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DEVELOPMENT OF A LOW COST DATA ACQUISITION SYSTEM FOR SUBSONIC WIND TUNNEL MEASUREMENTS

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Abstract- *In aerodynamic research wind tunnel is used for observing flow phenomena for practical engineering and measurement of various aerodynamic properties for any predetermined boundary conditions. A 30" subsonic wind tunnel has been constructed in Mechanical Department of Khulna University of Engineering & Technology. Instead of traditional manometric measurement system newly developed computerized data acquisition (DAQ) system will be used. This system includes simultaneous multipoint pressure measurement and automatic velocity calculation by use of integrated pressure sensors, analog to digital converter (DAQ) for high resolution digital conversion, Arduino based computer interfacing and LabVIEW based VI for data collection, processing and recording. Although there are many commercially available DAQ but because of high cost, these are not easily implementable for universities in a developing country like Bangladesh. The key interest of this concept is to develop an easily implementable and highly accurate data acquisition system at low cost. With custom designed separate ADC with open source firmware based interfacing hardware intended features can be achieved. The design is highly modular and allows easy upgrades with minimal cost. The system can be used for multipurpose application without changing hardware components but simply modifying the software. It is to be noted that with a computer-aided DAQ it is possible to take massive amount of data in a very little time and also simultaneous data for multiple points. Temperature sensing will also be included so that error correction and end calculation can be done inherently. The system will be tested and calibrated by comparing with other verified measurement systems in controlled environment. The data acquisition system can be deployed as complete aerodynamic measurement solution for any subsonic wind tunnel.*

Keywords: Wind tunnel, Instrumentation, Data Acquisition, Automation

1. INTRODUCTION

There are various methods used for wind tunnel measurements used in aerodynamics laboratories. In well-established laboratories there are highly automated and high tech measurements systems available which increases the speed and accuracy of the measurements and data collections. But also, there are a lot of facilities where the measurement and data collection are done manually by simple methods using liquid column manometers or analog pressure gauges. One of the main reasons why high tech measurement systems are not available at all facilities is the cost of developing and deploying such system.

The objective here is to explore the possibility of developing a measurement and data acquisition system which would have the basic qualities that the high end automated systems have in a low cost method. It can be deployed in almost any aerodynamics testing facility replacing the traditional methods. The idea is that, using simple Microcontrollers with separate high resolution Analog to Digital Converters and industrial MEMS (Microelectromechanical systems), paired with a personal computer, many of the functionalities of modern high end data acquisition systems can be achieved.

The goals set for the Data Acquisition System is to be able to take sample of pressure values of multiple points simultaneously through various setups of pressure probes in a wind tunnel test chamber, take wind velocity measurements through Pitot tubes in the wind tunnel test chamber, and to show, analyze and store the data automatically real-time through a computer interface.

2. DATA ACQUISITON SYSTEM

A basic data acquisition system mainly consists of a signal receiving part and a processing part. On the center of them there is usually a DAQ card. But using commercial DAQ cards are costly and defeats the purpose if used in a system targeted to be low cost. Thus, the system developed has a personal computer running the LabVIEW VI as the processing part, and modular Transducer Cards with individual ADCs as signal receiving part. Additionally, the transducers used for the pressure and velocity measurement are built in with the Transducer Cards. The Transducer Card system with built in ADCs give the design modularity, which in turn increases the extendibility of the system. The whole system is divided into three modules. Figure 1 shows the block diagram for the system and Figure 2 shows the constructed system with one transducer card.

