Digitally Programmable Analog Instrumentation Modu for Processing Vital Signs

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Abstract. Current data acquisition systems have a strong trend on transforming physical signals retrieved from the environment to a digital form regardless of the loss of information on acquired data due to the conversion process. Purely analog processors were the beginning of computer sciences, but they were difficult to manipulate and program so they were left aside even when they had very positive characteristics, like high-quality signal and fast response. In this paper we describe a digitally programmable analog module for signal processing vital signs, which goal is to provide high-quality digital representation of analog signals into an entire user-interactive device. The module can be programmed by using C language or by a friendly menu. The signal processing on the module has a mode of operation that can be chosen to be purely analog or digital depending on a particular application.

1 Introduction

The world we live in is analog. Through technology, we are able to detect, process manipulate any signal generated by nature. Mainly, for storage and processing purpose most commonly analog signals are converted into a digital format. In this form information can be stored, displayed and manipulated to program several devices actuators to respond on predefined levels of tolerance. As described by Tamcis Roska [1], the ability to store programs and data was the key fact that promoted the stron migration of processing to a digital form. However, purely analog signals that transformed into digital format lose information, which could be important in som implementations. The world is so digitally focused that many problems that could solved by using simple analog circuits are solved by using high-level programming more complex digital circuits.

The digital programming world has extended into hardware systems design to mak implementations more versatile which accelerate the design process. Field Programmabl Gate Arrays, for example, are being used more and more every day in computationa embedded and electronic designs. Current trends indicate that these will be the future for customizable systems development. They are accessible from many levels of programming and have great versatility for emulation.

Our motivation for developing this project is to design a device to improve the way analog signals, like metabolic signals of organisms and environmental variables like temperature, humidity, light and motion, among many others, interact with electronic and data acquisition tools to create customized instrumentation applications. Our approach is to propose an instrumentation module capable of manipulating several analog signals by programming. Therefore, it can be set up for different applications by software. Although there are a few test boards and integrated circuits that can customize analog components by software, most of them are specialized in automotive [2] and industrial applications, with characteristics that are far from being suitable for bio-electronic instrumentation like safety isolation stages.

In this paper we will describe the implementation of a programmable analog instrumentation module. It is designed to be programmed using a software interface within an embedded microprocessor in a FPGA.

The rest of the paper is organized as follows. On the second section we will cover previous wok on the area. On the third section described the design of the proposed module. On the fourth we discuss results that validate the design. On the fifth we derive some conclusions. Finally, we provide some guidelines to the next steps of our work.

2 Previous Work

Computational sciences were originated with the purpose of emulating and improving processing of data of nature source. Rapid technological development during the last decades has brought systems capable of computing huge collections of data in fractions of a second. Current technology has the advantage of storing and retrieving great amounts of data in fractions of a second. Hybrid systems, that is those that manipulate analog and digital signals are very useful for several applications and result in the generation of extremely efficient systems.

Some of the most interesting computational trends include: the development of molecular electronics, analog cellular computers and the interconnection of organic elements with silicon and data processing devices to achieve neural and biological functions. Mixing organics with electronics will be more frequently used in the near future to store information, to create parallel manipulation of data and to integrate new sensitive components and pathways in a similar way our brain and body do. This allows such capabilities to be embedded within the main structure of the material used to build the device [1]. These research topics compose a strong goal in computer sciences, because they can reduce the gap that separates the way nature generates, stores, manages and produces signals from the way humans emulate them. Important work is being developed on these areas. Results obtained so far indicate that remarkable performance can be achieved using these novel techniques that in the near future might promote the evolutio.. of computational sciences into something very different from what we use today.

Beyond the bio-electronic interaction at molecular and silicon integrated level, anoth kind of relationship is in development between biological and artificial organisms. new relationship consists in sharing signals to control activities at both ends transforming actions from one world to alter conditions in the other and vice vers Signals produced by metabolic and physiological activities in animals are being use today to control computers, machinery, robots, therapy aid equipment [3] and othe apparatuses [4], while sensors on those devices can be used to indicate operatin conditions to the living being. The virtual reality field has undoubtedly turned its eyes human-computer interaction at hardware level to improve the inmersive characteristics simulations. Virtual reality developers used to be concerned only about software utiliti and ways to make more realistic graphics but today some of them have realized merging perceptive capabilities of humans with software design significantly improve the interaction between living organisms and virtual scenarios [5].

