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The realization concept of a specific electronic musical instrument

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Abstract - **This paper presents the realization concept of a specific electronic musical instrument. The instrument allows playing notes by pressing certain keys, breaking laser beams and modifying pitch band and modulation wheel with accelerometer. The required hardware consists of lasers, laser beam receivers, accelerometer board, microcontroller, personal computer (PC), loudspeakers and other necessary elements to connect the entire system into a single unit. A real-time operating system installed on the microcontroller provides processing sensor and accelerometer signals and transfer of MIDI messages to the PC via RS-232/MIDI/USB interface. The PC generates appropriate music signals using music software. The software contains sound libraries of different instruments and interprets sent MIDI messages.**

Key words – electronic musical instrument; MIDI controller; laser harp;

I. Introduction

The paper provides an overview of the basic characteristics of electronic musical instruments, MIDI protocol, hardware components and software implementations on the microcontroller and the PC. At the end, test results and characteristics of the instrument are presented.

II. Electronic musical instruments

A musical instrument that produces its sound using electronics is an electronic musical instrument. Such an instrument outputs an electrical audio signal that drives a loudspeaker. It may include a user interface for controlling its sound by adjusting the pitch, velocity, duration or some other parameters such as volume or vibrato of each note. The user interface and sound generating functions are often separated into a music controller (input device) and a music synthesizer, respectively. These two devices communicate through a musical performance descriptive languages such as MIDI or Open Sound Control.

Electronic musical instruments are used in many musical styles, so the development of new electronic musical instruments, controllers and synthesizers is very interesting and active field of research [1].

III. MIDI

Despite the large impact on the music, MIDI (Musical Instrument Digital Interface) is not audio of any kind. MIDI was formed as the result of agreement among the developers of electronic musical equipment, computers, audio and other electro-acoustic devices in order to provide an industry-standard protocol for communication and synchronization of electronic musical instruments (synthesizers, drum machines), computers and other electronic equipment (MIDI controllers, sound cards, samplers). MIDI consists physically of a simplex digital current loop electrical connection sending asynchronous serial communication data at 31250 bits per second [2].

MIDI defines interface between various electronic devices (not just musical) and three types of ports. MIDI equipment is based on the microprocessor environment and it is also widely used outside synthesizer industry, such as light show control, theatre lighting, special effects, live videos and various types of presentations [3].

IV. The hardware of the instrument

The hardware of the instrument consists of microcontroller MSP430F449 and its peripherals, 3-axis accelerometer ADXL330, lasers, laser beam receivers, RS-232 to MIDI and MIDI to USB converters, PC and loudspeakers as shown on Fig. 1.

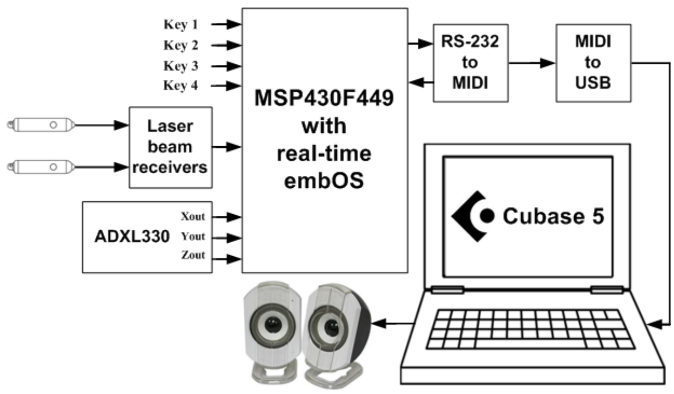

Figure 1. The hardware of the instrument

The user interface (input device) consists of four keys on the development microcontroller board, two laser beams and laser beam receivers (Fig. 2), PC keyboard, 3-axis accelerometer (Fig. 3) and the microcontroller board. Notes are generated by pressing keys 3 and 4 on the microcontroller board or keys on the PC keyboard or by breaking laser beams. Two accelerometer axes are used for pitch band and modulation wheel control of generated notes.

