Novel Machine Health Monitoring System

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Abstract Machines have been an inevitable part of our life in today's era. It has become paramount to look after various machines and keep them in safe as well as efficient condition. To check the health of such machines, various devices have been developed which measures vibrations, temperature, noise level, and power consumption. Any defect in the machine is indicated by unusual behavior in the above parameters. FFT analyzers are used to measure vibrations in the machine. However, the cost of FFT analyzers is very high and it may not be affordable to small-scale industries. Also, they rarely have a provision to measure the speed, temperature, and power consumed by the machine. The present research work is an effort to provide a low-cost solution to the existing health monitoring systems along with facility to measure various parameters like vibrations, noise, temperature, rotational speed, and power consumption. A low-cost controller Arduino Mega 2560 is used along with various sensors and integrated to MATLAB GUI to store and display the acquired data. The developed device was compared with existing systems and found to have a good agreement. This device can be used as a monitoring tool in small-scale industries where high-cost FFT analyzers become obsolete due to costing issue.

Keywords FFT · Machine health · Arduino · Vibration · Time domain Frequency domain

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1 Introduction

Inertial microelectromechanical systems (MEMS) sensors assume a huge part in the huge extension of today's personal electronic gadgets. Their little size, low power, simplicity of combination, abnormal state of usefulness, and wonderful execution energize, and empower development in contraptions, for example, cell phones, gaming controllers, motion trackers, and advanced picture outlines. Likewise, inertial MEMS sensors have generously enhanced unwavering quality and lessened expense in car wellbeing frameworks, permitting them to be conveyed in many cars [1]. The object of frequency analysis is to break down a complex signal into its components at various frequencies, and in order to do this, the practical engineer needs to understand the frequency analysis parameters and how to interpret the results of spectrum measurements [2].

The continuous advancement in practical integration and performance has conjointly helped MEMS accelerometers notice their approach into various industrial systems. Some of these applications offer lower-cost alternatives to current product and services, whereas others are segregating inertial transducer action in a new and unique way. New adaptations in vibration sensing area are concluding that fast distribution and affordable price of possession are the reasons to judge the integrated MEMS devices. Vibration monitoring is coming up as associate application that has each variety of users. Conventional instruments that observe machine health for maintenance and safety usually use piezoelectric technology. High-speed automation instrumentation setup monitors vibration to trigger feedback management of lubrication, speed, or belt tension or to switch off instrument for fast attention from the operating staff [3–5].

MEMS accelerometers provide quick, efficient integration, and cost-effective solution to a rising cluster of latest users. Additionally, their advanced practical integration permits devices like the ADIS16229 digital MEMS vibration sensing element with embedded RF transmitter and receiver to supply an entire resolution inclusive of communications and signal processing [6, 7]. This kind of device will wake itself up repeatedly, record time domain vibration information data, perform fast Fourier transform (FFT) on the information recorded, apply user-configurable spectral analysis on the FFT result, provide easy pass/fail results over economical wireless transmission, offer access to that information and results and then return to hibernate or sleep mode [8]. To enhance manual measurements, embedded MEMS-based sensors give a more cost-effective method for instrumentality that needs real-time vibration information.

2 Time Domain and Frequency Domain Analysis

Time domain and frequency domain are two ways that of observing at same dynamic system. They're interchangeable, i.e., no data are lost in conversion from one

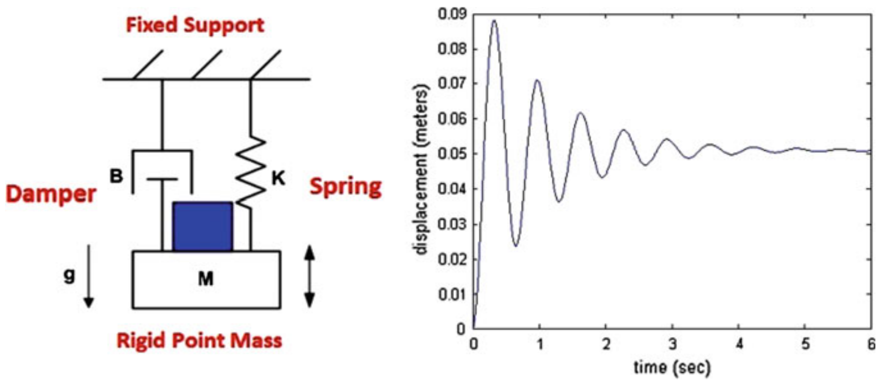


Fig. 1 Typical spring-mass-damper system and time domain response [10]

