Modular Measurement System for Strain Gauge Sensor Evaluation

Petr Dostálek, Jan Dolinay and Vladimír Vašek

Abstract**—** Process measurement is one of the most important tasks in the many areas of technical branches. Quality of the final products in a production sector can be reasonably improved when whole process is carefully analyzed by measurement of main technology parameters before batch production. Measurement of the cutting forces enables to find optimal ratio between work piece quality and processing time in dependency on used cutting tool. Work presents design of modular multichannel measurement system for strain gauge sensor evaluation in laboratory of mechanical engineering mainly intended for practical exercises of our students. Measurement device is based on 8-bit Freescale microcontroller unit which is the main control part of the device. Device implements modular hardware design enabling easy functionality expansion in future demands. Hardware of the device is split into the two parts: main board and measurement modules. Communication with supervision system is provided by USB interface. Software works under real-time operating system RTMON for HCS08.

Keywords**—** Strain gauge, data acquisition, microcontroller, MC9S08GB60, communication.

I. Introduction

PROCESS measurement is one of the most important tasks in laboratory environment. Present-day there is available number of devices performing data acquisition tasks – standard cards for PCI or ISA (today rare but still present in special measurement systems where its PCI alternative is not available) bus which are suitable for standard personal computers and its industrial versions and modules for industrial automation usually equipped with RS485, CAN and other interfaces. Independent category is formed by smart sensors incorporating sensor, converter to unified signal and data acquisition device in one embedded system with very compact dimensions and low power consumption. They have number of advantageous features such as automatic diagnostic and calibration, high accuracy and immunity against electromagnetic interference due to short signal paths. On the other hand lower operating temperature range reduces their usage to laboratory applications, automotive and aircraft industry where compact dimensions and low weight are crucial. Quite often occurred situations when it is necessary to measure data in terrain where it is not possible to use standard computer equipped with data acquisition card. In these cases laptop computer equipped with portable data acquisition device may be very advantageous. This measurement system structure is suitable for laboratory environment too due to frequent transfers of the measurement equipment between each workplace.

The paper deals with hardware and software design of multichannel measurement system for strain gauge sensor evaluation in laboratory of mechanical engineering. The utilization of the device is mainly focused on three axis measurement of cutting forces. These measurements enable to find optimal ratio between work piece quality and processing time in dependency on used cutting tool. Main requirements to the device are:

- Multichannel operation with up-to 8 strain gauge measurement channels.
- 12 bit analog-to-digital conversion.
- Software selectable input range and offset null.
- USB interface for high speed communication with host computer.
- Universal design allowing future functional expansion with different modules such as analog and digital inputs / outputs, counters, PWM modulators and other modules.
- Simple and efficient communication protocol.
- Low-cost of the whole measurement system.

II. Strain Gauge Sensor Evaluation

Strain gauge sensors can be basically divided to the metal and semiconductor gauges. Metal type gauges are used in wide range of applications depending on their type. They can be divided to the three categories by physical design:

- Thin wire strain gauges
- Foil strain gauges
- Metal film strain gauges

Thin wire strain gauges can be used for wide range

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measurements with long-term dynamical straining. Some special types can operate at high temperatures. Today are very perspective foil strain gauges due to better transfer of deformation to the sensor and wide possibility of their mechanical construction configuration. Metal film strain gauges are especially suitable for pressure sensors where sensing film is a part of main measurement membrane. Semiconductor gauges are due to their high sensitivity suitable for measurement of very small deformations. Very advantageous is their high resistance and long-term stability.

Because of resistance change of strain gauge sensor related to strain is very slight it is suitable to use Wheatstone bridge for its evaluation. Suppose we have bridge which schematic is depicted in the Fig. 1 consisting of four resistances R_1, R_2, R_3, R_4 supplied by constant voltage source U_{in}. To the bridge output is connected voltmeter measuring U_{out}. Due to its very high internal resistance (theoretically infinity) its influence to circuit functionality can be omitted. Then it is possible the Wheatstone bridge consider as two unloaded voltage dividers. Output voltage U_{out} is equal to difference of voltages on dividers formed by R_1, R_2 and R_3, R_4:

$$U_{out} = U_{in} \frac{R_2}{R_1 + R_2} - U_{in} \frac{R_4}{R_3 + R_4} . \quad (1)$$

Equation (1) can be rewritten to the form:

$$U_{out} = U_{in} \left(\frac{R_2 R_3 - R_1 R_4}{(R_1 + R_2)(R_3 + R_4)} \right) \quad (2)$$

From (2) is obvious that Wheatstone bridge is balanced (output voltage U_{out} is zero) when (3) is fulfilled.

$$\frac{R_1}{R_3} = \frac{R_2}{R_4} \quad (3)$$

Suppose R_1 is the strain gauge sensor which changes resistance due to influence of tension or compression and R_2, R_3 and R_4 are fixed value resistors (quarter bridge strain gauge). If no strain is applied to sensor all resistances or equal and bridge is balanced.

