A Survey on Data Acquisition systems DAQ

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Abstract — *Data acquisition systems have been used in various applications in our world. Numerous techniques and algorithms have been employed to achieve high quality acquisition. Each application has its own philosophy and data acquisition structure. Hence, in this paper, a survey on data acquisition systems has been presented. Different DAQ categories have been introduced. A comparison study between these categories has been presented. Different applications that need DAQs have been mentioned in more details illustrating DAQ technique used for each application*[1].

Index Terms — Data Acquisition, FPGA, ADC, Multiplexing.

I. Introduction

Data acquisition systems (DAQ) are devices that are used to acquire data from the environment surrounding it. Acquiring data helps to get certain information about the environment under consideration. Typically, data acquisition devices interface to various sensors that specify the phenomenon under consideration [1-3]. Most data acquisition systems obtain data from different kinds of transducers that produce analog signals. In most applications, these signals need some processing. Therefore, analog signals are converted into a digital form via analog to digital converter (ADC) to be processed [4]. Existing DAQs, can acquire single channel or multi-channel signals.

Indeed, multi-channel DAQs are recently considered as a focal research topic. Many applications demand the existence of a multi-channel DAQ [17, 20-29, 41-57]. Particularly, simultaneous multi-channel DAQs are employed in numerous applications [21, 22, 24, 31, 37, 39, 40]. If the signals are simultaneously acquired, simultaneous acquisition of additional data can be used to obtain additional information within the same acquisition time [31]. However, exiting computer based multi-channel DAQ systems are cumbersome, expensive, and/or require design redundancy to achieve high reliability and high speed acquisition. Therefore, embedded processing capability must be used to reduce system size, avoid design redundancy and reduce cost and power consumption.

An embedded system is a special-purpose computer system designed to perform one or a few dedicated functions, often with real-time computing constraints. Employing the embedded systems into the data acquisition environments can achieve low cost, low power consumption and portability [9, 10]. Embedded systems employ System-on-a-chip (SoC) which refers to integrating all components of a computer or other electronic system into a single integrated circuit chip. SoC designs consume less power and have a lower cost and higher reliability than the multi-chip systems that they replace. The SoC was realized in 1994. When Fujitsu launched the 0.35 µm process and the total integration of circuits on a single printed circuit board (PCB) became possible. To date, continuous advances have been made in SoC process technology and design methodology [5]. And with fewer packages in the system, assembly costs are reduced as well. Full custom, Standard cell ASIC and FPGA are technologies that used for SoCs fabrication. An application-specific integrated circuit (ASIC) is an integrated circuit customized for a specific use, rather than intended for general-purpose use. Field-programmable gate arrays (FPGA) are the state of the art technology for building a prototype which can be used in various applications. For smaller designs and/or lower production volumes, FPGAs may be more cost effective than an ASIC design. The non-recurring engineering cost for both ASIC and FPGA can run into the millions of dollars; ~$40M for 40nm chips. However, an FPGA-based SoC has various advantages. The prevailing FPGA advantage is the reconfigurability which allows reusing the same chip with different configuration. Reconfigurability allows design upgrades without hardware replacement. Moreover, FPGA provides a wide range of DSP operations. Fault tolerance via hardware fault reroute not by redundancy, shorter time to market, and lower non-recurring engineering costs. Hardware Description Language synthesis tools and FPGA place-and-route tools are now available, fast and inexpensive [5].

II. DAQ Classification

Various research papers have focused on DAQ systems. In this section, a classification of DAQ systems has been presented. Afterwards, a brief discussion about existing multi-channel DAQs and their applications has been presented.

