dsPIC-based Advanced Data Acquisition System for Monitoring, Control and Security Applications

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***Abstract*— This paper reports on design and implementation of data acquisition system based on dsPIC Microcontroller for Monitoring, Control and Security Application. Data acquisition is fundamental stage in any DSP, monitoring and digital control and security system. The efficiency and effectiveness of the system is defined by the quality of acquired data, which in turn depends on the characteristics of data acquisition system. There are two types of data acquisition; (a) digital (b) analog data acquisition, having different characteristics and system requirements. Microchip's dsPIC provides various on-chip integrated modules which enable efficient data acquisition such as 10/12-bit Analog to Digital Convertor (ADC) with up to 1Msps (Million samples per second) sampling rate, simultaneous sampling and various trigger mechanisms, Timers, Input Capture (IC), External (hardware) and Internal (software) Interrupt and processing capability up to 30 MIPS (Million Instructions Per Second). A system is developed for data acquisition of 16 analog signals with 10/12-bit resolution, simultaneous sampling of 4 signals, fixed and variable sampling rate, on chip storage and real-time signal processing capabilities. The system also supports for data acquisition of digital signals with time resolution of up to 33.33nsec and signal parameters like frequency, time period, pulse width, duty cycle, and delay & time difference between two signals. It can be customized according to the system requirements and provides advanced data acquisition capabilities to the low cost monitoring, control or security system.**

Key Words: dsPIC, DSP, ADC, MIPS, Data Acquisition, Microchip, Monitoring, Security

I. INTRODUCTION

The backbone of any digital system, interacting with real world, is the data acquisition of the process signals from various systems. The purpose of data acquisition is to measure an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound. While each data acquisition system is defined by its application requirements, every system shares a common goal of acquiring, analyzing, and presenting information. Data acquisition systems incorporate signals, sensors, actuators, signal conditioning, data acquisition devices, and application software [1]. Data acquisition involves gathering signals from measurement sources and digitizing the signal for storage, analysis, and presentation or control. Different sensing systems may require development in order to achieve the appropriate data acquisition. Sensors provide continuous data about a particular aspect of a process such as pressure, voltage, current, temperature etc. which needs to be collected and compiled in a desirable format so that it can be used in a fruitful way. An ideal solution would be to collect and (if possible) analyze the process signals close to the sensors which require embedded systems for data acquisition. In this way accuracy will be very high and the resulting monitoring will be effective. The obtained (analyzed/ processed) data may then be transmitted on a digital bus to the central processing unit for further analysis. Digital transmission is more immune to noise than analog data from the sensors. The sensor choice depends on the type and nature of the process parameter to be acquired. Generally the output of the sensor is either voltage or current which needs to be digitized, after necessary filtering and signal conditioning, for storage and processing. Similarly security application such as True/ Hybrid Random Number Generator involves data acquisition from various physical random noise sources and processing of acquired data to generate qualified random numbers.

Following sections describe design and concept of data acquisition using dsPIC Microcontrollers. For this system the necessary conditioning and filtering of the signal to meet the sampling requirements have been performed before interfacing the signal to microcontroller. Section II introduces the dsPIC Microcontroller dsPIC30F device used in this research while section III provides the overview of the development board which is used in this research. Section IV introduces different features of the device for efficient data acquisition system. Section V provides details of features for digital data acquisition and section VI discusses features of dsPIC devices and their uses enabling efficient analog data acquisition for monitoring, control and security applications; followed by conclusion in section VII.