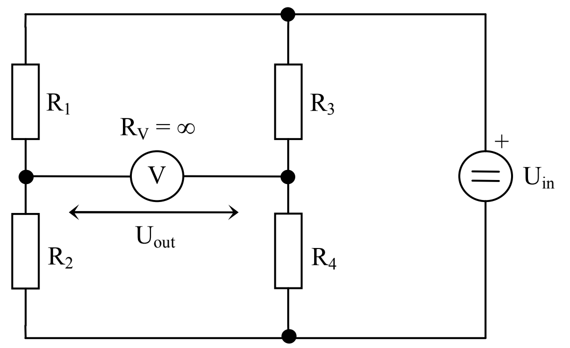

Fig. 1 Wheatstone bridge schematic.

When strain gauge sensor changes its resistance equation (3) is not satisfied so bridge is unbalanced and output voltage U_{out} is therefore nonzero. This small voltage must be before processing stage amplified in the instrumental amplifier to the level suitable for analog-to-digital converter in the data acquisition device.

Because of strain gauges are sensitive on temperature changes during measurement it is suitable to compensate this effect. This can be solved by adding compensation gauge R_C which must be same type as active gauge R_{SG1} but no strain is applied to it. Its placement should be near R_{SG1} to avoid temperature difference due to longer distance between them. Schematic of the quarter bridge strain gauge with temperature compensation is depicted in the Fig. 2.

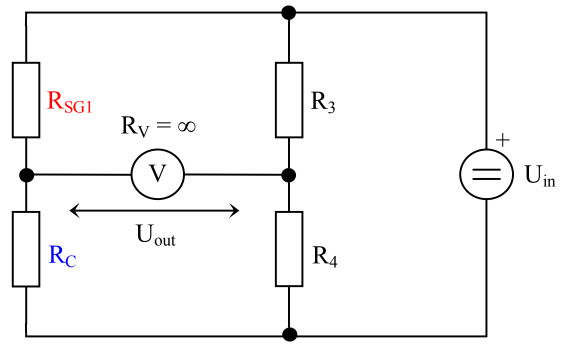

Fig. 2 Quarter bridge strain gauge with temperature compensation.

Sensitivity of the strain gauge evaluation circuit can be gained by utilization of the half-bridge strain gauge. In this configuration of the Wheatstone bridge two arms contain active gauge, for example on the positions of resistors R_1 and R_2 in the Fig. 1. Sensitivity improvement principle is obvious from the Fig. 3. Suppose we have specimen on which are installed two identical strain gauges SG_1 and SG_2 on its opposite sides. When no force F is applied to the specimen bridge is balanced and output voltage U_{out} is zero. When force F is applied downward on the specimen, SG_1 is strained and SG_2 is compressed at the same time. So resistance of SG_1 was increased and SG_2 was decreased resulting in higher sensitivity in comparison with quarter-bridge strain gauge.

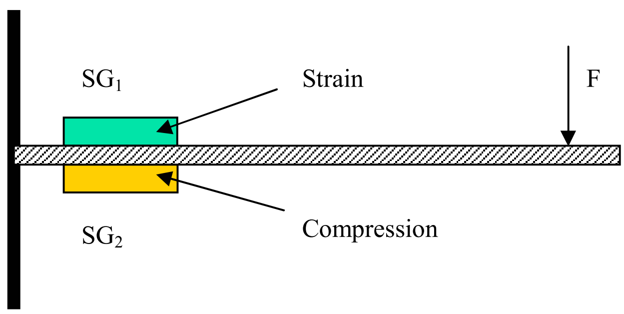

Fig. 3 Sensitivity improvement principle.

Next sensitivity gain can be achieved by using full-bridge strain gauge containing four active elements. Except this improvement it fully compensates nonlinearity of quarter and half-bridge configurations. Comparison of bridge output voltage level in dependence on gauge resistance change and actual bridge configuration is depicted in the Fig. 4. Nonlinearity can be noticed in quarter-bride graph due to purposely very high resistance change which does not occur in practice measurements. It is recommended to use quarter-bridge in only applications where resistance change of active element does not exceed approximately ±10 % of its nominal resistance to avoid nonlinearity error.

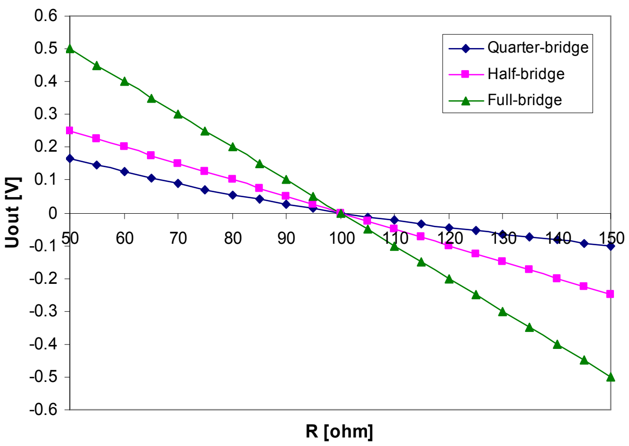

Fig. 4 Bridge output voltage in dependence on gauge resistance and bridge configuration.

