Development of microcontroller-based acquisition and processing unit for fiber optic vibration sensor

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Abstract. Microcontroller based acquisition and processing unit (MAPU) has been developed to measure vibration signal from fiber optic vibration sensor. The MAPU utilizes a 32-bit ARM microcontroller to perform acquisition and processing of the input signal. The input signal is acquired with 12 bit ADC and processed using FFT method to extract frequency information. Stability of MAPU is characterized by supplying a constant input signal at 500 Hz for 29 hours and shows a stable operation. To characterize the frequency response, input signal is swapped from 20 to 1000 Hz with 20 Hz interval. The characterization result shows that MAPU can detect input signal from 20 to 1000 Hz with minimum signal of 4 mV RMS. The experiment has been set that utilizes the MAPU with singlemode-multimode-singlemode (SMS) fiber optic sensor to detect vibration which is induced by a transducer in a wooden platform. The experimental result indicates that vibration signal from 20 to 600 Hz has been successfully detected. Due to the limitation of the vibration source used in the experiment, vibration signal above 600 Hz is undetected.

1. Introduction

Vibration sensor is widely used in many fields of application such as industrial, infrastructure and environmental monitoring to detect and diagnose failure, especially in rotating machine [1]. By adopting vibration sensing mechanism using accelerometer sensor, bridge monitoring system has been developed in order to detect bridge scour in real time [2]. Vibration sensor also has been used for a landslide early warning system [3].

Conventional vibration sensor is commonly based on piezoelectric technology which is sensitive to electromagnetic interference, whereas fiber optic vibration sensor provides more advantages such as immunity to electromagnetic interference, light weight and compact size [4]. Fiber optic vibration sensors can be classified into intensity, interferometers and gratings based sensor [5]. Intensity based vibration sensor have been extensively developed because of its simplicity where vibration can be detected from optical power variation [6]. Interferometric and grating based sensor can provide higher resolution and accuracy, but requires complex construction and interrogation system. Fiber optic vibration sensor can be developed using simple structure of fiber optic called SMS structure where a section of multimode fiber (MMF) spliced to the lead-in single mode fiber (SMF) and lead-out SMF [7].

Fiber optic vibration sensor commonly uses either PC-based Data Acquisition System (PC-DAQ) or Optical Spectrum Analyzer (OSA) to collect vibration signal and to process data [1, 4, 8]. The method that is widely applied to process vibration signal is fast fourier transform (FFT) which is used to extract vibration frequency from signal recorded in time domain [1, 4, 9]. Interrogation of fiber optic vibration sensor using either PC-DAQ or OSA adds more difficulties for implementation in remote area due to its size and complexity.
In this paper, the design of microcontroller-based acquisition and processing unit for fiber optic sensor is developed. The developed device acquires and processes the vibration signal fed from fiber optic sensor. The proposed design gives advantages such as low power, small and compact size, so this design can be implemented for vibration monitoring especially in remote area.

2. Methods

The schematic of MAPU for fiber optic vibration sensor is shown in figure 1. The core of this system is a development board from ST Microelectronics (Nucleo F411RE) which is also used for ST’s ARM 32-bit microcontroller, i.e STM32F411RET6. This microcontroller is equipped with some features such as 100 MHz max CPU frequency, 512 KB Flash, 128 KB SRAM, 16 channels 12-bit ADC and built in FPU which provides enough capability as signal processor.

![Figure 1. Schematic of acquisition and processing unit for optical vibration sensor.](image)

Analog input signal after filtered using first order low-pass passive filter is fed into channel 0 of MCU built-in Analog to Digital Converter (ADC). This ADC converts an analog signal within 0 - 3.3V range into a 12-bit digital representation. 2048 data are collected in 1 s window and then are processed using FFT method to extract signal feature in frequency domain. With sampling frequency at 2048 Hz, this system can process input signal from 0 to 1024 Hz. The LPF is designed to suppress all input signal beyond this range. The result of signal processing using FFT method is then transferred out serially as a string over USB which is captured by serial terminal software in laptop or pc. The flowchart of vibration measurement using MAPU is shown in figure 2.

![Figure 2. Flowchart of vibration measurement program](image)
3. Result and Discussion
The experiment to characterize MAPU for fiber optic vibration sensor is shown in figure 3. The sinusoidal signal from signal generator is fed to microcontroller, where signal is processed using FFT method to calculate signal frequencies. At the same time, signal amplitude is measured using digital multimeter.

To assess the stability, MAPU is fed with a constant frequency signal at 500 Hz while PC is used to monitor the calculated frequencies. After 29 hours measurement, MAPU shows a stable frequency output at 500 Hz as shown in figure 4. The frequency response of MAPU is examined by swapping input frequency from 20 to 1000 Hz with 20 Hz interval. The measurement is conducted for some level of input signal attenuation, including 0, -10, -20 and -30 dB attenuation.

Figure 5 shows that MAPU can detect input signal between 20 to 1000 Hz range with 0, -10 and -20 dB input signal attenuation. When input signal is attenuated to -30 dB, MAPU fails to detect frequency above 800 Hz. Voltage measurement using digital multimeter falls below 4 mV when input signal is attenuated to -30 dB and its frequency is above 800 Hz. It shows that MAPU can detect input signal in range of 0 to 1000 Hz with minimum amplitude is 4 mV RMS.

Figure 6 shows the experimental setup of MAPU for fiber optic vibration sensor. The vibration sensor is based on fiber optic SMS structure as shown in figure 7. The sensor is attached to a wooden platform which is vibrated by woofer driver loudspeaker. The loudspeaker is driven by sinusoidal signal from signal generator which is amplified using audio amplifier.

![Figure 3. Experiment setup for MAPU characterization.](image)

![Figure 4. MAPU stability assessment.](image)
Figure 5. MAPU frequency response

Figure 6. Experiment setup for vibration measurement.
In this experiment, a tuneable laser source tuned at 1560 nm is used to emit light into SMS fiber sensor. The high-speed photo detector is then adopted to capture output of SMS fiber sensor and convert it into electric signal. Because the transmitted optical power in SMS fiber structure is affected by the multimode interference, the photodetector output will reflect power fluctuation induced by vibration. Photodetector output is then processed by MAPU to extract the vibration frequencies. Figure 8 shows linear correlation data between input signal frequency that drives the loudspeaker and output frequency detected by MAPU. The experimental results show that input signal frequency is similar to the frequency detected by MAPU. Due to limitation of the vibration sources, MAPU cannot detect vibration above 600 Hz.

Figure 8. Responsivity test of optical vibration sensor

4. Conclusion
The microcontroller based acquisition and processing unit (MAPU) for optical vibration sensor has been successfully developed. During stability assessment, a stable operation in acquiring and processing input signal has been successfully demonstrated. Characterization shows that MAPU can detect input signal with frequency range from 20 to 1000 Hz and minimum amplitude 4 mV RMS. The experimental results demonstrate that MAPU can detect vibration frequency up to 600 Hz. The reduced detection range is caused by limitation of vibration sources used in the experiment. The development of MAPU will provide a compact and low power interrogation system for fiber optic vibration sensor.
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