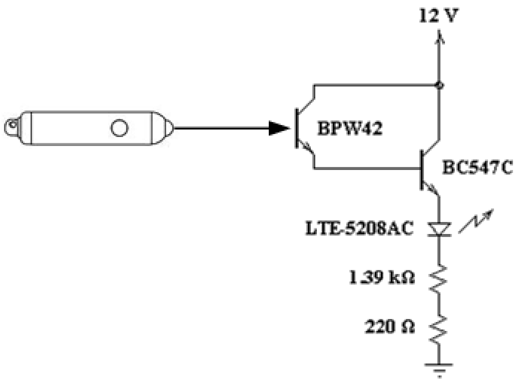

Figure 2. Laser and laser beam receiver

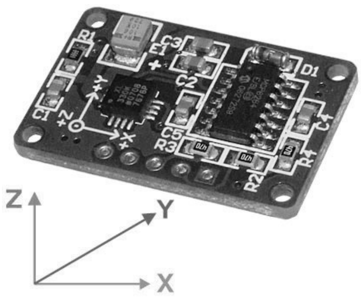

Figure 3. 3-axis accelerometer board ADXL330

The used lasers emit light in a wavelength range from 630 to 680 nm and have power less than 1 mW. Considering the laser beam receivers cover the range from 560 to 980 nm, some other light source could be used as a light transmitter instead of laser.

The central part of the input device is ultralow power microcontroller from MSP430 family. The device features five low-power modes, a powerful 16-bit RISC CPU, 16-bit registers and constant generators that contribute to maximum code efficiency. The microcontroller consists of several peripherals for various purposes. In the development of this instrument three peripherals are used: keys, fast 12-bit A/D converter and universal serial synchronous/asynchronous communication interface (USART). The USART is connected to circuitry that generates signals that comply with the RS-232 specification and RS-232 port is used as an interface from the side of microcontroller [4], [5].

The hardware of the music synthesizer consists of a PC and loudspeakers for sound generation. MIDI messages that are sent from the microcontroller (RS-232 port) are converted from RS-232 to MIDI voltage levels (Fig. 4) and than from MIDI to USB compatible signals (MIDI/USB cable from Konix Technology shown on Fig. 5) [6].

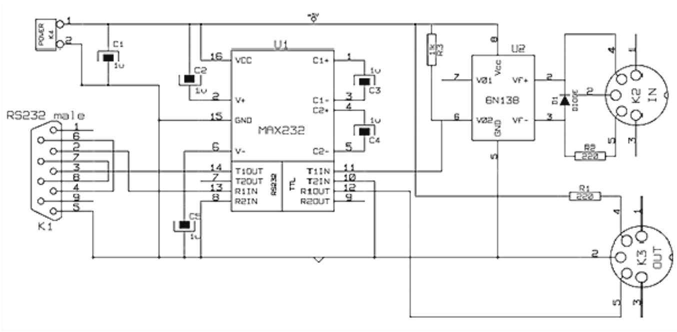

Figure 4. 3-axis accelerometer board ADXL330

Figure 5. MIDI/USB cable - Konix Technology

V. THE SOFTWARE OF THE INSTRUMENT

The software of the instrument is separated into the real-time software on the microcontroller and the music software Cubase 5 on the PC.

The software on the microcontroller is implemented on the embOS platform, which is priority-controlled real-time operating system, designed to be used for the development of embedded real-time applications. Tasks can communicate with each other using a complete palette of communication mechanisms such as semaphores, mailboxes or events. Interrupt service routines (ISRs) can also take advantage of these communication mechanisms [7].

The main program consists of four tasks, one software timer and A/D converter ISR. Communication block diagram is shown on Fig. 6.

Task1 has the highest priority (4) and its function is to calibrate accelerometer board. It reads data from Mail Boxes, which are digital values from three analog channels of A/D converter for X, Y and Z axes. Then key 1 is read and if it is pressed the X-axis unit gravity and Y and Z-axis zero gravity are calibrated. The instrument user has to set appropriate board orientation to gravity. After that, Task1 is temporary suspended. That way, some kind of key debouncing is done. This procedure is repeated two more times in order to complete calibration. At the end, considering Task1 is no longer required, it is terminated and other tasks get more space to compete for processor time.