3 Digitally Programmable Analog Instrumentation Module

The system we implemented consists in an analog module conformed by processing channels, an FPGA with a MicroBlaze embedded microprocessor configure for control and configuration of the entire device and flexible output stage that provide several options to output the retrieved signal and communicates with other equipmen units. The analog unit requires two 9-volt batteries and is electronically isolated wit optocouplers from the FPGA (input and output). It also includes safety requirements bio-electronic interfaces.

Next we will describe every block of our design in detail.

3.1 Description of the Analog Unit

Four data acquisition channels, as described before, constitute the analog unit. Two those channels are focused for instrumentation applications and consist in differentia input, high-impedance, low-noise amplifier, a band-pass filter, a general-purpos operational amplifier, and an integration/inverter block. Each of those components digital potentiometers, used to establish the value for gains and cutoff frequencies and enable/disable pins to redirect the signal through the path that better satisfies the user needs. Digital potentiometers were used because they allow digital command outputs the MicroBlaze processor to be translated into an analog value, in this case resistance. Figure 1 is shown the block diagram of a differential input channel.

3.2 Noise handling

In this analog design we prevent noise from altering the signals we acquire by including bypass capacitors between positive voltage and ground and between negative voltage and ground in most of our principal integrated circuits. We also use bypass filtering between +5V voltage and ground in the Analog to Digital converter. We use tantalum capacitors to improve the noise filtering in our bypass arrangements because they are suitable for high speed and high frequency applications. In our prototype printed circuit board (PCB) the grounding covers an acceptable percentage of the plaque and has a surrounding shape to help isolate the entire circuit. Very susceptible input pins, like amplifiers' inverting input, have been surrounded and isolated from the rest of the board (from the non-inverting inputs in the specific case of amplifiers) by placing ground lines around them. In our future work we will consider other noise reduction techniques like shielding to reduce the effects of other electromagnetic sources of noise.

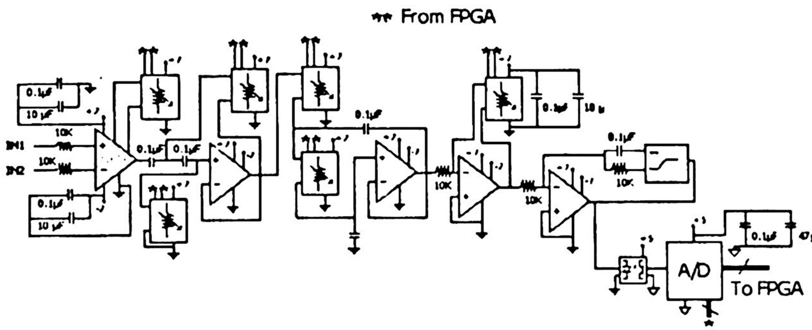

Fig. 1. Block diagram of Differential Input Channel.

The other two channels are targeted for use with sensors or with non-differential input sources. They consist on rail-to-rail operational amplifiers, which gains are also controlled using digital potentiometers. Figure 2 shows the block diagram of a non-differential channel.

3.3 Digital unit: Spartan 3 FPGA and MicroBlaze Embedded Microprocessor

Every input channel has an analog-to-digital converter at the end of the processing flow. In the block diagram this is shown as the connector to the embedded microprocessor within a Spartan 3 FPGA. As we stated before, some analog signals need to be treated in its pure form to preserve all available information, but we think it is important to be able to interact with other digital devices too. Inside the FPGA resides the structure MicroBlaze processor with customized output and input ports, a timer is dedicated display the signal when graphic mode is selected and controllers for memory and intern buses.

