Design and Development of FPGA Based Data Acquisition System for Process Automation

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Abstract

This paper presents a novel approach to the design of data acquisition system for process applications. The core heart of the proposed system is Field Programmable Gate Array (FPGA) which is configured and programmed to acquire a maximum of 16 MB real time data. For the real time validation of the designed system, a process plant with three parameters i.e. pressure, temperature and level is considered. Real time data from the process is acquired using suitable temperature, pressure and level sensors. Signal conditioners are designed for each sensor and are tested in real time. Designed FPGA based data acquisition system along with corresponding signal conditioners is validated in real-time by running the process and comparing the same with the corresponding references. The data acquired in real time compares well with the references.

Keywords

Field Programmable Gate Array; ADC; Temperature Sensor; Pressure Sensor

Introduction

In any of the process automation application the main objective is to keep the measurement error within the desired tolerance band. Design of the controller for this purpose requires a continuous monitoring of the various parameters in real time process applications. However, non-availability of sensors for the measurement of all state variables necessitates the design of parameter estimator to estimate the state variables for the feedback. Estimation necessitates the data of different process parameters over a period of time. If the number of data samples over a period is more, then the estimation becomes more accurate.

Estimator estimates the given parameter by the data that are observed. Data acquisition system is used to acquire the data from the various sensors. The acquired data can be stored and utilized for estimation. In data acquisition and recording system, it is a growing challenge to acquire the data at a required rate and to accumulate the data in an on chip memory processor. There are devices like microprocessors, microcontrollers, DSP which are available and can be programmed as a data acquisition system. The main disadvantage of using these devices is their slower data acquisition speed, non availability of sufficient on-chip memory. Apart from this, the rigidity in the hardware configuration of these devices does not allow flexibility for the user in configuring these devices according to the requirement. To overcome these drawbacks this research work proposes a novel technique of design and develop a data acquisition system using the Field Programmable Gate Array (FPGA) which provides flexibility in configuring the device according to the user requirement. The major defining characteristic of the FPGA is that it can be programmed. Programming an FPGA is very different from a microprocessor or a DSP processor. Microprocessor is a stored program computer. A computer system contains both a CPU and a separate memory that stores the instruction and data. The FPGA's Program is interwoven into the structure of FPGA. An FPGA does not fetch instructions. The FPGA's programming directly implements the logic functions and interconnections. In the FPGA's there is no wait for completing the design to obtain a working chip. The design can be programmed into the chip and can be tested immediately. When an FPGA is used in final design, the jump from prototype to product is much smaller and easier. They are having a large number of input and output lines compared to microprocessors, microcontrollers and DSP's. FPGA's are having a higher processing speed compared to microprocessors and microcontrollers which is a need in most of the control application such as industrial automation, process control applications, aircraft control and robot-control to name a few.

In this work the acquisition of process parameters such as temperature, pressure and fluid level, which is needed in a process control application, are considered. These parameters are measured using various sensors and those data are fed to FPGA based data acquisition system after proper conditioning. Thus, the objective of this work is the design of a data acquisition system on a FPGA chip which fetches the sensor data through an ADC and displays the parameter values on the LCD display.

The organization of this paper is as follows: section 2 gives the principles of the design of the signal conditioning circuits for the sensors, interfacing of sensors, ADC and FPGA. Next the required software development for data acquisition, data manipulation and display is highlighted in section 3. The results and analysis are given in section 4 and finally conclusions are drawn in section 5.

Principle of design

Here we have designed a FPGA based data acquisition system for a milk pasteurization unit, where the temperature, pressure and level are to be monitored and controlled. Design mainly involves the development of signal conditioning circuits for the pressure, level and temperature sensors used in the application and programming the FPGA using a hardware description language. FPGA utilized as a data acquisition system is programmed to send the output signals for channel selection and start of conversion for ADC. The Programming is done to fetch the data at the output of ADC once an end of conversion is received from the ADC. The program will also output the measured values on an LCD display in a user friendly mode by converting the acquired data with the aid of proper mathematical calculations.

Hardware Configuration:

Fig. 1 gives the block diagram representation of the hardware configuration. The hardware consists of temperature sensor LM35, pressure sensor MPX10GC, Float sensor for level measurement and their signal conditioning circuits, ADC 0809 and Spartan-3E FPGA board. FPGA controls the ADC by sending the start of conversion and channel selection signals. According to the select lines ADC will select one of the three inputs and convert the input signal to its digital equivalent. Once the conversion is completed of it will send an end of conversion signal to the FPGA. The FPGA then acquires the data from the output of ADC, processes the input data and sends the measured value to the output LCD display.