II. dsPIC DSC MICROCONTROLLER

The dsPIC30F device family employs a powerful 16-bit architecture that seamlessly integrates the control feature of a microcontroller (MCU) with the computational capabilities of a digital signal processor (DSP). The resulting functionality is ideal for applications that rely on high-speed, repetitive computations as well as control. The DSP engine, dual 40-bit accumulators, hardware support for division operations, barrel shifter, 17 x 17 multiplier, a large array of 16-bit working registers and a wide variety of data addressing modes together

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provide the dsPIC30F CPU with extensive mathematical processing capability. Flexible and deterministic interrupt handling, coupled with a powerful array of peripherals, renders the dsPIC30F devices suitable for control applications. Reliable field programmable Flash program memory and data EEPROM ensure scalability of applications that use dsPIC30F devices [2]. The dsPIC has facilities well-suited for signal acquisition, processing, and communication with the outer world. It has a fast 12-bit Analog to Digital Convertor (ADC), large memory, 16- and 32-bit timers, and large number of external interrupts, input capture module, digital I/O ports, and multiple communication modules including CAN (Controller Area Network), SPI (Serial Peripheral Interface), and UART (Universal Asynchronous Receiver Transmitter).

III. DSPICDEM1.1 DEVELOPMENT BOARD

The dsPICDEM1.1 development board (as shown in fig. 1) supports a dsPIC30F6014(A) device. It is a low cost development tool that has all the required components to fully utilize capabilities of dsPIC30F's 16-bit architecture, high performance peripherals and powerful instruction set. This development board is an ideal prototyping tool to help quickly develop and validate key design requirements. It provides a CAN bus communication interface (with on-board CAN transceiver) to allow communication between devices on the Controller Area Network. It also has RS-232 and RS-485 communication channels. There is a 122x32 dot addressable Liquid Crystal Display (LCD) controlled by an on-board PIC microcontroller, which is connected to dsPIC30F6014 via SPI [2]. The LCD along with switches and potentiometers provides a significant tool for user interface and information display. It can be used to display the process signal or messages to inform the operator about the health of the system. It also has on-board Microchip temperature sensor, Microchip Digital Potentiometer and a low pass filter resulting in D/A converter, which can act as final stage in a DSP/control system.

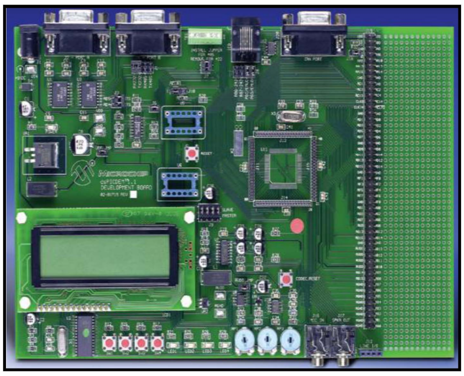

Figure 1. dsPICDEM 1.1™ General Purpose Development Board [2]

IV. DATA ACQUISITION SYSTEM

An effective monitoring/control system relies heavily on the efficient data collection system. The dsPIC30F has powerful modules: External Interrupts (INT), Change Notification (CN) on I/O pins, timers/counters, Input Capture (IC), and a 12-bit Analog to Digital Converter (ADC). These enabled data acquisition (both digital and analog) in an efficient manner. Next two section provide enabling features of the device used for Digital Data Acquisition such as Change Notification Pins, Input capture Module and Output Compare Module and feature used for Analog Data Acquisition such as A/D Convertor features, A/D Result Buffer Alignment, Simultaneous and Sequential Sampling, Automated Sampling, Channel Scanning and Variable Sampling Rate.

V. DIGITAL DATA ACQUISITION

The Digital signals are discrete in nature and possess one of a pre-determined range of values at any given time. Normally digital computers / microcontrollers deal with the binary signals, which have only two states i.e high or low. Voltage levels used to represent high or low state vary amongst different representation schemes & platforms and appropriate signal conditioning is required to make them TTL compatible (0-5V) before their interfacing with the dsPIC MCU. Using digital signals, information can be represented in different formats such as state (high or low), timing information (rising or falling edge or both), event (pulse), quantity (number of pulses), frequency/rate (number of pulses in a unit time) and pulse width modulation (duty cycle).

The dsPIC30F features (IC, timers/counters; External Interrupt (INT) and Change Notification (CN) on I/O pins) make digital signal acquisition an efficient task. The change in a signal can be detected by using CN or External INT functionality which generate an interrupt when the signal changes. Distinct from PIC18 microcontrollers, the dsPIC provides the facility to define an Interrupt Service Routine (ISR) for each interrupt. Each interrupt can be given priority level from 1 to 7 (with 7 being the highest priority). This feature decreases software overheads; making the system much faster and more efficient.

