

RMS G-meter

Team 12

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Proposal

Executive Summary

Ideal operating conditions for machinery and demand for quality shipments require a simple tool to monitor vibration damage. Instrumented Sensor Technology (IST) is sponsoring this project to develop a real time acceleration instrument as a solution. The goal is to design a “G-meter” that outputs the acceleration in units of the Earth’s gravitational pull as a peak, average, or integrated value. The project will start by researching several accelerometers and microchips that meet the required design specifications. The components will be selected by several factors such as power, manufacturability, and cost. A prototype will be created and tested which will be perfected and turned into the final product.

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Introduction

Devices that measure acceleration are important for many industries. In the freight industry, \$47 million USD worth of packages were destroyed in 2002 due to a phenomena called “hunting”¹. This occurs when a train car vibrates at resonant frequency. At resonant frequency, the train car violently oscillates causing damage to its contents. Specialized accelerometers are currently used to monitor and detect hunting. Paper mills are another industry that uses acceleration sensors. If a machine is vibrating more than its specification allows, the paper that is produced will not match the specifications and cannot be sold. This is a waste of resources for the mill. In avionics, acceleration sensors are used to show how much force is being exerted on the airplane. This helps indicate to the pilot the current G levels they are experiencing so they can maintain safe aircraft operation.

The proposed product, the RMS G-meter, is a device that will be used to measure root-mean-squared (RMS) acceleration. It will be a small handheld device capable of being attached to machines for taking and displaying onsite measurements. The RMS G-meter can also be used for measuring force exerted on package shipments by placing a meter either inside the package itself or in the container carrying the packages.

Background

Aircraft Spruce & Specialty Company manufactures the Flight Data G-meter GT-50.² The GT-50 is used in aircraft instrumentation and is advertised as the “best G-meter value available” with a cost of \$154.00. Although the RMS G-meter will not include all of the features of the GT-50, it will have the potential to cost less. The RMS G-meter will also have a greater variety of applications.

IST manufactures numerous sensors that record acceleration data, one of which is the MotionMaster® (EDR-6DOF).³ The MotionMaster® is designed to measure shock, vibration, and temperature. The time and date are recorded for each angular velocity or linear acceleration event. A problem with the EDR-6DOF is that the data is stored and cannot be retrieved without a computer and the proper software. The RMS G-meter will take real-time measurements and display them on the simple external LCD screen.

IST also manufactures a device specifically to measure the “hunting effect” on railcars. The Railcar Hunting Detector (RHD-2000)¹ is limited to measure “hunting” and counts the number of times a railcar experiences a 3G or greater force. “Hunting effect” could be measured more accurately with the RMS G-meter. Measuring up to 5G, The RMS G-meter will provide more information with the three modes to better characterize the conditions present on the railcar. The RMS G-meter augments what is already available in IST’s product line-up and adds a simple yet versatile G-meter to the market.

Objectives & Design Specification

1. Develop an acceleration sensing platform

The main goal is to interface an accelerometer with a microcontroller. It must operate with a full 5G scale with 1% precision. In order to eliminate any high frequency noise, a 500Hz 4 pole low pass Butterworth filter will condition the signal coming from the accelerometer. The filter will be implemented before the microcontroller uses the accelerometer output for calculations.

2. Develop a simple user interface

The interface for the final design needs to be self explanatory. It should not require a manual to explain how the modes are used or how to interpret the data. The LCD must display digits in “xx.xx” (G-RMS) format and update every three seconds.

3. Implement multiple modes

There are three modes that will be implemented. The first mode is peak mode which updates the highest G-RMS value since activation. The second mode is average mode which displays the averaged G-RMS values from the time the unit is activated. The third and final mode is integrated G-RMS which outputs the sum of all G-RMS samples computed since activation.

4. Low power usage

The G-meter must be able to perform all of the tasks for a minimum of 24 hours.

5. Packaging

The final packaging must be durable and non-pliable so the packaging will not dampen any acceleration.

6. Verification

The final design must be fully tested to be certain that the data it displays is accurate to within the 1% precision requirement.

Design Methodology

The design focuses on size, cost, and user interface. The size is intended to be smaller than existing products. With its small size the product can be used in many places and be easily attached to machinery or packages. The display and user controls will be simple with few buttons and an easy to understand LCD.

Ranking of Conceptual Designs

The RMS G-meter requires a specific type of accelerometer, a single axial accelerometer which measures 5G full scale range. With this requirement set forth, the deciding factors are the price of the device and the precision of the sensor. An accelerometer measuring less than 5G would not work because it does not measure the required amount of Gs. If the accelerometer measures more than 5G, there is a greater chance of getting extra noise that is not necessary for the measurements. Using an accelerometer measuring more than 5G may require an amplifier which could increase the chance of having an error in the reading. The most significant differences among the manufacturers are the price and precision because accelerometers produced by different manufacturers have similar specifications. There are multiple manufacturers which sell accelerometers which fulfill the requirements. They include: Freescale Semiconductor, Analog Devices, and Measurement Specialties.