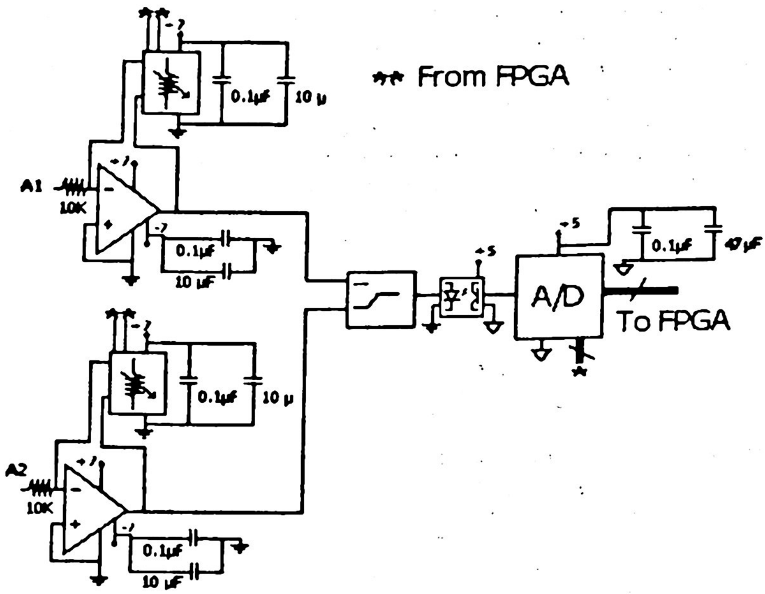

Fig. 2. Block Diagram of Non-Differential Channel

Code in C++ language was developed for programming the components of the anal module, as well as to control the input signal, which has been pre-processed by the analo block. The configuration program includes several modes of operation and control for analog unit. The initialization of the system consists on changing the digit potentiometers to obtain predefined primary gains for every channel. The initial selecte channel is differential input channel 1; signal graphs on VGA, the digital mode integration are disabled by default.

The following code corresponds to the initialization of channel 1 of our design. A signal is output on the FPGA's pins to change the value of the digital potentiometers achieve startup configuration.

```
xil_printf("Ajusting Initial Parameters for Analogic
Module... \n\r");

//INSTRUMENTATION1
//Low-freq. counter
reslp[0] = sqrt(1/(pow(freq_lp[0]*3.1416,2) *
0.00000000000001));
goal_clkcount_ad5220[0][5] = (Xuint32)(reslp[0]/RESISTANCE);
goal_clkcount_ad5220[0][6] = (Xuint32)(reslp[0]/RESISTANCE);
//High-freq counter
reshp[0] = sqrt(1/(pow(freq_hp[0]*3.1416,2) *
0.00000000000001));
goal_clkcount_ad5220[0][2] = (Xuint32)(reshp[0] /
RESISTANCE);
goal_clkcount_ad5220[0][3] = (Xuint32)(reshp[0] /
RESISTANCE);
//Instrumental amplifier counter
goal_clkcount_ad5220[0][1] =
(Xuint32)(49400/((gain_inst_amp[0]-1)*RESISTANCE));
//Amplifier counter
goal_clkcount_ad5220[0][4] =
(Xuint32)((gain_gen_amp[0]*10000)/RESISTANCE);

//Generate signal for each potentiometer
for(i = 0; i < 6; i++){
      while(clkcount_ad5220[0][i+1] !=
      goal_clkcount_ad5220[0][i+1])
            clockcount_pots (i+1);
}
```

Once the initialization is finished, a *menu* is displayed on a Communication Software (Hyperterminal) using Serial Rx Tx. Our system has two basic modes of operation: purely analog (selected by default), or analog-digital. On purely analog mode none of its digital treatment capabilities is activated and the user can only adjust parameters on the analog section. On analog-digital mode the user can adjust every component as on the previous operation mode, but the features for digital processing are available: detection of minimum and maximum values, offset nulling, graphic output and latching (many others, like digital filters, could be developed to cover the user's needs due to the flexibility offered by the Microblaze processor) and the output section is fully operational.

One important characteristic of the second mode is that the program is allowed to reduce the gain on the input amplifiers automatically to constraint the signal received as input in the ADC to avoid saturation. Automatic gain modifications are only disabled if purely analog mode is selected. Figure 3 below shows the response of the differential input channel to a mioelectric signal generated by a human biceps muscle.