A. *Change Notification Pins*

The CN pins in dsPIC30F devices provide the ability to generate interrupt requests to the processor in response to a change of state on selected input pins. Up to 24 input pins may be selected (enabled) for generating CN interrupts. The total number of available CN inputs is dependent on the selected dsPIC30F device. This frees the program from the need of scanning a large number of inputs.

B. *Input Capture (IC) Module*

The IC module is used to capture a timer value upon an event on an input pin. The IC features are useful in applications requiring frequency (time period) and pulse measurements [3]. Fig. 2 shows a simplified block diagram of the IC module. It has multiple operating modes (for example it can be used for the selection of a capture event on rising, falling or each edge) selectable via ICxCON register. The IC works with timer 2 or 3 which is selectable for each IC module. It reads the associated

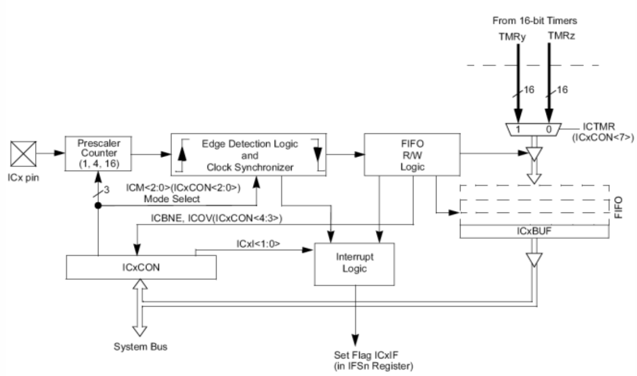

Figure 2. Block diagram of Input Capture Module [3]

timer value at the selected event and stores in a four-level First In First Out (FIFO) buffer (ICxBUF). The IC module has the ability to generate an interrupt based upon a selected number (1 to 4) of captured events. In particular, this module was used for measuring the width of the output pulse from an ultrasonic distance sensor (PING)))^{TM})[4]. The module was set to capture at appropriate stages both the rising and falling edges of the input signal pulse and store the timer 3 in ICxBUF. A CPU Interrupt was generated after 2 capture events. The pulse width of the echo pulse from the sensor was determined by the difference in successive reading from the IC buffer register. The resolution of the digital signal acquisition is dependent upon the system clock frequency (F_{CY}) and setting of the Timer module which can be configured to run at fractions of the overall processor rate by configuring the prescaler register. With a prescaler value of 1, the best time resolution which can be achieved is equal to 1/FCY. i.e. 33.3nsec at 30MIPS.

C. *Output Compare*

Like most dsPIC peripherals, it also has the ability to generate interrupts-on compare match events. The dsPIC30F device may have up to eight output compare channels. Each output compare module has the following modes of operation: -

1. Single Compare Match mode
2. Dual Compare Match mode generating with Single/ Continuous Output Pulse(s)
3. Simple Pulse Width Modulation mode with/without FAULT Protection Input.

VI. Analog Data Acquisition

Most signals; typically those representing load, current, voltage, speed, or temperature are analog in nature. These signals have to be converted into digital format before processing by a computer or a microcontroller. The dsPIC devices are equipped with a fast 12-bit Analog to Digital Converter (ADC) which provides this transformation. Analog to digital conversion is a very important step towards the digital signal processing and analysis. If correct signal is not acquired, correct analysis are not possible. It is effectively a three step process: sampling, quantization and conversion as shown in fig. 3.