Task2 has lower priority (3) and at the beginning, it reads the state of key 2. If it is pressed, Task1 sets or resets (alternately) event Mode which enables instrument control by laser beams and keys 3 and 4 or by PC keyboard. After that Task2 is temporary suspended in order to debounce key 2.

Task3 (priority 2) reads status of event Mode and depending on it, instrument is controlled by laser beams and board keys 3 and 4 (first mode) or by PC keyboard (second mode). In the first mode, keys 3 and 4 are read as well as data from Mail Boxes (data are mapped with A/D converter channels on which laser beam receivers are connected). If some of the keys are pressed or some of the laser beams are broken, appropriate MIDI messages are sent through USART to turn earlier defined notes on or off (alternately) with specified velocities. In the second mode, no action is undertaken at this moment. At the end, Task3 is temporary suspended in order to debounce keys 3 and 4.

Task4 has the lowest priority (1) and its function is to read data from Mail Boxes (data are mapped with A/D converter channels on which accelerometer output pins are connected), calculating pitch band and modulation wheel parameters and sending MIDI messages for control of these parameters. At the beginning of the task, Task4 reads status of event Mode and examines whether some of notes are turned on or off. MIDI messages are not sent only in case when instrument is controlled by laser beams and board keys and all notes are turned off.

SoftTimer is software timer which is used for start of A/D conversion. Timer is periodically retriggered to enable periodic conversion.

ADC12_ISR is interrupt service routine of A/D converter which is entered after A/D conversion. A/D converter memory registers are read (accelerometer output pins and laser beam receivers) and data are written into Mail Boxes.

In addition to the main program, there is initialization file where initialization of I/O pins is done as well as setting A/D converter and USART in required modes.

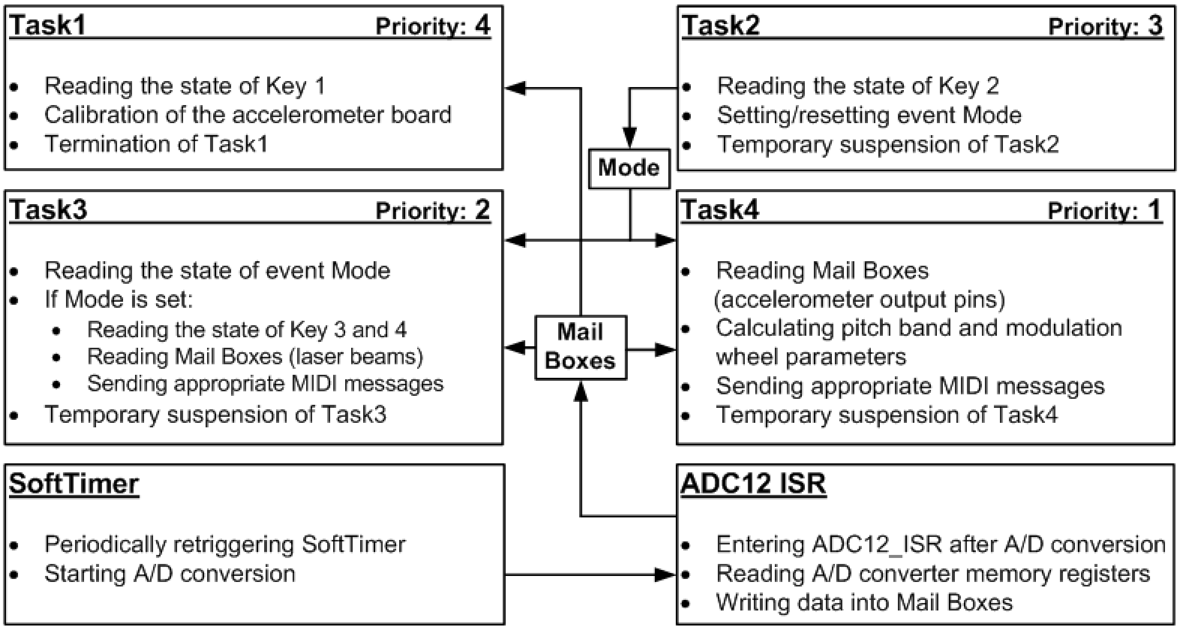

Figure 6. The software of the instrument on the side of microcontroller

The software on the PC platform, which presents music synthesizer, is Cubase 5 developed by Steinberg for music recording, arranging and editing. Cubase is also able to work with MIDI (it can interpret MIDI messages, edit MIDI files etc.) and with VST (Virtual Studio Technology) instruments. Steinberg's VST is an interface for integrating software audio synthesizers and effect plugins with audio editors and hard-disk recording systems [8], [9].