The microcontroller on this RMS G-meter must be able to calculate the peak, average, and integrated RMS. Many microcontrollers have analog to digital (A/D) converters built in. An A/D converter is necessary in the design because the input signal is analog and a digital signal is required to perform calculations. Two types of microcontrollers are being considered for this design, 8-bit and 16-bit microcontrollers. For the RMS G-meter, a 16-bit microcontroller is implemented because it operates faster with a 12-bit A/D converter. For instance, an 8-bit microcontroller would require two

operations for an addition of the 12-bit data. The main differences between the 16-bit processors are the accuracy processing power, number of input/output (I/O) ports and RAM (Random Access Memory) bytes. The RMS G-meter does not require many I/O ports because the device does not have many inputs and outputs. Various manufacturers such as Microchip and Analog Devices produced similar 16-bit microcontrollers. Therefore, the final decision will be based on the price of the microcontroller.

The LCD outputs the peak, average, or integrated RMS value of the measured acceleration. It must also be easy to read. Most importantly, the display must be power efficient. This is because the 9V battery must last for at least 24 hours. Two kinds of displays meet the specifications required for the RMS G-meter. One is a LCD developed by Maplin which requires multiple screens to display the data. Multiple screens would require more wiring and larger area. Another display is a LCD built by Matrix Orbital. This display only uses one screen to display the necessary data. When selecting the display, specifications and appropriateness will be taken into consideration.

Design Description

To measure vibrations of an object, an accelerometer will be used. This will be connected to a PIC microcontroller to process the input from the accelerometer and output it to an LCD. The PIC will be programmed to implement the Butterworth filter, and will also contain an A/D converter which is needed to output the data to the LCD. Figure A shows the basic schematic of the connections between these devices.

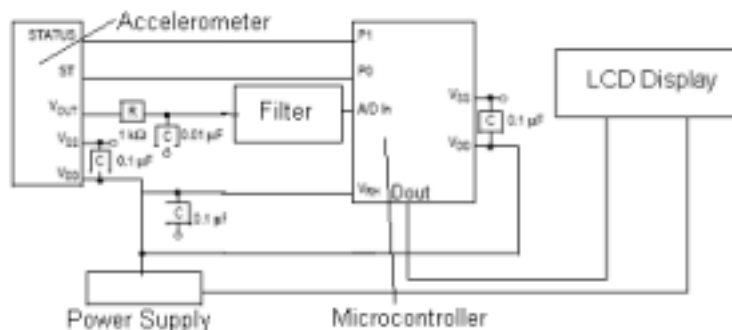


Figure A: Design layout of G-meter⁴

The accelerometer chosen for the device is the MMA1250D chip manufactured by Freescale Semiconductors shown in Figure B. This is a single axial sensor in the z direction with a sensitivity of $\pm 5G$, which is a perfect fit for the design specifications. The accelerometer has a sensitivity of 400 mV/G, which will be enough to meet the required precision of the product. This device requires an input voltage of 5V and has an output range of 0.5V to 4.5V.

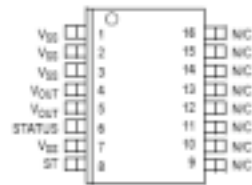
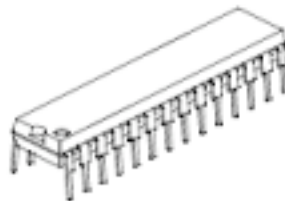


Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V _{DD}	Redundant connections to the internal V _{DD} and may be left unconnected.
4	V _{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V _{DD}	The power supply input.
7	V _{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

Figure B: Accelerometer layout⁴

The PIC being used, shown in Figure C, is a dsPIC30F3013 manufactured by Microchip. It is a 28-pin chip with 24 KB programmable flash memory, 20 I/O ports, which are needed for the LCD and for switching between output modes. The chip also features a 12-bit high speed A/D converter needed for sampling the signal coming from the accelerometer. This PIC operates with a supply of 5V.

Figure C: PIC visual⁵

The LCD being employed is the MLP-AL082B-BYFY manufactured by Matrix Orbital and is shown in Figure D. It is an 8 figure, 2 line display which operates with a supply of 5V.

Figure D: Liquid Crystal Display⁶

A 9V battery will be used as the power supply. The LM7805 fixed voltage regulator will be used to convert the 9V battery power to the correct voltage needed for the various components. This regulator has an output of a constant 5V with an input range from 1V to 35V. The layout of the regulator is shown in Figure E.

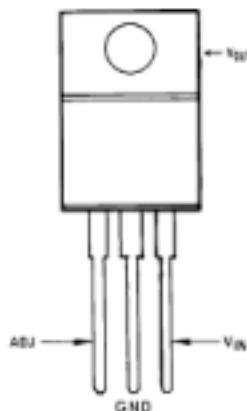


Figure E: Layout of voltage regulator⁷

Build and Test Plan

The build plan revolves around three major sections: firmware, hardware, and testing. The firmware programming has been separated into three portions: data sampling and filtering, post processing, and interface. The hardware design is separated into many pieces. The hardware subsections are PCB design, board construction (soldering), power supply and regulation, packaging, and user interface. The plan is to develop an initial firmware build as quickly as possible so that work can begin on the hardware setup and testing. Firmware changes will be necessary to improve accuracy, efficiency, and calculation speed over the entire design process. In order to perfect the code and design as quickly as possible, a functional build is the first task that must be done. Since the firmware can be upgraded easily the PCB design will be finalized once the first build is operational. When the PCB design is complete the packaging can be finalized.