DAQ systems can be classified into three main categories. The first one is computer based, which utilizes computer processing power to perform desired data manipulation, visualization, storage, and/or decision making. In this category, DAQ can be further sub divided into internal and external modules. Internal DAQs are in a form of extension cards that connect to PC expansion slots (PCI, ISA). It is worth mentioning that DAQs in this category are dependent on the obsolescence of PC in use. For example, an expensive and properly functioning DAQ card on ISA bus will need to be replaced with a newer DAQ card on the advanced PCI bus in a computer that no longer supports ISA bus. The need to change computers is often forced by other applications, and not just

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Fig. 1. Computer based Data Acquisition System [8].

the data acquisition. If the space on the computer expansion bus is too limited, an external DAQ module has been used. External DAQs are in a form of a module that connects to computer ports (parallel, serial, USB, etc...) [6]. External DAQ modules often require special cables to connect to the PC [7]. Some external DAQ modules, like the AVR32 [8], shown in figure 1, which provide high performance signal processing capabilities costs $1750 not including the cost of the PC. This computer based DAQ category obviously has the disadvantages of high cost, cumbersomeness, high power consumption and fixed hardware architecture.

The second DAQ category is the embedded microcontroller based systems. These systems are used extensively in many areas such as healthcare, automotive industry, environmental monitoring, and power plants [11-13]. These systems have advantages such as portability and high performance but they have fixed architecture [14, 15]. This category has some advantages such as low cost, compact size and low power consumption. However, it is not reconfigurable due to its fixed hardware architecture. Fixed architecture embedded microcontroller DAQ systems have many disadvantages. If an existing DAQ system uses one processor with 16 bits, for example, there are times when it is needed to enhance the performance by using two processors with 32 bits each. In such cases it will be required to replace the whole embedded microcontroller DAQ system with a new one. Further, the size of the cache of a microcontroller is a design parameter that cannot be reconfigured after fabrication. In addition, inserting floating point operations, or changing the ALU functionality is not possible. Also, in fixed architecture DAQs, robustness, and fault tolerance are achieved by redundancy. This in turn increases the size, power consumption and the cost of the system. Hence, another DAQ technology is needed which is adaptive to the changing requirements; is robust against faults; and small in size. Dynamically reconfigurable DAQ systems will have crucial impact in some applications, such as hazardous environments, or isolated areas, for remote architecture reconfiguration.

However, there exist a third category of DAQs which involves hardware reconfigurable Field Programmable Gate Array (FPGA). National Instruments, the leading industry in DAQs, recently provided PCI and PXI DAQ cards with FPGAs, such as the NI LabVIEW FPGA Module [16]. However, since its DAQs are computer based, the FPGA is only used for limited purpose such as timing and triggering, or reconfigurable control algorithms. So, the FPGA is not fully utilized.

DAQs involving FPGAs can be re-designed while mounted in the target system (hence the name field programmable) to reach a fine-tuned performance, or to reroute a faulty circuit to a new place. Recently introduced high capacity FPGAs allows for the integration of multiple components on a single chip. In addition, it can have all the processing, storage and I/O capabilities needed by a data acquisition system.

III. Multi-channel DAQ

An intuitive implementation of the multi-channel A/D conversion is to use a dedicated ADC for each channel as will be shown in the next paragraph. However, this approach has different drawbacks. First, the use of the multi ADCs is expensive. Second, it requires special synchronous techniques across all ADCs. Third, the total power consumption of the system with multiple ADCs is very high. Another ADC technique is time division multiplex with a single ADC [17]. It has been used to overcome the previously mentioned drawbacks of multiple ADCs. The time division multiplex with a single ADC has unique challenges. First, time skewness occurs due to channel multiplexing [18, 19]. Time skewness affects the quality of sampled data near the switching time. Second, the utilization of the single ADC has to be optimized to not limit the number of input channels [26].

Researches done in [41-50] provided a detailed discussion about the multi-channel DAQ. A special sampling technique, event timing, was employed. A sample value is taken at time instants when the input signal crosses a sinusoidal reference function. A prevailing limitation on the number of input channel was acknowledged. An extended research tried to reduce this limitation. However, there still some drawbacks in this research. First, the reconfigurability is not achieved due to the use of a computer and only using the FPGA for controlling the time to digital converter (TDC). Second, amplitude, frequency, phase angle of the input channel signals have to be given in advance. Third, the acquisition quality depends on the frequency of the reference sinusoidal signal. Increasing of the reference signal is limited. It was mentioned in these researches that these drawbacks have to be traded off with the low power consumption of their proposed system.

