditional single-sensor AVC systems.

1. Introduction

Vibration control becomes increasingly important for high-precision equipment developers to respond to the request for more stable processes and higher positioning accuracies. Due to the limitations of passive vibration control approaches, considerable attention has been paid to active vibration control systems. An active vibration control (AVC) system continuously senses and reacts to vibration disturbances. It uses actuators, sensors and electronic control to reduce vibrations in real-time. Vibration is attacked with a counter-force that drives the structure to respond in a way that the total response of the system at the location of interest can then be significantly reduced [1,2]. A schematic of the control loop for a typical AVC system is shown in Fig. 1. There is an increasing demand for innovative active vibration control systems that can provide wide vibration suppression range up to sub-micron level or even nanometer level. An economic and efficient vibration detection approach is needed in such an AVC system.

The state-of-the-art active systems employ digital signal processors (DSPs) as the embedded controller. Comparing with an analogue controller, a DSP is designed for very-high-speed numeric real-time processing of digitized signals, and is generally considered as well suited for most modern control systems. It can provide straightforward adjustment of control parameters, easy incorporation of adaptation, estimation and identification stages, and direct overall operational monitoring and maintenance [3,4].

The first step in AVC is the detection of vibration disturbances. Although direct velocity feedback is ideal for active vibration control [2], it is difficult to measure the vibration velocity due to the lack of a reference position for a sensor to measure the absolute velocity, and also the extensive cost for the velocity sensor like laser Doppler vibrometer (LDV). Therefore most AVC systems are using accelerometers as the feedback sensor because of the low cost, small size and easy to use [5–7].

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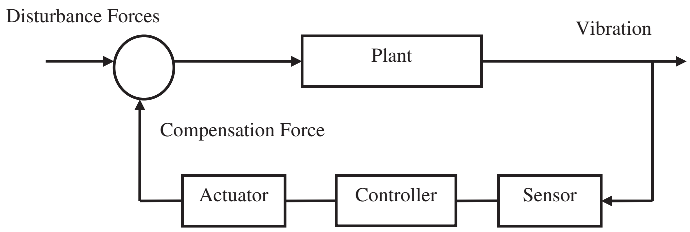

Fig. 1. Schematic of an active vibration control (AVC) system.

A problem with a DSP-based AVC system using acceleration feedback is to deal with a wide dynamic range of the vibration disturbances. The acceleration signal from a common accelerometer device such as a piezoelectric accelerometer is an analogue signal. To prepare the acceleration signals for processing by digital hardware like a DSP controller, it has to be converted to digital signals by an analogue-to-digital converter (ADC). Analogue-to -digital conversion, also known as digitization, consists of the sampling (digitization in time) and quantization (digitization in amplitude) processes. In the quantization process, the amplitude of each discrete-time sample is quantized into one of the 2^B levels, where B is the number of bits that the ADC has to represent for each sample [4]. Due to the fact of finite number of bits, there exists a resolution given by dividing a full-scale range with the number of quantization levels, 2^B, and the difference between the quantized number and the original value is defined as the quantization error or noise [4]. It is clear that an ADC with higher number of bits can output more quantization levels, and thus can represent analogue signals more accurately with larger signal-to-quantization-noise ratio (SQNR). However, high number of bits means high cost, which is controversial to the requirements of the embedded control systems on compact design, low power, and low cost. Therefore a trade-off between the measurement range and accuracy is necessary. For the most widely used DSP controllers for motor control or vibration control, such as the TI C2000 platforms, the integrated A/D converters are 12-bit. A 12-bit ADC has 4096 (2^{12}) levels of quantization, which provides 72 dB SQNR.

The dynamic range of vibration signals is usually very large in reality. For a sinusoidal vibration signal, the amplitude in terms of displacement D and acceleration A can be correlated by $A = \omega^2 D$, where $\omega = 2\pi f$ is the angular frequency of vibration. For vibration with sub-micron level displacement ($D < 10^{-6} m$) at low vibratory frequency (f in the range of a few Hertz), the resultant acceleration level (A) to be detected is very small. On the other hand, vibration with high level displacement at high frequency can exhibit very high acceleration. Thus it is highly desirable for the AVC system to be able to detect vibration at a wide dynamic rang in terms of acceleration with acceptable accuracy.

However, this is hard to realize in practice with a single sensor system due to two reasons. Firstly, as a result of hardware limitation, accelerometers with high upper detection limits usually have big threshold values for the lower limits. On the other hand, those with small threshold values can only detect accelerations within a small range. For example, a PCB model 352C03 accelerometer has a measurement range of ±500 g pk and a sensitivity of 10 mV/g, with a broadband resolution of 0.0005 g rms. In comparison, a PCB model 352C33 accelerometer has a measurement range of ±50 g pk and a sensitivity of 100 mV/g, with a broadband resolution of 0.00015 g rms. Thus it is difficult to find a single sensor that can satisfy

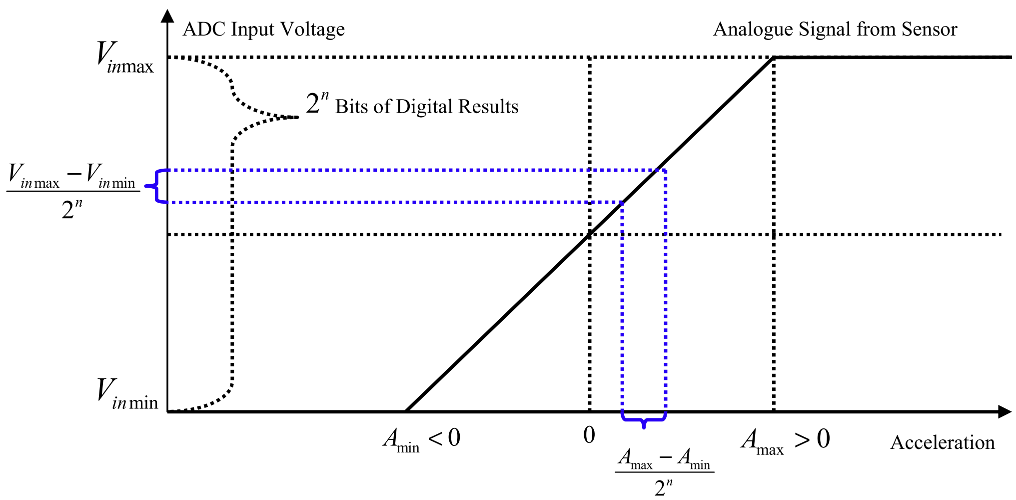

Fig. 2. Detectable acceleration range using a DSP and single-sensor system.