domain to other. They are unit complementary points of view that result in an entire, clear understanding of the behavior of a dynamic engineering system. Roughly speaking, in the time domain, we tend to find how long one thing takes, whereas in the frequency domain, we tend to find how fast or slow the response of system is. The time domain data are a record of the output of a dynamic system, as shown by some observed parameter, as function of time. This can be the standard way of observant the output of a dynamic system [9].

Example of time response is the displacement of the mass of the spring-mass-damper system versus time in response to the quick placement of additional mass on the hookedup mass as shown in Fig. 1. The output response is the step response of the system because sudden impact force. Usually after we examine the enactment of a dynamic system, we tend to use because the input to the system as step input [10].

3 Mechatronic Interface and Control System Design

The sensing element choice and signal-processing design depend on the application's aims. Schematic diagram of the sensors connected to the microcontroller is shown in Fig. 2.

An external power supply is provided to the Arduino. The sensors used in machine health monitoring system are K-type thermocouple, temperature sensor MAX6675, accelerometer ADXL335, current sensor AC712, noise sensor MAX4466, and a voltage divider circuit. Figure 3 denotes a sequence of operation with ADXL335 accelerometer along with Arduino mega 2560 microcontroller that uses an analog tri-axial vibration sensing element with FFT analysis and storage to observe the spectral content of apparatus vibration.