III. Measurement Device Design

Design of the measurement device for strain gauge sensors evaluation is adapted to easy functionality expansion in future applications by simple adding of measurement modules with required features. This is achieved by splitting the whole measurement system into the two basic parts:

- Main control board consisting of master microcontroller, communication interface, power supplies and expansion connectors;
- Measurement modules which will be inserted to expansion connectors in main board. Because of board interface is fully digital each module must be equipped with analog-to-digital converter in case of need.

A. Main control board hardware design

Main control board electronic circuits are based on Freescale MC9S08GB60 microcontroller (MCU) coordinating all operations of the measurement system. It is a member of low-cost, general purpose, high-performance 8-bit flash-based microcontrollers with Von-Neumann architecture. Central processor unit with enhanced HCS08 core is fully upward compatible with Freescale HC05 family. CPU architecture is fully optimized for C language compilers.

On the chip are integrated following modules [1]:

- One 3-channel and one 5-channel 16-bit timer/pulse width modulator modules
- Two serial communication interfaces
- Serial peripheral interface
- Inter-integrated circuit bus module
- Internal clock generator module
- 10-bit analog-to-digital converter with 8-channel analog multiplexer
- On chip 64KB FLASH memory with in-circuit programming capability
- 4KB on-chip RAM
- 56 general-purpose I/O pins (16 high-current pins)
- 8-pin keyboard interrupt module
- On-chip debug module (DBG)
- Software selectable pull-ups on ports when used as input
- Watchdog system
- Low-voltage detection
- Illegal operational code and address detection

Central processing unit (CPU) features [2]:

- 40 MHz operation at 3V
- 8-bit accumulator (A)
- 16-bit stack pointer (SP) with new stack manipulation instructions
- 16-bit index register (H:X) with index register instructions
- Memory to memory moves without using the accumulator
- Fast 8-bit by 8-bit multiply and 16-bit by 8-bit divide instructions
- 64 KB program/data memory space

Correct program function is monitored by integrated watchdog system and illegal operational code and address detection. Internal program loading and debugging is provided by on-chip debug module (DBG). Internal bus frequency can be 20 MHz at 2.08 to 3 V supply voltage range or 8 MHz at 1.8 to 3 V supply voltage range. Microcontroller mainly communicates with measurement system expansion modules using serial peripheral interface (SPI) which is included with other signals in the all eight expansion connectors. It is four wires synchronous serial interface which can work in master or slave operation mode. In the measurement system main microcontroller is master device (initiates and controls all SPI data transfers) and all other connected units operate in slave mode. Slave select signal is not implemented due to different way of active board and corresponding SPI devices selection (expansion board can contain more SPI devices). Operation options of the SPI interface are fully programmable so it is possible to program transmit bit rate, serial clock phase and polarity, MSB first or LSB first shifting and other possibilities. Transmitter and receiver double buffering eliminates possible character losses when high bit rates are used. Maximum clock frequency in master mode is bus frequency (f_{BUS}) divided by 2, in slave mode it is f_{BUS} divided by 4.

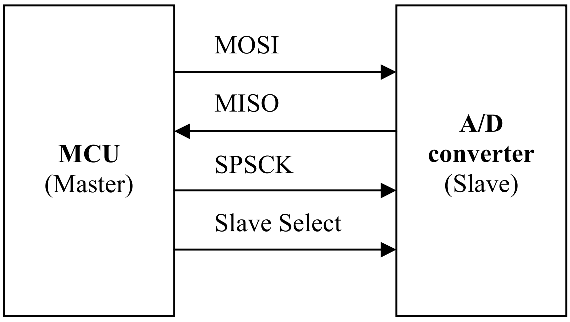

Fig. 5 Serial peripheral interface operation.

Serial peripheral communication interface operation is obvious from Fig. 5. Master device, in our case microcontroller unit (MCU), initiates communication by selecting slave device using slave select signal which is active in logic low level. Then interface shifts data from the internal register to the MISO line (Master Out – Slave In) while on the SPSCK line is generated clock signal. At the same time master device receives data from the MISO (Master In – Slave Out) line. Slave select signal is pulled high logic level when communication with slave device is done. Because measurement system can utilize more then one SPI device there are implemented general purpose output control signals for slave selection logic which can be used for other functions when currently selected expansion board has no SPI devices.

