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Development of an Analyser for Flaw Characterisation in Dimensional Stone Blocks using Transient Signals

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ABSTRACT

One of the major concerns in the field of dimensional stones is the identification of hidden internal defects, cracks and joints prior to processing of the stone blocks. The presence of these defects results in a low yield of production and damages in stone slabs during slabbing and polishing process. Hence there is a need to develop a nondestructive testing method to identify defects in a dimensional stone block prior to slicing. In this context, a battery-operated, hand-held unit is developed to collect and study the characteristics of transient signals due to hammer impact on dimensional stone blocks. The device is designed using 32bits ARM Cortex- M3 STM32L151 microcontroller. It has LCD graphic display (128x64), 8 Mbytes Flash memory, micro SD card and 3.6V Li-Ion Battery with USB for charging and data transfer. One such prototype model is developed.

Keywords

Dimensional stone, defect, graphic display, microcontroller, piezoelectric accelerometer, transient signal.

1. INTRODUCTION

Natural stones have been used for centuries as building material [1], [2]. In historical time, it was mainly used as building blocks but with the development of new processing techniques, it became commercially feasible to produce thin facades for cladding, flooring and other commercial uses [3].

To a rough estimate, 30% of the mined out dimensional stone blocks get rejected due to hidden defects or cracks found during slicing and slabbing stage. The prior detection of these defects will help in the quality assessment of these blocks before processing like slabbing and polishing or otherwise. Hence there is a need for identifying and characterising these hidden defects in-situ through a credible scientific method. There are no commercially viable tools to detect such hidden flaws within standard blocks of one meter or more for daily uses. The existing ultrasonic flaw detectors are able to detect inherent flaws in stones up to approximately one foot or less [4], [5]. Attempts are made in the past for flaw characterization using time domain algorithm but it failed to detect minute flaws in stones [6], [7], [8], [9]. In order to accomplish this, an instrument is designed to capture the transient signals passing through rockmass under both known and unknown defects conditions. These transient signals are generated by a gentle impact on the material by impulse hammer.

2. CONSTITUENTS OF DATA ANALYSER

In planned approach, a small impulse hammer with round stainless steel head is used to generate the transient signal. This impact generates a transient signal of 10 to 50 msec duration. This transient signal is picked up by the accelerometer and converts the vibrations due to stress waves in the voltage signal. This voltage signal is fed to control module which converts in digital wave and store in it for further analysis.

The complete system has an impulse source (hammer), a receiver (accelerometer), the medium under test (stone block) and a prototype unit. They are explained here briefly:

2.1 Impulse hammer

To collect data by the system, stainless steel hammer is used and its detailed specifications and image are shown in Table 1.

Table 1. Roundhead point hammer with a fibre glass handle, Model GY10565 [10].

	**Material**	Stainless Steel
	Weight	300 gm
	Manufacturer	Shaurya Industries, Jalandhar, India.
	Model	Goodyear Ball Pein Hammer, GY10565

2.2 Piezoelectric Accelerometer

The piezoelectric accelerometer is selected based on its flat frequency response within the expected range of the vibratory mechanical signal of material and its resonance frequency. It is found that transient frequencies response vibratory signals are within 100 - 5000 Hz as per literature and test conducted [11]. The accelerometer's upper-frequency limit is dependent on its resonance frequency whereas the lower cut-off frequency is limited by the time constant of charge Amplifier. Two types of piezoelectric accelerometers are available in market one with integrated electronics (IEPE) and nonintegrated electronics (PE). The IEPE transducer needs an external current source and consumes more power as well as costlier than their PE counterpart. Considering these factors, Endevco model 2224C PE accelerometer is selected for study and its major specifications are given in Table 2 [12].

Table 2. Major specifications of the piezoelectric accelerometer, Endevco Model 2224C [12]

Dynamic charge sensitivity	12 pC/g	
Frequency response	1–6000 Hz with ± 5%	
Resonance frequency	32 kHz	
Internal capacitance	800 pF	

2.3 Charge amplifier

The basic diagram of charge amplifier with its different electrical flows is shown below in Fig 1 [13].