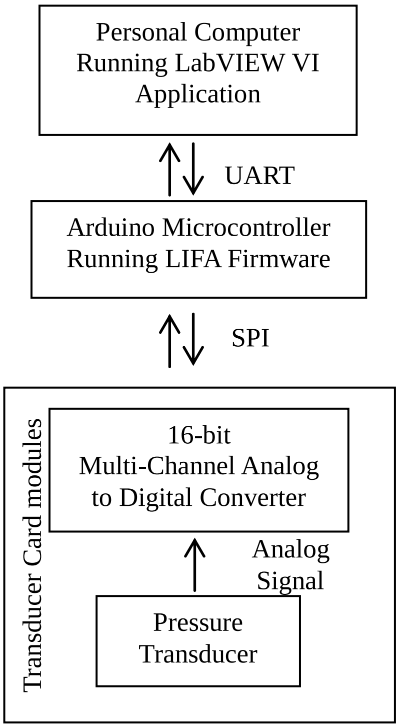

Fig. 1: Functional Block diagram of the Data Acquisition System.

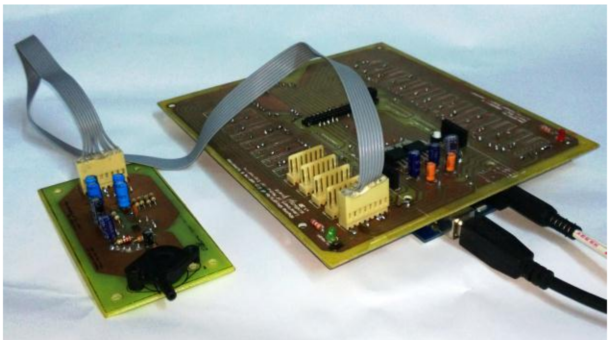

Fig. 2: Constructed system with one transducer card.

2.1 LabVIEW VI

The LabVIEW VI (Short for Virtual Instrument) [1] application running on a personal computer acts as both the processing part and the interface part of the system. It communicates with the Arduino using the open source LIFA (LabVIEW Interface For Arduino) [2] library and obtains the data from the ADCs using the Arduino's SPI communication port. The VI then converts the raw binary value of the ADC to the measurement value. It then displays or stores the data and also does farther processing using the LabVIEW arithmetic library as per requirement of the test setup of the wind tunnel.

The VI also has the control interface for the system. It contains controls like the sampling interval, the sampling mode and the output data format controls. The VI can show the direct sensor values from the transducer, like showing pressure for each the pressure probes attached to a transducer, or can process the data to obtain a result in real time and show them, like calculating the velocity of a stream by calculating from multiple pressure data obtained from the sensors attached to a pitot tube.

The VI runs on a personal computer and communicates with the Arduino board using the Serial UART. It uses the LabVIEW VISA drivers to communicate over Arduino's Serial UART and then uses the LIFA library to control the Arduino's IO and communication pins directly. Thus it also controls the SPI communication to the ADCs directly.

2.2 Arduino

The Arduino is an open source physical computing platform that is basically an Atmel AVR microcontroller [3]. The particular Arduino board used here is the Arduino Mega with ATmega 2560 microcontroller. It has enough GPIO pins and communication ports to match the system's requirement. The Arduino is used here as a communication hub and not as a processing device. It communicates with the multiple ADCs being used with its SPI bus and then supplies the data to LabVIEW via its UART connection.

The firmware used in the Arduino is open source and a part of the LIFA package. It contains routines and functions required with the VI's LIFA library components. This firmware enables the LabVIEW VI to directly control every GPIO pin of the Arduino as well as all of its communication buses.

The ADCs are connected to the Arduino with a common SPI bus. The SPI bus allows connecting multiple chips to same bus as long as each have a separate chip select pin to control which chip is active on the bus. This feature is used to connect up to 25 separate ADCs on a single SPI. The SDO and SCK pins of the bus are common for all ADCs and a separate GPIO pin of the Arduino is used as chip select pin for individual ADC. Figure 3 shows the method used for connecting multiple ADCs to single SPI bus [5].