Cubase interprets MIDI messages which arrive from the microcontroller on the USB port. Sound is generated using VST and selected instrument from instrument libraries. Loudspeakers are the final link in the instrument chain.

In order to provide low latency and high fidelity interface between a software application (Cubase) and a PC sound card, ASIO (Audio Stream Input/Output) computer sound card driver protocol is used. ASIO bypasses the normal audio path from a user application through layers of intermediary Windows operating system software so that an application connects directly to the sound card hardware. Each bypassed layer means a reduction in latency [10], [11].

VI. TEST RESULTS AND INSTRUMENT CHARACTERISTICS

The realized electronic musical instrument is tested through playing in both modes. The instrument performances depend on two main factors. The first one is total latency and the second is the quality of parameters control.

Total latency is the elapsed time from the moment when the board or keyboard key is pressed or laser beam is broken (note on/off event) to the moment when loudspeakers generate sound. It is the sum of the time from detecting note on/off event to receiving MIDI messages on the USB port, input latency (the time it takes to have data in Cubase from receiving MIDI messages on the USB port), processing latency (the time needed for Cubase to interpret MIDI messages and send appropriate audio data) and output latency (the time needed to have audio digital data from within Cubase until it is electronically outputted by the soundcard). These latencies depend on the microcontroller characteristics and used algorithm, PC performances, sound card, audio driver, sample time, buffer size etc. The best obtained total latency in real-time live performance is about 80 ms which is quite good considering relatively poor PC and sound card characteristics.

Fig. 7 shows pitch band and modulation wheel parameters recorded in Cubase. It can be seen that signals achieve full range and there are no peaks, so the quality of controlled parameters satisfies requirements from these points of view.

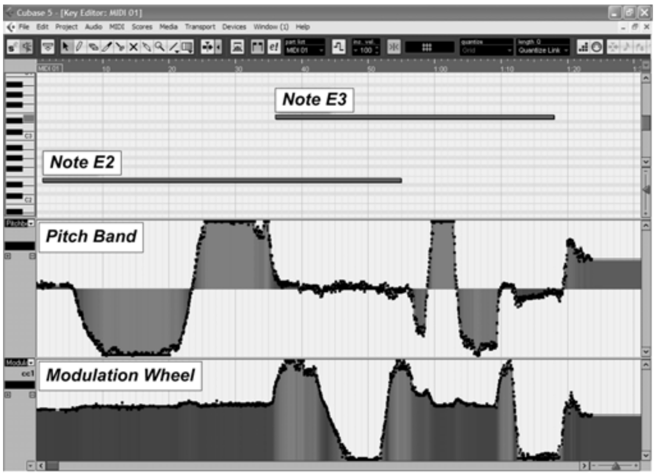

Figure 7. Recorded pitch band and modulation wheel parameters in Cubase

VII. CONCLUSION

The development of realized electronic musical instrument was limited to hardware characteristics presented above. These characteristics do not satisfy professional requirements. Considering that, it can be concluded that instrument performances are quite well.

Improvements could be made using embedded system design, professional audio hardware, lasers with higher power, multiplexed laser beam receivers in order to detect more beams and optimized software of input device.

In practice, this instrument or some modified version of it could be realized. This concept of electrical musical instrument could have broad application, such as laser harps or specific MIDI controllers. It could be used in theatre performances for example in order to produce and modify sound by breaking the laser beams and using accelerometer board on the actor's hand. For this purpose and in general, wireless transfer from accelerometer to the microcontroller could be made.

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