Communication with supervision system is provided by FT232BM USB 1.1 and 2.0 compatible universal asynchronous receiver / transmitter (UART) integrated circuit (IC) which is intended for many application areas such as: USB to RS232 converters, smart card readers, bar code readers, USB hardware modems, USB instrumentation and many other applications. It is capable to communicate at TTL levels with data transfer rates up to 3 MBd. On the chip integrated transmit and receive buffers with capacity of 128 B and 384 B respectively enables high data throughput. IC operates from single power supply with voltage of 5 V. USB input / output interface is supplied from integrated 3.3 V voltage regulator. Due to integrated level converter for UART I/O signals it is possible to connect it with logic circuits operating at 3.3 V or 5 V power supplies [7]. FT232BM is wired in manufacturer recommended wiring for self powered application with 3.3 V input / output interface. Clock signal is generated externally by crystal oscillator Q_2 with frequency of 6 MHz. Activity of serial interface is indicated by two LEDs LD_1 and LD_2 for receive and transmit mode separately. FT232BM UART signals RxD (receive data) and TxD (transmit data) are cross-connected to pins TxD and RxD of the main microcontroller UART pins which is able to achieve communication speed of up-to 1.25 Mbits per second at 20 MHz bus clock. Serial interface control signals RTS (request to send), CTS (clear to send), DTR (data terminal ready), DSR (data set ready) except DCD (data carrier detect) and RI (ring indicator) are connected to general purpose input / output pins of the microcontroller enabling utilization of hardware flow control in case of need. Microcontroler's UART interface supports full-duplex operation utilizing standard non-return-to-zero (NRZ) format. Transmitter and receiver can be enabled separately allowing lower power consumption. Their double buffering enables high speed communication without problems with received characters losses. Main features of the UART interface are [1]:

- Hardware parity generation and checking
- Programmable 8-bit or 9-bit character length
- Programmable baud rates
- Interrupt-driven or polled operation

To the FT232BM is connected too optional 1 Kbit EEPROM memory 93C46 with selectable (128 x 8 or 64 x 16) internal organization. It can be used for storage of USB vendor identification (VID), device class definition for physical interface devices (PID), serial number and product description strings. Memory can operate at wide power supply voltages – low voltage (1.8 V to 5.5 V) or standard voltage (2.7 V to 5.5 V). Its connection with UART IC is provided by 3-wire synchronous serial interface operating up-to 2 MHz clock rate at 5 V power supply.

Eight 30 pin expansion connectors JP_2 to JP_9 include all signals necessary for expansion modules function. They provide voltage sources of 3.3 V, 5 V for digital and +15 V, -15 V for analog circuits, serial peripheral interface for communication with master microcontroller (MISO, MOSI, SPSCK) and finally 8 input and 8 output general purpose digital interface (DI0-7, DO0-7) which is utilized for internal logic control of the connected modules. Currently active expansion connector is selected by microcontroller in cooperation with 3-to-8 line inverting decoder 74HC138 on which outputs are available eight board select signals BS_0 to BS_7 active at low state. Only one expansion module can be in active state and communicate via module interface with microcontroller. Other modules (with board select signal in high state) must stay in the high impedance state. Expansion connectors pin assignment is provided in the Table I.

Table I. Expansion connectors pin assignment

Pin number	Signal name	Pin number	Signal name
1	DO7	2	DO6
3	DO5	4	DO4
5	DO3	6	DO2
7	DO1	8	DO0
9	DI7	10	DI6
11	DI5	12	DI4
13	DI3	14	DI2 (BID2)
15	DI1 (BID1)	16	DI0 (BID0)
17	MISO	18	MOSI
19	SPSCK	20	+15 V
21	BS	22	-15 V
23	+3.3 V	24	+3.3 V
25	+5 V	26	+5 V
27	GND	28	GND
29	GND	30	GND