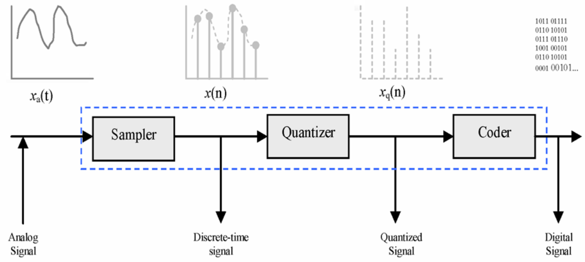

Figure 3. Basic parts of an ADC (Adopted from [5])

Sampling is the conversion of a continuous-time signal x_a(t) into a discrete-time signal x(n)= x_a(nT) obtained by taking samples of the continuous time signal at discrete-time instants [5]. If sampling is done at a Nyquist rate i.e. twice the highest signal frequency or higher, the full signal information can be retrieved from the sampled signal [6]. The difference between discrete time signal x(n) and quantized signal x_q(n) is called quantization error and is irreversible. The precision and resolution of the ADC depends on the number of quantization levels. In the coding process, each discrete valued x_q(n) is represented by a b-bit binary sequence; which is the ADC output. A 12-bit coder is required for a 4096 quantization level ADC. The dsPIC has 12-bit ADC which provides 4 times more resolution as compared to the 10-bit ADC of previous PIC microcontrollers.

A. *A/D Convertor Features*

The Analog-to-Digital (A/D) Converters on dsPIC30F provide up to 16 analog inputs with both single ended and differential inputs. These modules offer on-board sample and hold circuitry. To minimize control loop errors due to finite update times (conversion plus computations), a high speed low latency ADC is required. In addition, several hardware features have been included in the peripheral interface, to improve real-time performance, like

1. Result alignment options
2. Automated sampling
3. Automated channel scanning
4. Dual Port data buffer
5. External conversion start control

There are two versions of A/D converters available for the dsPIC30F family of devices: (1) 10-bit high-speed A/D module (2) 12-bit high-resolution A/D module. The 12-bit Analog-to-Digital Converter (ADC) allows conversion of an analog input signal to a 12-bit digital number. This module provides a maximum sampling rate of 200Ksps where as 10 bit A/D module provides a maximum sampling rate of 1 Msps.

The ADC module has up to 16 analog inputs which are multiplexed into a sample and hold (S/H) amplifier. The output of S/H is the input into the converter which generates the result. The analog reference voltage is software selectable to either the device supply voltage

(AVDD/AVSS) or the voltage level on the (VREF+/VREF-) pin. For a typical 0-5volt range, one quantization step (resolution) is equal to 5/212=1.22mV. The resolution can be improved by selecting the reference voltages such as to provide a smaller input voltage range. The ADC has a unique feature of being able to operate while the device is in Sleep mode with RC oscillator selection. It can convert an input signal manually (under software control) or automatically (the conversion trigger is under ADC clock control). The conversion trigger can also come from an external Interrupt (INT0) or Timer 3 (TMR3) modules [7], providing flexible sampling rates.

The operation of the ADC module is controlled by three control resisters ADCON1-3 and configuration registers (ADCHS, ADPCFG and ADCSSL). ADCHS selects the input channels to be converted; ADPCFG configures the port pins as analog inputs or as digital I/O and ADCSSL selects inputs for scanning. The module contains 16-word dual-port read only buffer called ADCBUF0 … ADCBUFF. Sampling per Interrupt can be set between 1 and 16. In this way the frequency at which ADC interrupt occurs can be decreased. This allows more time for the processing of a signal using sophisticated algorithms like FFT which require longer computation time. This feature has been used while implementing the overlap FFT algorithm for real-time frequency analysis.

B. *A/D Result Buffer Alignment*

The RAM is 10-bits wide, but the data is automatically formatted to one of four selectable formats when a read from the buffer is performed. The FORM<1:0> bits (ADCON1<9:8>) select the format. The formatting hardware provides a 16-bit result on the data bus for all of the data formats. Fig. 4 shows the data output formats that can be selected using the FORM<1:0> control bits.