ADC 0809:

The ADC0809 data acquisition component is an 8-bit analog-to-digital converter, with 8-channel multiplexer.

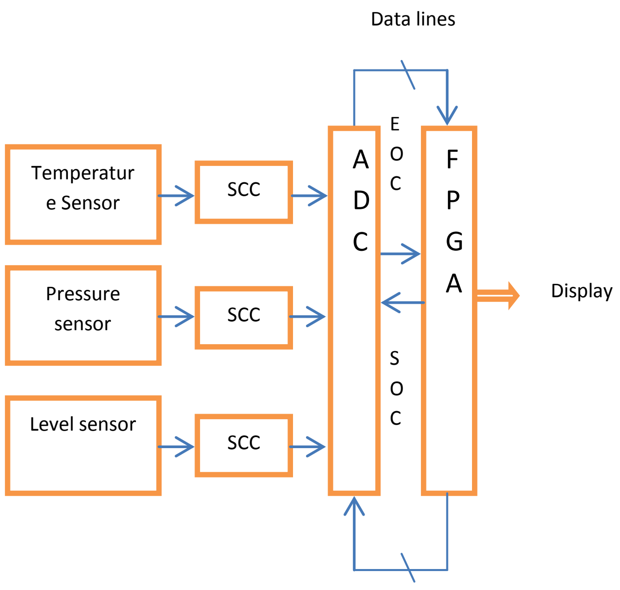

FIG.1 BLOCK DIAGRAM

The circuit diagram of the signal conditioning circuits interfaced with the ADC is shown in Fig. 2.

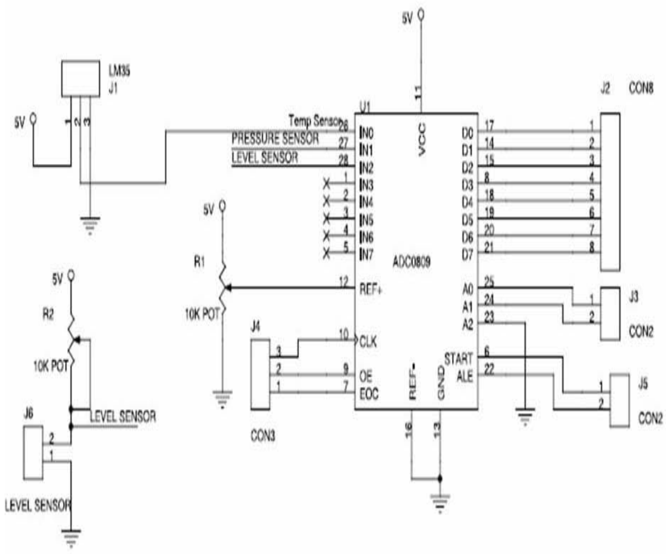

FIG.2 SIGNAL CONDITIONING CIRCUITS CONNECTED WITH ADC

First three input lines of the ADC IN0, IN1 and IN2 are selected as the input lines for temperature sensor, pressure sensor and level sensor respectively. The output lines of the ADC are connected to the FPGA through a connector cable, and the reference voltage applied to the ADC is +3.3V and 0V for $+V_{ref}$ and $-V_{ref}$ respectively as the FPGA operates in this range.

Signal Conditioning Circuit for Pressure Sensor:

The MPXV10GC device is a silicon piezo-resistive pressure sensor providing a very accurate and linear voltage output directly proportional to the applied pressure. Fig. 3 shows a schematic of the internal circuitry on the stand-alone pressure sensor chip. This pressure sensor can measure the pressure in the range of 0-10KPa or 0-1.45Psi and give output voltage in the range of 0-35mV.

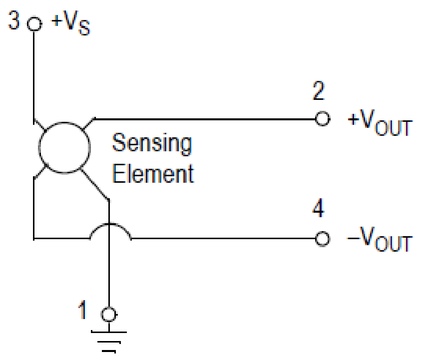

FIG3: SCHEMATIC DIAGRAM OF PRESSURE SENSOR

Fig. 4 represents the signal conditioning circuit designed for the pressure sensor given in Fig. 3. The pressure sensor needs a biasing of 5V. The output of the pressure sensor is connected to a high precision op-amp LM308. This op-amp is that it is well suited for a device with high source impedance and gives the advantage that the differential pressure is directly connected across the two inputs of the op-amp where it produces a differential output.