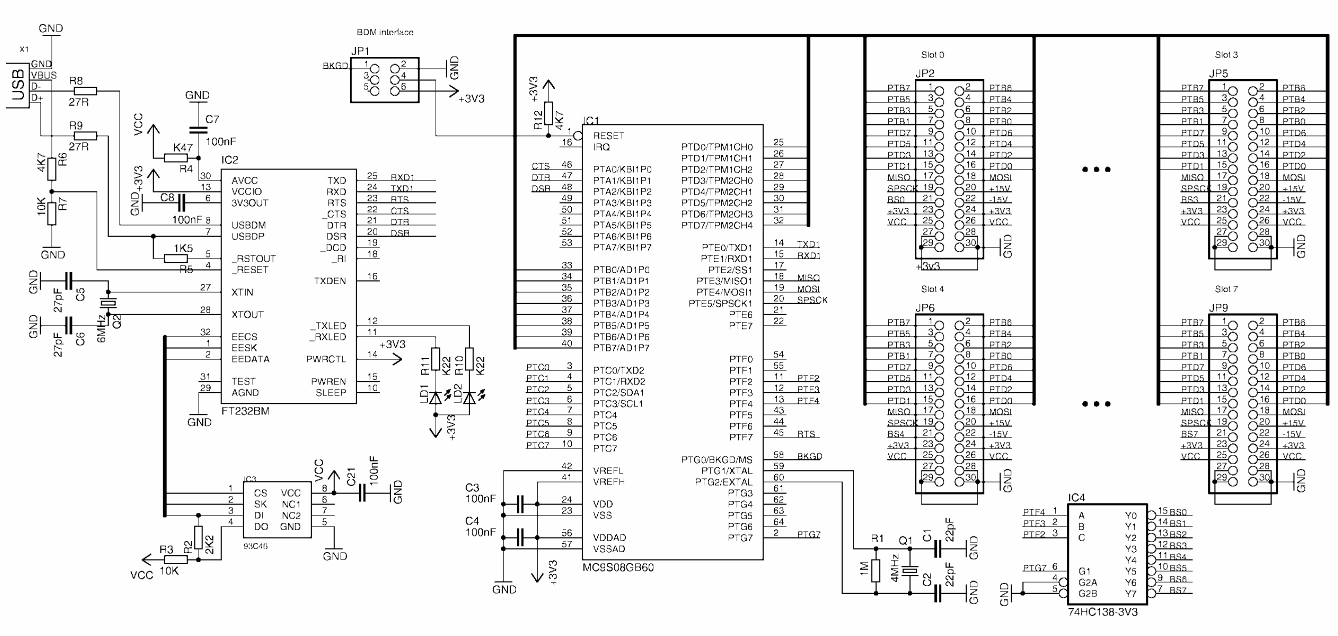

Fig. 6 Main control board schematics.

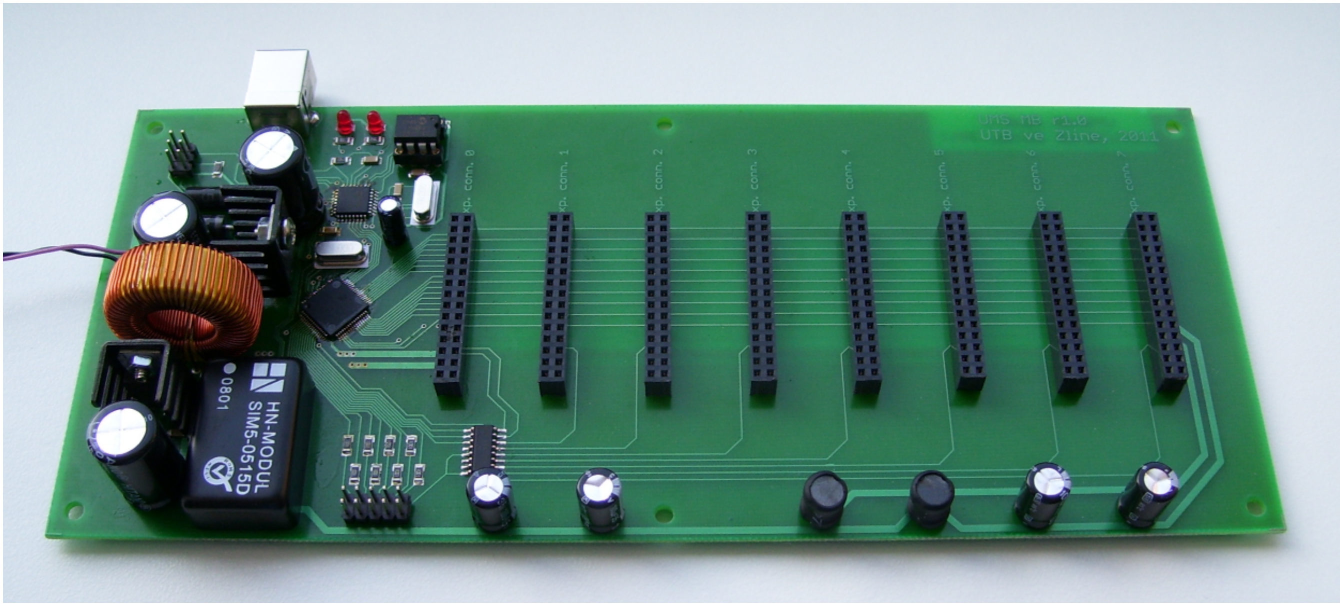

Fig. 7 Photograph of the finalized main board PCB.

Main board of the measurement device requires 12 V DC regulated power supply. This voltage is by internal circuits changed to the values required by implemented digital and analog circuits. Main power supply is based on LM2576 high efficiency (typically 77% at full load) step-down voltage regulator with output voltage of 5 V and current of 3 A. It works at 52 kHz fixed frequency generated by internal oscillator. Regulator requires only four external components – input capacitor, output capacitor, inductor and catch diode. Parts parameters were calculated using design procedure published in [9]. From the 5 V main voltage rail are derived all other supply voltages. Power supply for 3.3 V digital circuits utilizes very low drop voltage regulator LF33. Analog circuits based on operational amplifiers used in expansion boards work with symmetrical supply voltages ±15 V. Due to requirement that whole measurement device must be powered from simple 12 V DC wall adapter DC-DC converter from 5 V to ±15 V with power of 3 W was used.