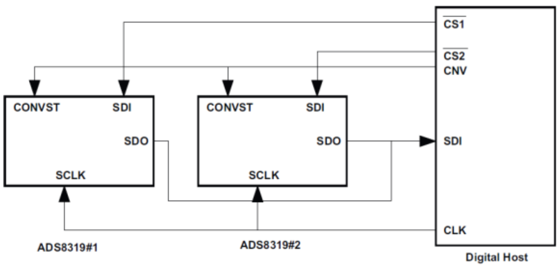

Fig. 3: Connecting multiple ADC to single SPI bus

Some daughter boards called "shields" are used to add additional functionality to the main Arduino board. A shield was developed which has connection ports for the transducer cards. The developed shield currently includes 5 connection ports and power supply regulators for ADCs for the transducer cards. Up to 20 more connection ports can be added with the current design. The shield is also stackable meaning additional shields can be added for additional functionality such as instrumentation controls or even more connection ports. Figure 4 shows the shield attached with Arduino Mega2560 board.

Fig. 4: Arduino board with shield for connecting transducer cards.

2.1 Transducer Card

The Transducer Cards are modular cards with the transducers and ADC in a single PCB. The basic problem with low cost devices with analog segments is the quality degradation on the connector and signal transport parts. By placing the transducers and ADCs close together in individual single PCB makes the signal path much reliable. After conversion of analog signal to digital data, the quality of signal path becomes less significant.

In this particular system built for the subsonic wind tunnel at Khulna University of Engineering & Technology, the pressure transducers used are Freescale Semiconductor MPX4250A absolute pressure sensors. This sensor has a input pressure range of 20 - 250 kPa [4]. They are sufficient for any type of measurement, both pressure and velocity through pitot tube to a full subsonic range. They have ratiometric output range of 0v - 5v DC with temperature compensation and built in gain amplifier. They have a maximum error rate of ±1.5%. The pressure transducers have 5mm pressure input ports which can be connected to any type of probe assembly using rubber tubes. There is a set of transducer cards which have thermocouple temperature sensors to provide the VI with temperature data required for any type of post processing of the data.

The ADCs paired with each transducer are matched to the transducer output range to utilize the full range of the transducer. 16-bit ADCs are used to provide the required measurement resolution of 0.005 kPa from the pressure transducers. The particular ADC used is the Texas Instrument ADS8319 [5]. It is a 16-bit SAR ADC with serial SPI output and maximum of 500 KSPS sample rate. This provides enough speed of the ADC to utilize the maximum data transfer rates of the communication buses.

The ADC has a SPI output port with separate CONVST interface, enabling the system to take the snapshot of transducer signal of all the ADCs at once by triggering the CONVST pin and then sequentially read all the converted data from them. This in turn, enables accurate time based measurement of different probes on even a highly dynamic condition. The ADC reference voltage input is tied with the sensor excitation source voltage which has an inherent advantage of maintaining the measurement accuracy even with low quality power supply with fluctuating output which is common in low cost setups.

The ADCs SPI interface is used in this design as 4-wire CS mode, where the SDI pin of the ADC is used as the chip select pin and connected to a GPIO of the Arduino for each individual ADC, as shown before on Fig.3. This enables the VI to select and read particular ADC data through the common SPI bus.

The transducer card module houses both the ADC and the transducer on a single piece of PCB along with all other passive component required for connecting and filtering the signal between them. This PCB is completely separate from the Arduino board and is connected to the Arduino board with Molex connectors. This method provides two benefits, the first is the analog part of the circuit is unaffected from the digital noise of the Arduino board; the second is that the transducer cards can be attached, detached, swapped and upgraded at any time without changing the whole system. Figure 5 shows one of the transducer cards. It includes a Molex connector, ADS8319 analog to digital converter and MPX4250 absolute pressure sensor.