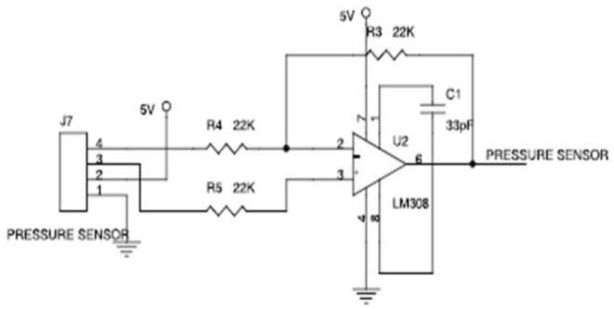

FIG.4 SIGNAL CONDITIONING CIRCUIT FOR PRESSURE SENSOR

The voltage due to differential pressure is available between the two output pins of the pressure transducer which is applied to the input of the op-amp through series resistors.

Signal Conditioning Circuit for Level Sensor:

Level measurement is done by using a mechanical type float sensor. The float sensor is a pivoting float-type gauge which typically utilizes mechanical or electrical mechanisms that sense the angular position of the float arm with respect to a stationary support arm. The output of this device is the change in resistance which is linear with respect to the angular position of the float arm. The signal conditioning for this sensor is shown in Fig. 5.

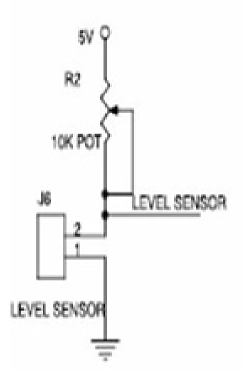

FIG.5: SIGNAL CONDITIONING CIRCUIT FOR LEVEL SENSOR.

The level sensor is connected in series with a 10kΩ potentiometer which makes the circuit as a voltage divider network. This configuration is set in a way that it produces an output of 100mV for every 1mm change in the level of the liquid.

The Temperature Sensor:

Temperature is measured with LM35 which is a precision integrated-circuit temperature sensor, whose output voltage is linearly proportional to the Celsius temperature. This sensor gives an output of 10mV for every 1°C change. Hence the need of complex signal conditioning is not necessary at the sensor output. FIG.6 shows the signal conditioning circuit for the sensor

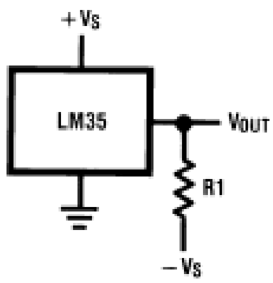

FIG.6: SIGNAL CONDITIONING FOR TEMPERATURE SENSOR

A single load resistor connected at the output of the sensor will provide the required signal conditioning. The output across load resistor is connected to IN0 channel input to ADC. This sensor also helps in the reduction in the size of the hardware. This sensor can measure a range of temperature from -55 to 150°C that will satisfy the range needed in our work.

Software Implementation

The FPGA has to work as a data acquisition system. The operations that will be performed by the FPGA are shown in the flow chart in Fig. 7.

The program is written in the hardware description language VHDL. The programs for ADC controller and LCD display are synthesised separately and these programs are bind to the main program. The FPGA will send the select line signals to the ADC and issue a start of conversion (SOC). After the SOC is issued the program will be in wait mode for 110μs.

This delay introduced in the program as the conversion time of ADC is 100μs. Then it will look for the end of conversion (EOC) signal from the ADC. If FPGA gets an EOC from the ADC then the FPGA will acquire the data present in the output of the ADC. The acquired data will be a binary word and will be converted from binary to real by programming and the calculation of parameter values is done according to the selected input channel. The calculated output will be sent to the LCD unit to display the current value of the parameter. Once all the three channels are scanned the channel selection input will be reset to zero and the process will be repeated.

Results and Analysis

FPGA based data acquisition system is designed and integrated into an experimental setup constructed around a prototype milk pasteurization unit, where the temperature, pressure and level are to be monitored and controlled. Real time data is acquired by the system and displayed on the LCD. As the validation is compared with the reference data of the thermometer, side tube of the tank and an analog pressure gage are here used as the reference devices. Table 1 shows measured samples and the corresponding reference values.

It is seen from the table that there is some error presented in the measured readings. This is due to the limitation of the number of output bits in the ADC. Thus it is found that the measured data, displayed on the LCD compares well with those of reference values.