Six pin BDM interface connector is used for programming of master microcontroller. This connector can be used for further measurement device firmware update.

Simplified schematic of the main control board without power supply circuits is depicted in the Fig. 6. Photograph of the finalized main board PCB is in the Fig.7.

B. Strain gauge measurement module

Electronic circuits of the strain gauge measurement module can be divided into the six functional blocks as illustrated in the Fig. 8: amplifier with software selectable gain, 4^{th} order low pass filter Bessel-type filter, offset null circuit, 12-bit D/A converter, 12-bit A/D converter and digital interface for communication with main control board.

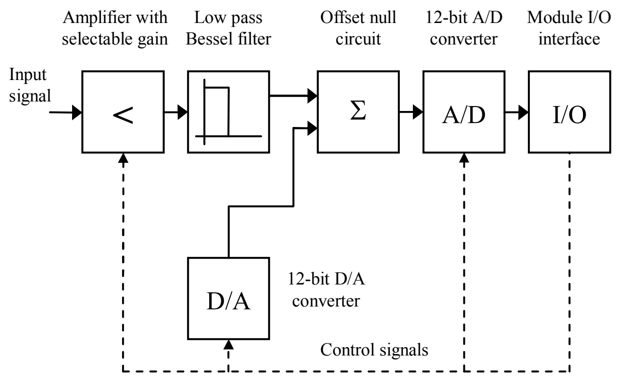

Fig. 8 Block diagram of the measurement module.

Input voltage signal from strain gauge sensor is amplified to suitable voltage level for analog-to-digital converter in two stage amplifier utilizing two low offset and drift JFET operational amplifiers LF411. First stage works as differential amplifier with fixed gain of 5 followed by non-inverting stage with five program selectable gains of 1, 1.5, 3, 10 and 30. Gain is controlled by changing resistance of the feedback resistor by five relays with 5 V coil operating voltage. Relays are directly driven by hex D-type flip-flop 74HCT174 which is capable to work with 3 V logic signals on its inputs while supply voltage is 5 V. Module input voltage ranges are ±10 mV, ±30 mV, ±100 mV and ±300 mV.

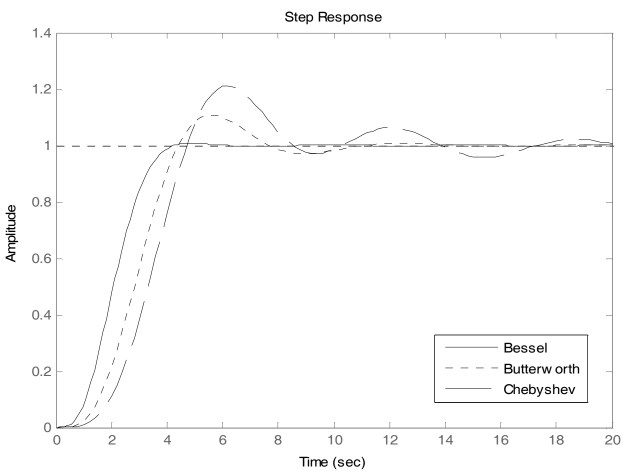

Fig. 9 Step responses of commonly used filters.

Amplified input signal passes 4^{th} order active low pass Bessel type filter with Sallen–Key topology implemented by operational amplifiers to eliminate ripple in the input signal. Filter parts was designed for cutoff frequency of 200 Hz and gain of 0 dB in the passband. This type of the filter was chosen due to advantageous step response with small overshot as depicted in the Fig. 9. On the other hand its drawback is smaller slope of the stop-band part of the frequency characteristic in comparison with Chebyshev or Butterworth approximations.

Parts values was designed using procedure published in [8]. Computation is based on transfer function of Sallen-Key 2^{nd} order low-pass filter (4) where coefficients a_1 and b_1 are equal to (5) and (6).

$$A(s) = \frac{A_0}{1 + a_1 s + b_1 s^2} \quad (4)$$

$$a_1 = \omega_c \left[C_1 (R_1 + R_2) + (1 - A_0) R_1 C_2\right] \quad (5)$$

$$b_1 = \omega_c^2 R_1 R_2 C_1 C_2 \quad (6)$$

Final transfer function of the 2^{nd} order low-pass Sallen-Key filter is:

$$A(s) = \frac{A_0}{1 + \omega_c\left[C_1(R_1 + R_2) + (1 - A_0)R_1 C_2\right]s + \omega_c^2 R_1 R_2 C_1 C_2 s^2} \quad (7)$$

where ω_c is a cutoff angular frequency, A_0 is gain of the filter in the passband and a_1 and b_1 are filter coefficients determining its properties. After the formulation of R_1 from equation (6) and constituting to (5) we obtain quadratic equation:

$$R_2^2 C_1^2 C_2 \omega_c^2 - a_1 R_2 C_1 C_2 \omega_c + b_1 (C_1 + C_2 - A_0 C_2) = 0 \,. \quad (8)$$