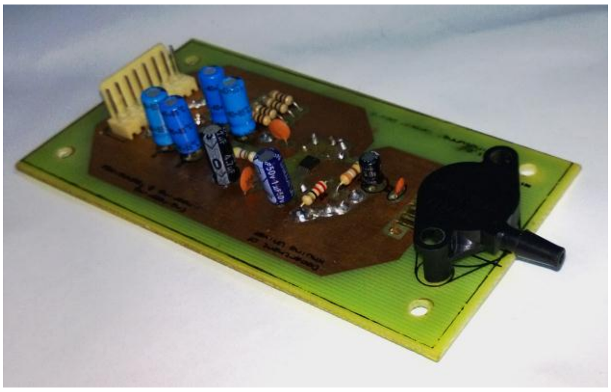

Fig. 5: One of the transducer cards used in the system.

3. PROGRAM STRUCTURE

The basic workflow of the system is shown on Fig.6. After initialization of the program the VI takes input of necessary control information. This includes the probe type, the sample rate, the measurement units, output data type, output location for storage etc. After all the inputs are completed and the sampling starts, the VI uses the Arduino GPIO pin used for CONVST signal to trigger acquisition of all of the ADCs of all of the Transducer Boards. Then it waits for a specified time for completion of all of the ADC conversion. After that, the VI activates the LIFA SPI module to communicate with the ADCs and read back the converted value. The VI uses GPIO pins to select the ADCs one by one to read the data from. The SPI communication is by default at 4MHz, Mode 0. The data from the 16-bit ADCs are two-byte wide and read MSB first. After reading the data from each ADC, the VI stores them into an array and reads data from the next ADC. After completing the reading cycle, the data stored in the array is processed to obtain the actual measurement value. The incoming data is in straight binary, and the converting is done by Equation 1 shown below.

$$\text{Pressure} = \frac{\text{Range(250kPa)}}{65536} \times \text{Binary Data} \qquad (1)$$

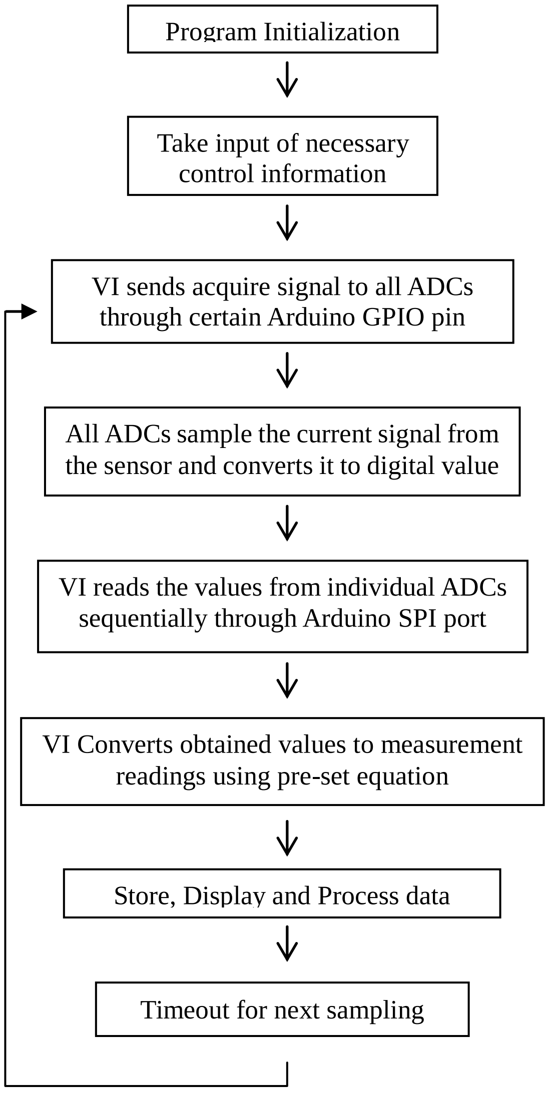

Fig. 6: Overall operation structure of the system.

The measurement value is then processed to obtain the desired output value. If Pitot tube mode is being used, the pressure data from the static pressure probe and the dynamic pressure probe is used to calculate the velocity directly using the arithmetic library functions [6]. Also, the data from temperature sensors are used for calculation and error correction.