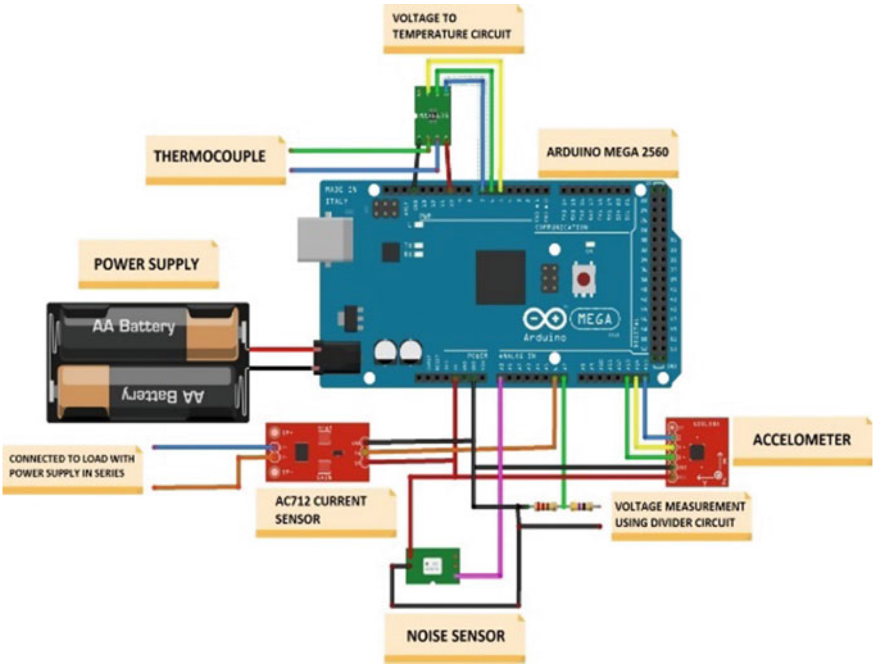


Fig. 2 Integration of sensors with controller

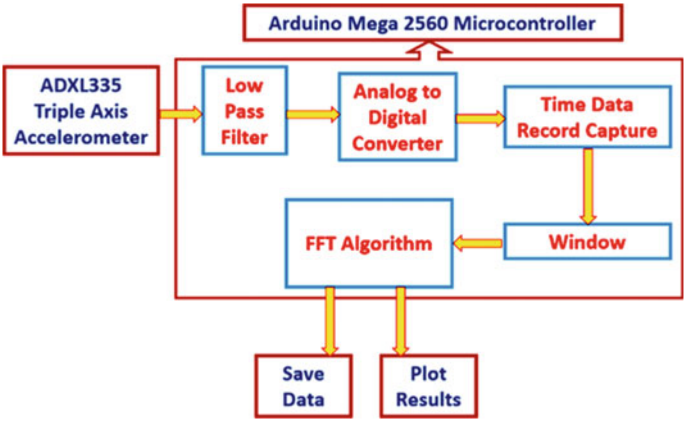


Fig. 3 Control system for vibration analysis

3.1 Core Sensor ADXL335 Accelerometer

The core sensing elements for either approach are often a MEMS accelerometer. The foremost vital attributes for choosing a core sensing element are the quantity of axes, package/assembly necessities, electrical interface (analog/digital), frequency response (bandwidth), measuring range, noise, and linearity [11]. The ADXL335 accelerometer used in this research work implements silicon on insulator (SOI) MEMS technique and takes benefit of automatically coupled, however, electrically remote differential sensing cells. Movement of the detector frame changes the differential capacitance. On-chip electronic circuit determines the change in capacitance and transforms it into an output voltage [12].

3.2 Analog Low-Pass Filter

The analog filter limits the signal content to at least one Nyquist zone that represents one half the sample rates within the example system. Even once the filter cut-off frequency is at intervals the Nyquist zone; it is not possible to possess infinite rejection of higher-frequency elements, which may still fold into the pass band [15].

3.3 Windowing

Time-coherent sampling is generally not sensible in vibration sensing applications, as nonzero sample values at the beginning and finish of the time record lead to massive spectral discharge, which may degrade the FFT resolution. Applying a window operate before scheming the FFT will facilitate manage the spectral leak [13].

3.4 Fast Fourier Transform (FFT)

FFT is an economical algorithmic program for analyzing distinct time information. The method transforms a time record into a distinct spectral record, where every sample represents a distinct frequency section of the Nyquist zone [14]. The main concept of this algorithm is that DFT of a sequence of N points can be expressed in terms of two DFT of length $N/2$. Therefore, if N is power of 2, it is easy to apply recursively this algorithm until we obtain DFT of single point [15]. The algorithm was formulated using the MATLAB analytical software. The flowchart for the algorithm is shown in Fig. 4. GUI is made using MATLAB which facilitates the connection to ARDUINO Mega 2560 and also gives flexibility to set the time for which the data have to be acquired. We can even select the axis through which we desire the time-acceleration data. Besides, we can save the results in.mat file format for later use. A suitable frequency range can be provided for maximum and minimum extremities.