Its solution is equation for computation of R_1 part value (9), R_2 part value can be computed by (10).

$$R_1 = \frac{b_1}{R_2 C_1 C_2 \omega_c^2} \quad (9)$$

$$R_2 = \frac{a_1 C_1 C_2 \omega_c + \sqrt{(-a_1 C_1 C_2 \omega_c)^2 - 4 C_1^2 C_2 \omega_c^2 b_1 (C_1 + C_2 - A_0 C_2)}}{2 C_1^2 C_2 \omega_c^2} \quad (10)$$

In order to obtain non-negative value under square root in (10), capacitors values must fulfill (11).

$$C_2 \geq C_1 \frac{4 b_1 A_0 + a_1^2 A_0 - a_1^2}{a_1^2 A_0} \quad (11)$$

Practically the easiest way is to choose first capacitors C_1 and C_2 manufactured usually in E6 series and then compute resistor values. Exact resistor value can be reached by connecting more resistors in parallel or in series.

Bessel-type filter coefficients for both filter stages are provided in the Table II.

Table II. Bessel filter coefficients [8].

Filter order	Stage i	a_i	b_i	Q_i
1	1	1.0000	0.0000	-
2	1	1.3617	0.6180	0.58
3	1 2	0.7560 0.9996	0.0000 0.4772	- 0.69
4	1 2	1.3397 0.7743	0.4889 0.3890	0.52 0.81

Filtered signal enters to offset null circuit which sums it with digital-to-analog converter output voltage. This voltage is controlled by master microcontroller to obtain zero readings when no strain is applied to strain gauge sensor. Its nominal value is 1600 mV when bridge is in perfectly balanced state. Circuit utilizes Microchip MCP4921 12-bit D/A converter with SPI interface [6].

Analog-to-digital conversion of the amplified and filtered bridge output signal is performed by the A/D converter Microchip MCP3202. It is low power, dual channel, 12-bit A/D converter which can operate on 2.7 V to 5.5 V power supplies [5]. Communication with microcontroller is handled by SPI interface.

Schematic of the amplifier and low-pass filter with offset null is in the Fig. 10. Photograph of the finalized strain gauge measurement expansion board PCB is in the Fig. 11.

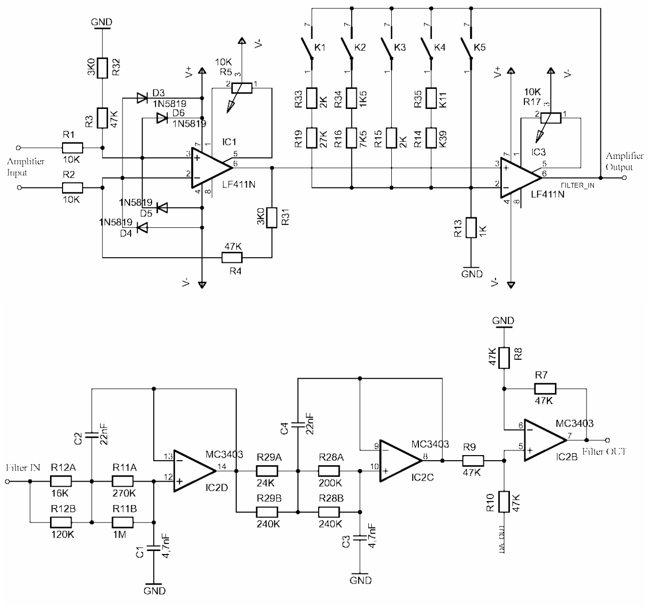

Fig. 10 Amplifier and low pass filter schematics.

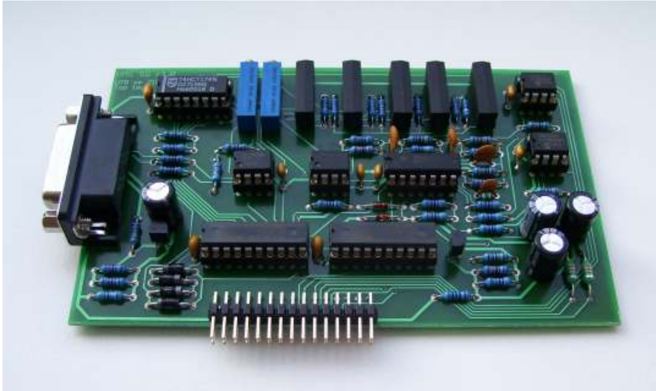

Fig. 11 Strain gauge measurement expansion board PCB.

IV. Device Firmware

Measurement device firmware is based on real-time operating system RTMON for HC08, which was developed on our department especially for microcontroller-based embedded systems with CPU08 main processor core. So software is formed of RTMON OS core and individual processes which perform all necessary tasks. Each process activity is controlled by operating system core on the basis of process priority and other information stored in the task descriptor.