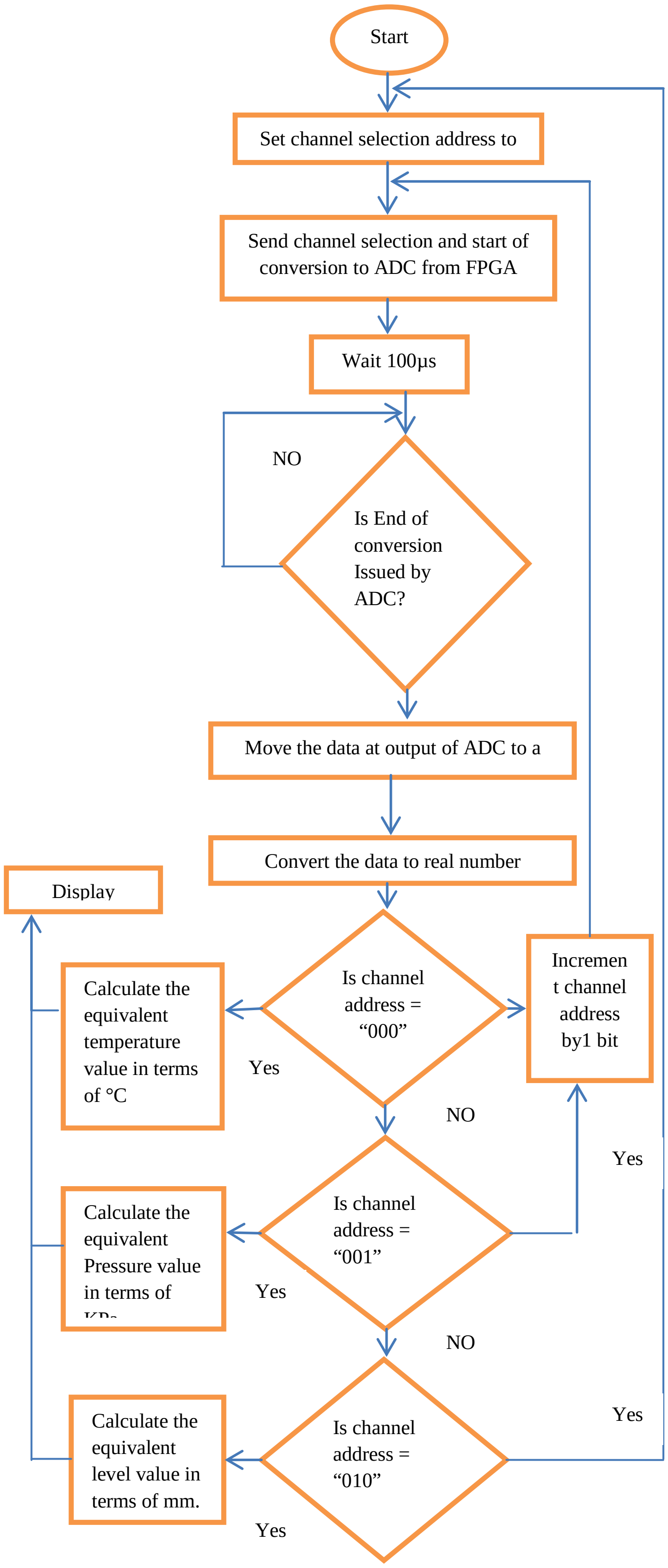

FIG.7 FLOW CHART

TABLE 1: RESULT TABLE

Parameter	Reference value	Measured value
Temperature	34°C	33°C
	47°C	44°C
	56°C	53°C

Parameter	Reference value	Measured value
Pressure	1KPa	1Kpa
	2.5Kpa	2.4Kpa
	6.5Kpa	6.2Kpa

Parameter	Reference value	Measured value
Level	4mm	3.9mm
	5.2mm	5.2mm
	13mm	13mm

Conclusion

FPGA based data acquisition system for the process application is designed and validated in real time. The proposed system is capable of acquiring a maximum of 16 MB real time data. For the validation of the designed system of a simple process plant with three parameters i.e pressure, level and temperature is considered. The system acquired the online data from different sensors and displayed them. Acquired data shows a small measurement error which is due to the limitation of the number of output lines in the ADC. If the ADC is replaced by an ADC of higher resolution then more accuracy in the output can be achieved.

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Dr. Meenakshi is guiding PhD and M.Sc engineering by research students in VTU, Belgium. Her research interests are controls, signal and image processing and real time systems.