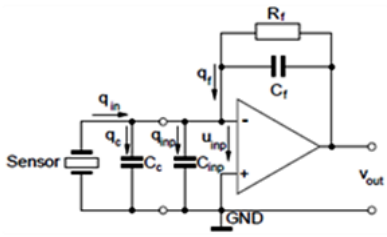

Fig 1: Basic charge amplifier

The charge amplifier gets connected to accelerometer via cable and converts the input charge to voltage. The output of Charge Amplifier is given by an equation as

$$V_{out} = -{}^{q_{in}}/_{C_f} \tag{1}$$

where q_{in} is input charge and C_f is feedback capacitor of charge amplifier. The equation (1) indicates the benefits of charge amplifier compared to voltage follower and its charge sensitivity does not effect by cable capacitance. The feedback resistor R_f provides DC stability and decides the time constant of amplifier thereby setting the lower cutoff frequency response of amplifier. The lower cutoff frequency, f_c of the charge amplifier is given by an equation as below:

$$f_c = 1/2\pi R_f C_f \tag{2}$$

The charge amplifier is designed with a sensitivity of 12mV/g and lower cutoff frequency of 7 Hz. The selection of operational amplifier for charge amplifier is done considering the high input impedance, low bias current, Rail to Rail Input and Output, unity gain stable with single power supply operation [14].

2.4 Data analyser

The data analyser has hardware and firmware that are necessary for signal acquisition, processing, displaying and communication of marble block impulse response data on USB. The instrument is composed of five different modules: a control module, an acquisition module, a storage module, graphical user interface module, and power module. The block diagram of the prototype instrument is shown in Fig 2 and the photo of prototype instrument is shown in Fig 3.

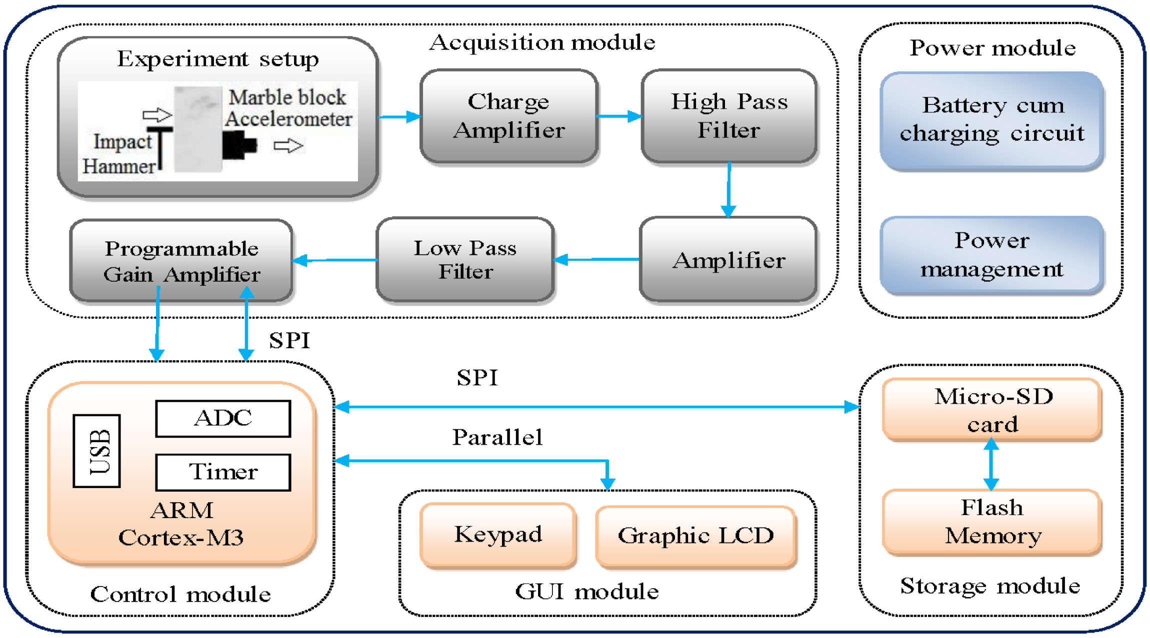

Fig 2: Block diagram of data analyser

Fig 3: Photograph of data analyser

2.4.1 Control module

The instrument is designed using a microcontroller, STM32L151 [15] from ST Microsystem, running at 24 MHz and inbuilt 384 Kbytes of flash memory, 48 Kbytes of RAM and 12 Kbytes of EEPROM. The STM32L151 controller is a 32-bit ARM Cortex-M3 core and is responsible for acquisition, storage, displaying, communication and processing of impulse data. The data acquisition is performed with help of a hardware timer event which occurs at a fixed frequency based on sampling rate selection.