Another filed that requires multi-channel DAQ is measuring the water conductivity. Research papers [51-53] proposed a system that is able to acquire 4 channels; each channel had its own ADC. Many commercial types of equipments are available from many manufactures [54, 55]. However, the main problems that are always associated with water conductivity measurements are related to measurement dynamic range. They need a dynamic detection of the input signals.

IV. Applications of Multi-channel DAQ

Different applications need to simultaneously acquire signals with a variety of frequencies and polarizations. In the environmental field, the operational satellite synthetic radar was used to simultaneously acquire different data at different frequencies in order to estimate the soil moisture in different sites on the earth [21]. The development and evaluation of the system has been quite limited. The system required to acquire many signals within short period of time due to the uncontrollable changing site conditions. In [24], a prototype was used to model the soil moisture.

In military field, a high speed multi-channel DAQ for coherent radar was presented in [22]. The radar applications require a fast ADC to satisfy the radar signal processing and radar target recognition characteristics. In this research, they used a host computer to do the whole task. The FPGA was only involved in the grating display system. This research lacks the full utilization of the FPGA capabilities. Moreover, the cumbersome size of the host computer is not suitable for the military field.

In the biomedical field, the first step of diagnose a patient is recording biomedical data. Monitoring the vital signs of the patient in acute life-threatening states or being under surgical procedures or anesthesia conditions requires online analysis and immediate visualization [30]. If the immediate visualization is irrelevant, storage of the acquired data is needed. We can see from the SIESTA project [30]; European project in bio-signal analysis; that the human body has many different signals that can be acquired to help in patient diagnosis. These body signals are different in frequency. They vary from very low frequency such as the Auxiliary signals which is 0.1 Hz to the higher frequency signals such as the breathing sound of 5000 Hz. In [27], a multiplexing data acquisition system for multi-channel bio-magnetic signal measurement was proposed. A computer was employed for storage and signal processing purposes. Dedicated ADC was used for each channel.

Electrocardiogram (ECG) devices are the most important diagnostic tools for heart patients [32]. Various research papers were presented in the field of improving the ECG performance and reducing its cost and size [32, 33, 34, 35, 36]. In [32, 34], an ECG device was proposed. This system was connected to a computer to perform the signal processing. The heart signals were acquired synchronously. In [35], heart sound signal recorder system was proposed. Heart sound signals were acquired sequentially. Another research [37] proposed to simultaneously acquire ultrasound data. A computer was used with a LabView (National Instrumentations).

Respiratory problems represent one of the main causes of disease in our world [38]. Some papers [39, 40] were done in this field. Lung sounds were acquired by a microphone array which, in turn, was attached to the back of the patient. Sounds were acquired by a system developed at Metropolitan Autonomous University. They used a computer to process the data and they used a sequential acquisition.

Most of research papers proposed in this field use computer-based devices to acquire signals from the human body.

V. Conclusion

There is an extensive range of applications that necessitates the acquisition of multi-channel signals. Some of these systems require large number of channels such as in bio-sensing devices or in automatic monitoring of human health. Sequential acquisition is not enough in many applications. Hence, simultaneous acquisition is needed to get more information regarding the phenomena under investigation. Exiting computer based multi-channel DAQ systems are cumbersome, expensive, and/or require design redundancy to achieve high reliability and high speed acquisition. Microcontroller-based DAQ can work with low power consumption and small size. However, it lacks the reconfigurability part. FPGA-based DAQ is the outstanding approach to achieve the low cost, small size, portability, considerable power consumption and the more importantly the reconfigurability.

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