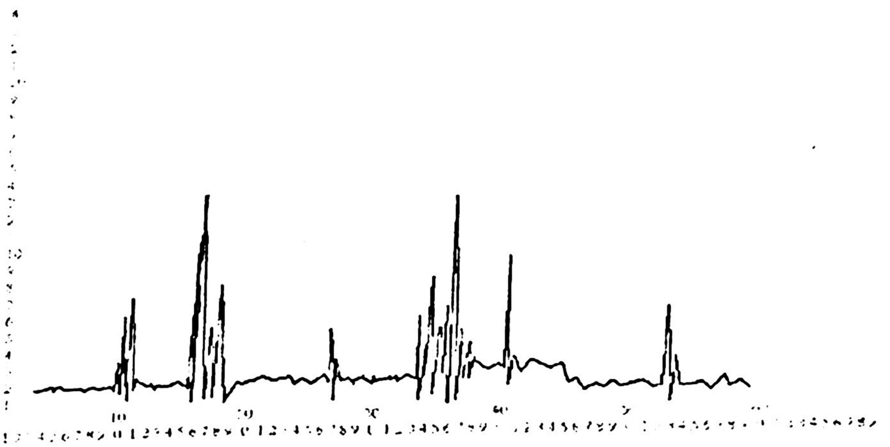

Fig. 3. VGA output of a post-processed mioelectric signal obtained using the differential inp channel and Ag / ClAg electrodes placed on the biceps muscle of a human tester.

3.4 Output stage

Our system has a very accurate post-digital module attached to a digital-to-analo converter with current-variations-based on radio frequency (RF) transmissions, puls width modulation (PWM) and analog voltage level output. The set of output capabilitie for our application are designed to be supportive for wireless and long-wire transmissions, as well as for coupling with other devices, microcontrollers and actuators.

Up to this point we have described an implementation that is capable of processin analog signals responding to constraints specified by the user with software. Then, digitally post-process the signal output by the analog stage, provides a very flexible outp section with current-variations-based and RF transmissions, PWM and analog voltag level. Next we discuss results obtained with our module.

4 Results

We were able to integrate our design and manipulate signals received at external senso and transducers. We noticed some limitations on the detection levels for the digital mod of operation, because we could only work with signals within a 5V limit. Beyond that, system proved to be configurable for amplification gains between 0 and 10,000. filtering stage worked properly above the band-pass bandwidth of 150 Hz. Digit treatment of signal was proven to work as expected for the signals we worked wit

However, more work in refining the design is needed to fully interact with analog signals that can vary from high positive to high negative levels.

5 Conclusions

The design described on this paper represents a very flexible tool for implementing bio-electronic interfaces. It is built to merge the natural and artificial worlds into cooperative inter-feedback applications. We developed an analog unit that can be programmed at high level or configured using *menus* to provide an accurate processing unit. It integrates features from both the analog and digital worlds, trying to create a specific purpose system responding to the emerging development areas of organic-artificial interaction at the macro level.

6 Future Works

We want to extend our work improving the programming limits and components of our design to cover a wider set of applicative options. Later, we want to take our design into an integrated circuit to have a single chip extremely flexible and programmable solution for bio-electronic interface design and implementation.

The future of our project targets the creation of an application-specific integrated circuit (ASIC) which can be used to develop several applications by specifying constraints with software and which can manipulate signals analogically. It can transform analog into digital, if necessary, and include the features needed to merge natural with artificial systems, everything one chip.

References

[1] Roska, T. Analogic Computing: System aspects of Analogic CNN Sensor Computers. 2000 STH IEEE International Workshop on Cellular Neural Networks and Their Applications Proceedings, 2000.

[2] Melexis Microelectronic Systems. MLX90308. Programmable Sensor Interface, 2004.

[3] Upshaw, B.J. Sinkjaer, T. Real-time digital signal processing of electroneurographic signals. Engineering in Medicine and Biology Society, 1994. Engineering Advances: New Opportunities for Biomedical Engineers. Proceedings of the 16th Annual International Conference of the IEEE. Pages. 1346 - 1347 vol.2, 1994.

[4] Diaz, M. and Rudomin, I. Object, function, action for tangible interface design. ISMAR 04. Pages: 106 – 112, 2004.

[5] Díaz, M., Hernández E., Escalona, L. Rudomin, I., Rivera, D. Capturing Water and Sound Waves to Interact with Virtual Nature. ISMAR 2003.