During the process of vibration data acquisition, the STM32L151 controller handles the tasks of data collection, display, keypad and storage in RAM and Flash memory. A USB port is provided to download data to the computer for post processing operation. The multiple tasks handling is done using a real-time kernel which makes sure that all the tasks are serviced without any lockup condition in a round robin method. The tasks of data acquisition handled by a hardware interrupt to avoid non-uniform sampling rate and data loss problems.

2.4.2 Acquisition module

The acquisition module is the most critical of an analog instrument with respect to hardware and software design. It is the interface between the physical and digital world. While designing it, the balance between piezoelectric accelerometer output, input dynamic range of ADC, power supply voltage, power consumption, and noise are kept in mind to meet the implied requirements of long life and low weight of the instrument. These requirements are critical for a battery-operated the portable device in the field due to limited availability of power source to recharge the instrument and to continue testing for a long duration.

The frequency response spectrum of the hammer with steel tip has a wide band with an upper range of 5 kHz. The problem of noisy and false sample capturing has been addressed using the selectable trigger threshold level based on the condition of the object (stone block) under test. Major specifications of acquisition module are shown in Table 3 below:

Table 3. Specifications of acquisition module

	Parameter	Value
1.	Sampling rates	8, 16, 32 and 128 kHz
2.	Amplifier gain	1, 2, 4, 5, 8, 10, 16, 32
3.	Trigger threshold level	0.4, 0.6, 0.8 and 1.0 V
4.	Pre-triggered points per sample	16, 23, 64 and 128
5.	Total points per sample	512, 1024, 2048 and 4096
6.	ADC input range	0 to 3.3V
7.	ADC bits	12 bits

The acquisition module uses the STM32L151 controller's inbuilt ADC for conversion with maximum conversion rate supported up to 1 Msps. The clipped signal detection algorithm has been implemented in software to take care the saturation limit of analog signal conditioning section. The rail-to-rail input and output single power supply operational amplifier MCP6L91/94 [14] from Microchip has been used for charge amplifier, fixed gain amplifier, and low pass active filter. These amplifiers provide 10 MHz gain bandwidth product (GBWP), low input bias current of 1 pA, high input impedance of the order of 10^{13} ohm and 850 uA per amplifier quiescent current. These features are favorable for battery powered system.

The internal timer of the STM32L151 controller is used to periodically start the ADC conversion of data precisely for selected sampling rate. The converted data is stored in RAM buffer for a single sample. It is checked for saturation limits of signal conditioner for clipping condition. Once the clipped free data are captured for a sample which includes pre and post triggered, the data buffer is copied to processing RAM buffer for display, storage to non-volatile memory and further signal processing. While capturing the data of a single event, if the clipping occurs for one data, the whole data buffer get rejected and data acquisition module is refreshed for new sample acquiring process. The flowchart of data capturing from the accelerometer for the sample is shown in **Fig 4**.