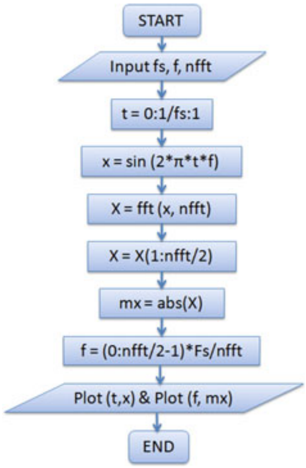


Fig. 4 Flowchart for the FFT algorithm

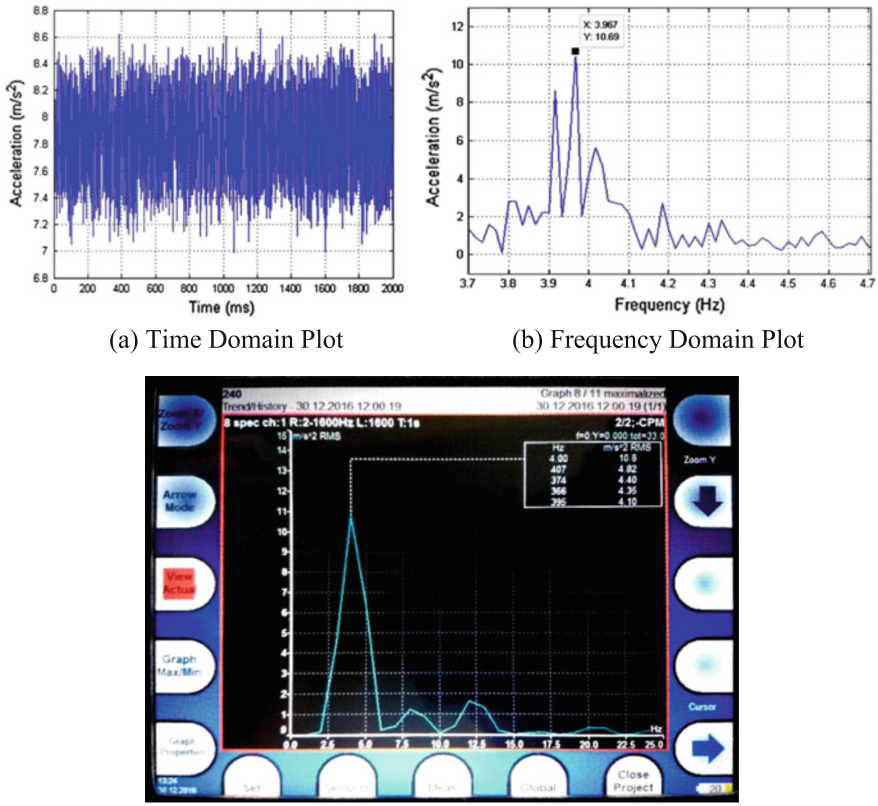
4 Results and Discussion

The above system was experimentally tested on cam follower apparatus having an involute cam profile due to which follower produced vibratory motion of a single frequency at a constant speed. At a speed of 240 rpm of cam, the analytical frequency can be determined by the formula $\frac{2\pi n}{60} = 25.13\ \frac{\text{rad}}{\text{s}} = 4$ Hz. According to the results obtained from the graph in Fig. 5b, it can be clearly seen that we obtain a peak at 3.967 Hz which shows good agreement with analytical frequency. These results were compared with the results from ADASH make A4400-VA4 FFT Analyzer, and from Fig. 5c, it can be clearly seen that we get a very good agreement in amplitude as well as forced frequency for the system.

Comparison between developed device and commercially available analyzer is shown with the help of graph given in Fig. 6. The time response of a system does not give much useful information. Since the dynamic characteristics of individual components of the system are usually known, we relate the distinct frequency components (of the frequency response) to specific components. The energy concentrates near peak frequency, i.e., it is related with the rotational speed of variable motor which is connected to cam jump apparatus. Developed system reflected good accuracy with commercially available Adash 4400-VA4 analyzer up to 99.175%.

5 Conclusion

A novel health monitoring system was developed by using low-cost controller like Arduino Mega 2560. Initially, the sensors were identified to measure various parameters related to machine health. Further, these sensors were integrated with micro-



(a) Time Domain Plot (b) Frequency Domain Plot

(c) Reading from Adash make FFT Analyzer

Fig. 5 Time and frequency domain plots at 240 rpm

controller and a control system was designed to access the real-time input to be acquired from various sensors. For vibration analysis purpose, logic was developed to convert time domain data into frequency domain. The GUI was designed that could handle, process, display, and store the real-time input data from sensors. After due experiments on cam jump apparatus, this novel device reflected good accuracy with the standard FFT analyzer up to 99.175%. This device can provide more number of input channels for more numbers of sensors, and accuracy can be further increased by enhancing the resolution of input ports and controller.

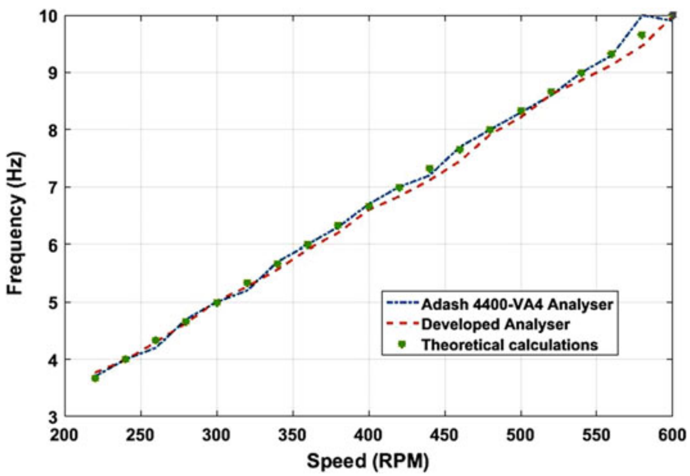


Fig. 6 Comparison of peak frequency determined by developed and commercial analyzer

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