A. Real-time operating system RTMON

RTMON is preemptive multitasking operating system which is simplified to great extend to allow easy use for programmers. It is written in C language with the exception of small platform-specific code written in assembler. The scheduler assigns time slices to processes based on their priority. The priority is integer in the range 1 to 254. Priority 0 is the highest and is reserved for the RTMON initialization process and priority 255 is the lowest and is reserved for the idle process (called dummy in RTMON).

RTMON allows execution of two different types of processes (tasks): normal processes which execute only once (such process typically contains infinite loop) and periodical process which is started automatically by RTMON with given period. These periodical processes are useful for many applications, for example, in discrete controllers which need to periodically sample the input signal and update the outputs.

The priority of each task must be unique, so that in each moment one task (the one with highest priority) can be selected and executed on the CPU. The scheduler does not support cyclical switching of several processes with the same priority on the CPU in round-robin fashion; it simply chooses the task with highest priority from the list of tasks which are ready to run. Processes can be created on the fly, but it is not possible to free and reuse memory of a process. No more than the maximal number of processes can be created, even if some processes were previously deleted.

There are only two objects (data structures) which RTMON contains: process (task) and queue. The queues are buffers for transferring data between processes. It would more properly be called mailboxes in our implementation as each queue can contain only 1 message. Several queues can be created, each containing a message (data buffer) of certain size. The size can be specified when creating the queue and is limited by the total size of RAM reserved for all buffers of all the queues (queue pool size). Processes can read and write data to the queue and wait for the queue to become empty or to become full. This allows for use of the queue also as a synchronization object (semaphore) [3], [4].

B. Implemented processes

Structure of the measurement device firmware is depicted in the Fig. 2. It consists of eleven processes each performing its specialized tasks. Process switching on central processing unit is controlled by real-time operating system core.

Process 1 "System Initialization" is highest priority process which performs measurement device hardware initialization after power up or reset. First of all it starts to search installed expansion modules and on the basis of their BID (Board Identification number) performs their automatic setup and basic functionality tests. Successfully recognized expansion boards are recorded to the internal data structures for next firmware activities. After that it setups serial communications interface to communication speed of 115200 Bd, 8-bit data frame, 1 start bit and 1 stop bit and finally initializes all necessary data structures. Because of its highest priority no other processes can be switched by RTMON core into the "run" state before this process is completely finished. After all initializations are done it suspends itself.

Process 2 "Command processing" performs all tasks related to command interpretation and execution. It waits for complete command string in the receiver buffer which is serviced by communication process. When command is completely received in the buffer, process will decode it and executes required action by starting of the corresponding expansion board service process.

Process 3 "Communication" provides communication via asynchronous serial interface with the supervisory system. It receives characters from UART interface and stores then to the command buffer. When this buffer contains complete and valid command process commits it to the process 2 for next processing. It generates too responses to all commands regarding to defined communication protocol include error processing. It has defined lowest priority among of all processes so it is not possible to communicate with the measurement device if it is in busy state (last command is not completely processed yet.

Process 4 "Watchdog" periodically checks correct function of all running RTMON processes by polling their status. Device is stopped and all expansion board activity LED indicators start to flash indicating device fault state.

Process 5 to 11 "Expansion Board services" includes all needed program code for expansion board control. Each board is identified by its own board identification number which can be read from expansion module interface pins named BID0-2. For example strain gauge measurement module has BID = 0 so process 5 will perform all operations with this module.

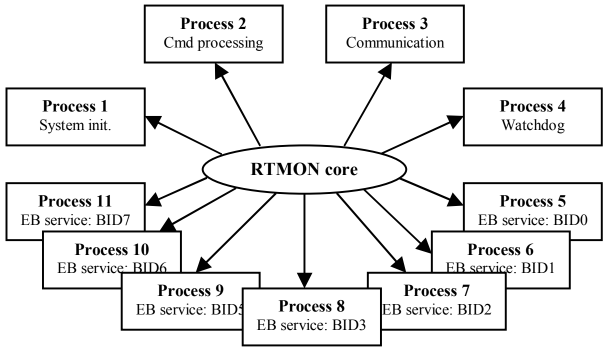

Fig. 12 Measurement device firmware structure.

V. Conclusion

This contribution deals with design of the multichannel measurement system for strain gauge sensor evaluation. Device implements modular hardware design dividing of the whole measurement system to the main control board and input / output eventually measurement modules. Main board is based on 8-bit Freescale microcontroller. Expansion modules are automatically recognized by master microcontroller by unique identification number in the range 0 to 7 where board ID 7 is reserved for empty expansion connector. Communication with supervision system is provided by USB interface which is recognized in OS as standard serial port. Software works under real-time operating system RTMON for HCS08 which was developed on our department for control and monitoring applications.

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