Testing will be done in tandem with the build process. There will also be a final testing and verification for the end product. During the build process, tests will focus on overall operation of the prototype such as switching modes and reading the accelerometer output correctly. The other tests during the build process will focus on algorithm accuracy. When the initial design is complete we will start more exhaustive tests. These tests will focus on accuracy and proper functionality of the desired modes. There will be more than one prototype constructed in order to verify each unit produces the exact same results.

Evaluation Plan

The final evaluation will be based on extensive testing. This will confirm that the design is ready to be declared the final prototype. The tests will cover three major areas; accuracy, overall operation, and post processing. Post processing involves comparing calculations from the prototype to ideal calculations generated on a computer. Accuracy testing will be done through applying guaranteed predetermined forces and also comparing between the prototypes and other related devices. The three modes will be

tested by performing separate post processing of data. Lastly, the battery lifetime and casing robustness will be tested using simulated real world usage. When the prototype passes all of these tests it will be complete.

The tests we are planning are:

1. Tilting/rotating the accelerometer at precise angles to get fractions of 1G acceleration measured. This targets precise measurements and is an easily verified source of acceleration.
2. Finding a third party accelerometer or force transducer in order to compare the prototype data against a second, already verified source. This test will ensure that the device is accurate and reports the correct raw measurements.
3. To test the three modes of operation the same predetermined forces will be applied over the period of 1 hour for each mode. The prototype outputs will be logged and compared to Matlab calculations to compare ideal values to the prototype data.
4. Power usage will be tested by leaving the devices running in different conditions to make sure that regardless of applied forces the prototype stays active for a minimum of 24 hours.

Risk Analysis

The biggest concern for the project failing is with the accelerometer. This is because the accelerometer is used to measure all of the data that will be analyzed. The specification requires the accuracy of the final product to be within a 1% margin of error. If the accelerometer cannot achieve close to this accuracy, then after passing the signal through both the filter and the analog to digital converter, there will be more error. The total error may cause the product to not function within the precision requirement. The most accurate commercially available accelerometer has been chosen for this project, so if the accelerometer fails to meet the specifications, the project will fail to meet this requirement. A remedy for this would be to construct a new accelerometer. This is something that is beyond the scope of this project and would cause the project to go over the budget, equipment, knowledge, and time constraints currently allowed.

Processing speed is another concern. If the microcontroller cannot perform the necessary calculations and display the results via the LCD at a rate of 1kHz, the device will be too slow and inaccurate for this project. If this happens, a new microcontroller will need to be chosen and significant time will be lost redesigning the circuit and converting the firmware to the new microprocessor.

Project Management Plan

Personnel and Tasks

Each member on the team is assigned a non-technical role as well as multiple technical roles as follows:

Manager – Omar Bennani

The team manager will be responsible for calling meetings, making sure that deadlines are met, and revising the project plan in response to changing circumstances. Omar will also be responsible for coding involving the A/D converter and filter as well as diagnostic coding to verify proper functionality.

Website – Adam Young

The webmaster will be responsible for designing and maintaining team's website. In addition, Adam Y. will be responsible for researching and designing the filter to be used and building the board, including soldering.

Document Preparation – Adam Eshkanian

Adam E. will prepare documents including proposals and reports. Coding for the processing of computations and implementing the power supply will be the responsibility of Adam E.

Presentation Preparation – Cammi Stewart

Cammi creates and coordinates presentations and posts on the website. For the technical role, Cammi is programming the interface which includes the LCD display and user interface.

Lab Coordinator – Takahisa Nakahama

The lab coordinator is responsible for keeping the lab clean, and for ordering and tracking parts with the ECE shop. Taka will be responsible for board layout and unit packaging as well as circuit schematic and poster.

Facilities/Resources

This project require the use of a microcontroller, A/D converter, a single-axis accelerometer, signal filter, LCD display and battery power supply. A PIC programmer and debugger and soldering iron will be used in the build process.

Schedule

See GANTT chart attached for proposed schedule.

Budget

Estimated cost of production:

Part	Name of the part	Manufacturer	Cost(USD)
Accelerometer	MMA1250	Freescale Semiconductor	\$11.51
Microcontroller	dsPIC30F6015	Microchip	\$7.95
LCD Display	MOP-AL082-BYFY	Matrix Orbital	\$9.99
Voltage Regulator	LM7805	Fairchild Semiconductor	\$0.65
Casing	Project Enclosure (5x2.5x2")	Generic	\$3.69
TOTAL COST:			\$33.79

References

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