C. *Simultaneous and Sequential Sampling*

A sample/convert sequence that uses multiple S/H channels can be simultaneously sampled or sequentially sampled, as controlled by the SIMSAM bit (ADCON1<3>). As shown in fig.5, simultaneous sampling of multiple signals ensures that the snapshot of the analog inputs occurs at precisely the same time for all inputs. The selected channels are sampled simultaneously with one sampling period. The channels are then converted sequentially. Sequential sampling takes a snapshot of each analog input just before conversion starts

Figure 18-12: A/D Output Data Formats

RAM Contents:					d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00
Read to Bus:																
Integer	0	0	0	0	d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00
Signed Integer	$\overline{d11}$	$\overline{d11}$	$\overline{d11}$	$\overline{d11}$	$\overline{d11}$	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00
Fractional	d11	d10	d09	d08	d07	d06	d05	d04	d03	d02	d01	d00	0	0	0	0
Signed Fractional (1.15)	$\overline{d11}$	d10	d09	d08	d07	d04	d03	d02	d01	d00	d01	d00	0	0	0	0

Figure 4. Contents of A/D Result buffer for different result alignment modes

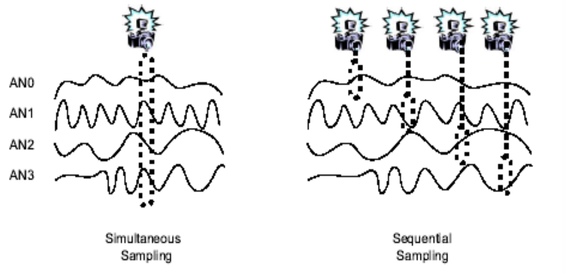

Figure 5. Simultaneous and Sequential Sampling

on that input, and the sampling of multiple inputs is not correlated. The Simultaneous sampling feature is very useful in motor control applications where all 3 phases need to be captured at the same time.

D. *Automated Sampling*

Automated sampling enables up to 16 samples to be converted before the buffer is full and interrupt is generated. For example Converting One Channel 16 Times/Interrupt will result into buffer memory map shown in fig. 6.

E. *Scanning through 16 inputs per interrupt*

Auto scanning mode can be used to all 16 inputs or any of them to be converted before any interrupt is generated. Memory map when scanning through all 16 channels is given in fig.7.

Buffer Address	Buffer @ 1st Interrupt	Buffer @ 2nd Interrupt	
ADCBUF0	AN0 sample 1	AN0 sample 17	
ADCBUF1	AN0 sample 2	AN0 sample 18	
ADCBUF2	AN0 sample 3	AN0 sample 19	
ADCBUF3	AN0 sample 4	AN0 sample 20	
ADCBUF4	AN0 sample 5	AN0 sample 21	
ADCBUF5	AN0 sample 6	AN0 sample 22	
ADCBUF6	AN0 sample 7	AN0 sample 23	
ADCBUF7	AN0 sample 8	AN0 sample 24	. . .
ADCBUF8	AN0 sample 9	AN0 sample 25	
ADCBUF9	AN0 sample 10	AN0 sample 26	
ADCBUFA	AN0 sample 11	AN0 sample 27	
ADCBUFB	AN0 sample 12	AN0 sample 28	
ADCBUFC	AN0 sample 13	AN0 sample 29	
ADCBUFD	AN0 sample 14	AN0 sample 30	
ADCBUFE	AN0 sample 15	AN0 sample 31	
ADCBUFF	AN0 sample 16	AN0 sample 32	

Figure 6. Memory Map for automated sampling mode

Buffer Address	Buffer @ 1st Interrupt	Buffer @ 2nd Interrupt	
ADCBUF0	AN0 sample 1	AN0 sample 17	
ADCBUF1	AN1 sample 2	AN1 sample 18	
ADCBUF2	AN2 sample 3	AN2 sample 19	
ADCBUF3	AN3 sample 4	AN3 sample 20	
ADCBUF4	AN4 sample 5	AN4 sample 21	
ADCBUF5	AN5 sample 6	AN5 sample 22	
ADCBUF6	AN6 sample 7	AN6 sample 23	
ADCBUF7	AN7 sample 8	AN7 sample 24	. . .
ADCBUF8	AN8 sample 9	AN8 sample 25	
ADCBUF9	AN9 sample 10	AN9 sample 26	
ADCBUFA	AN10 sample 11	AN10 sample 27	
ADCBUFB	AN11 sample 12	AN11 sample 28	
ADCBUFC	AN12 sample 13	AN12 sample 29	
ADCBUFD	AN13 sample 14	AN13 sample 30	
ADCBUFE	AN14 sample 15	AN14 sample 31	
ADCBUFF	AN15 sample 16	AN15 sample 32	