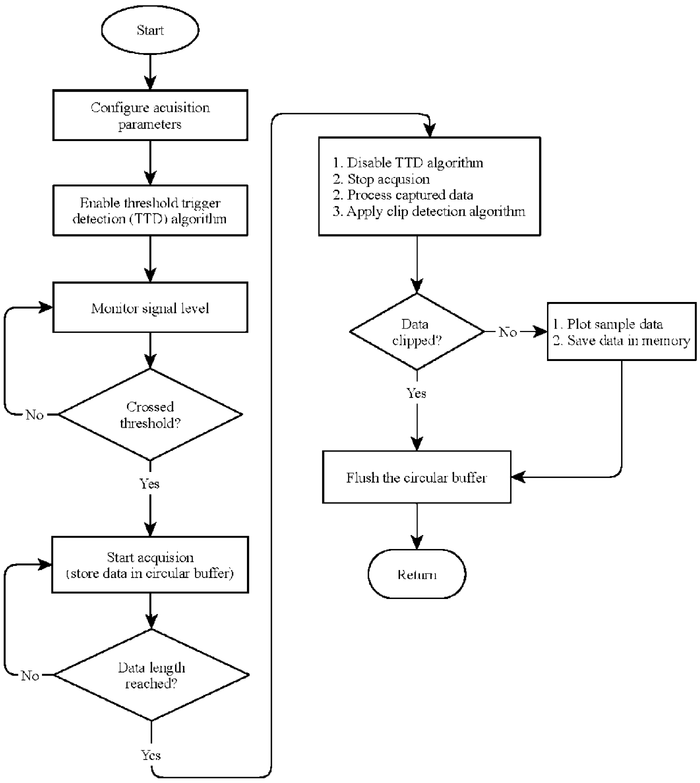

Fig 4: Flow chart of single impact data collection

2.4.3 Storage module

The impulse response data acquisition is characterised by high sampling rate, high resolution and a large number of data per impact event. These samples are saved in a non-volatile serial NOR flash memory W25Q64 [16] from Winbond having a capacity of 8MB using embedded Flash File System FAT16 so that these sample data can be read as a file for each sample and can be replayed on a local display or can be sent to the computer via USB. The instrument also has provision for a 2 GB Micro-SD card as storage media to enhance the storage capacity if needed. Both the storage media are connected to control module via high-speed SPI bus. The instrument has provision for real time clock DS3231 [17] from Maxim and temperature sensor TCN75A [18] from Microchip and these are connected to control module via I2C bus.

2.4.4 Graphical user interface module

The device has 16 keys to support the functionality and selection of parameters i.e. gain, sampling rate, data per sample, threshold level, and replay and upload of samples. The parameters are selected from drop down list to avoid any error in the entries. The numerical keypad is also included for setup configuration. The parameters, pop-up messages, results and impulse transient wave are displayed on the size of 128x64 monochrome graphic LCD 64128E [19] from Displaytech. It is a low power COG module operating at 3.3V with internal contrast control and inbuilt-voltage generator for biasing. The LCD module is connected to control module with parallel interface.

2.4.5 Power module

The instrument is powered by a 3.6V@1000 mAH rechargeable lithium-ion battery which is connected to a recharging circuit of MCP73811 [20] from Microchip. The battery can be charged through a USB port available on the instrument. The power module uses a linear low voltage dropout regulator MCP1825 [21] from Microchip for regulation to sustain long duration. L-C filters are used to remove noise from the power supply for analog circuits.

To extend the battery life of the instrument, it is equipped with low-power components with a sleep and wake up mode. The design strategy consists of three modes. The first mode is fully operational in which all components are working. In the second mode, the power switches off of the charge amplifier, programmable amplifier, and LCD backlight to reduce the power consumption when there is no data acquisition task. At last, when the instrument does not receive any command from USB or key-pressing in a preset time period, the instrument goes to deep sleep and power off.

In order to estimate the average power consumption of different operation modes, the instrument is powered by a DC regulated power supply at 3.6V. The results of average current and power consumption are shown in Table 4. Since the capacity of the lithium battery selected is 1000 mAH, the operation time of the instrument is evaluated and the results are given in Table 4. In fully operational mode, the device can work continuously for about 10 hours. When all modules enter sleep mode, the current consumption is only 0.14 mA. Therefore, this sleep and wake up mode help to extend the life. These optional modes allow to use limited available energy more effectively.

Table 4. Power consumption test results of the device in different modes

Operation modes	Current (mA)	Power (mW)	Life (hours)
Full operation	110	396	10
No data acquisition	32	115	34
All module sleep	0.14	0.50	7857

3. SUMMARY

A portable prototype instrument for marble industries has been developed. Further refinement of firmware, hardware and visuals can be done in the professional model. There is a provision in the hardware and firmware for improvement of the product in future. This device with associated accessories is needed to carry out day to day testing in the field. A charger is needed to charge the device from AC mains. In future, it is proposed to modify the firmware for suitability of flaw characterization in all types of dimensional stone blocks in the field and provide enhancements and improvements.

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