Figure 7. Memory Map when scanning through all 16 channels.

F. *Other Combinations*

Following are some examples of other options and combinations can be obtained from reference manual: -

- Scanning through 16 inputs/interrupt
- Sampling Three Inputs Frequently While Scanning Four Other Inputs
- Using Dual 8-Word Buffers
- Using Alternating MUX A, MUX B Input Selections
- Converting Two Sets of Two Inputs Using Alternating Input Selections
- Sampling Eight Inputs Using Simultaneous Sampling
- Sampling Eight Inputs Using Simultaneous Sampling
- Sampling Eight Inputs Using Sequential Sampling

G. *Variable Sampling Rate*

A variable sampling rate was required to be used for the real-time frequency analysis and Multiband IIR filter analysis for the tool monitoring system [8]. Therefore it was necessary to setup the ADC in a fashion that allowed the sampling rate to be easily changed. The on-chip Timer 3 module (as shown in fig. 8) was used for this purpose. The system clock pulse (T_{CY}) was divided with a Prescaler to generate the timer trigger pulse and the timer incremented with each pulse. Timer 3 was set to generate an ADC Event Trigger, whenever the timer value (TMR3) matched timer period (PR3), which can be calculated as follows [9]:

$$PR3 = F_{CY} / (f_s \times Prescaler)$$

Where F_{CY} *is the system clock frequency and* f_s *is the required sampling rate in Hz.*

The prescaler was set to minimum to obtain maximum frequency resolution as PR3 was rounded to an integer during calculations.

Now simply updating the timer period value changed the sampling rate of the timer. The ADC was set to acquire a sample on the ADC event trigger from timer 3 becoming true. In this way variable sampling rates were realized without requiring any modification to the ADC registers, which would have required stopping the ADC before modifying any control registers. The timer period register can be update without stopping the timer; this method thus provided very fast updating of the sampling rate. This novel technique, which utilizes the ADC feature to vary sampling rate on the go, will enable the monitoring of tool breakage with varying spindle speed.

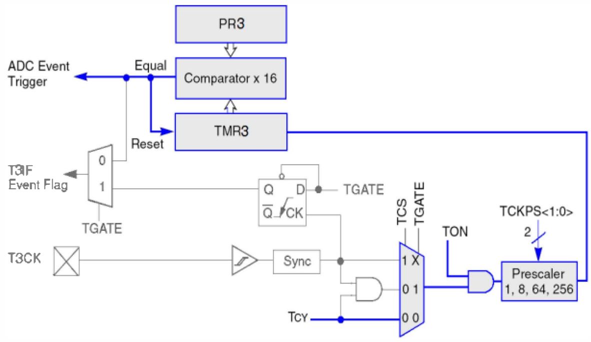

Figure 8. Timer 3 operation to generate ADC event trigger (adopted from [9])

VII. CONCLUSION

The dsPIC Microcontroller provide features which enable implementation of an advanced data acquisition system for efficient monitoring and control and security applications. It provides data acquisition of up to 16 analog channels with 10/12 bit resolution, simultaneous sampling of 4 signals, fixed and variable sampling rate, on chip storage and real-time signal processing capabilities. The system also supports for data acquisition of digital signals signal parameters like frequency, time period, pulse width, duty cycle, and delay & time difference between two signals. Its typical security related application is implementation of a True/ Hybrid Random Number Generator in which different noise sources are captured using ADC module and further signal processing is performed to obtain qualified random numbers.

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