After processing the data, the data is displayed on indicators on the VI front panel, as well as logged on the selected format to the personal computer's hard drive.

As soon as the data is passed out from the array and processed, the VI waits for the required period of time to match the set sampling rate, and then triggers the CONVST again. The cycle is continued until the wind tunnel testing is complete and operator stops the VI.

4. RESULTS AND DISCUSSION

A test run of the system in the subsonic wind tunnel was done to check the system. The measurement was done with a Pitot tube of 1mm nozzle. Free stream velocity of the air in wind tunnel test chamber was measured. The measurement was done by both the Data Acquisition System and the Inclined Manometer currently being used in the facility. The following table shows the comparison of measured value from both systems.

Table 1: Comparison of data obtained from the Data Acquisition System and traditional Inclined Manometer

Observation no.	Velocity calculated by taking data from Inclined Manometer	Velocity found from LabVIEW GUI	Difference (%)
1	30.27	31.302	3.409316155
2	34.6	35.002	1.161849711
3	38.55	37.632	2.381322957
4	41.38	42.234	2.063798937
5	42.85	42.672	0.415402567
6	45.75	44.95	1.74863388
7	47.12	47.893	1.64049236
8	51.09	52.126	2.027794089
9	53.851	53.772	0.146701083
10	56.6	53.264	5.893992933

The results obtained are acceptable. Also, the data obtained from this system have higher resolution than what is obtainable by a manometer. The data is collected automatically and at very high speed compared to the manual process of reading the data from each manometer visually and recording them. This automated data collection ensures that the values of static pressure and dynamic pressure are taken exactly at the same time, rather than taking one first, recording and then taking the other. This is very helpful if the test conditions are unstable or turbulence is a part of the experiment.

5. COST ANALYSIS

One of the goals of the project is to build the data acquisition system as less costly as possible. The following table shows the costs for major components of the system hardware.

Table 2: Cost Analysis for overall data acquisition system hardware

Item	Cost (USD)
Pressure Transducers (3 piece minimum)	45
Analog to Digital Converters (3 piece minimum)	24
Arduino Mega board	60
Power supply	25
Miscellaneous passive electronic components	30
Cables, connectors, buttons and switches	20
PCB manufacturing and assembly	40
Total	**244**

Compared to the commercial DAQ hardware with 16-bit resolution reaching 1000 USD without including transducers, this setup requires only around 250 USD even including the transducers which is very reasonable. The software part of this system is still costly. Although the LIFA library and Arduino firmware both are free and open source, the license price for LabVIEW development system is high. But this cost can also be reduced by using open source platforms. More on this topic is discussed on future directions section.

6. CONCLUSIONS AND FUTURE DIRECTIONS

This project completes the basic requirements of the modern data acquisition systems at a very low cost. The project is successful to complete its goals with a very low hardware cost. But the software cost can be reduced by farther work. Though the LabVIEW package and it's graphical programming is most suitable for laboratory purposes, the cost of the LabVIEW development package is too high for low cost applications. This can be solved by replacing LabVIEW with some other open source platforms developed using "Processing" or "Firmata", developing standalone and completely new software's which can do similar task of the VIs and new firmware for the Arduino which can communicate with the developed software.

Also, this project is designed to be highly modular; meaning any part of it can be changed, replaced and upgraded with ease. Thus, any part of the system can be upgraded with new design to match new requirements in the future. For example, the ADCs can be replaced with higher resolution ones, the transducers can be replaced with more accurate and sensitive ones. The Arduino Mega board itself can be replaced with newer faster edition of Arduino boards if required.

Another future upgrade possibility is that, using the Arduino Mega board's unused communication port developing an instrumentation control system; along with a mechanical probe traversing system. This will allows to fully automate the total wind tunnel testing procedures by positioning, measuring, recording data from various probes continuously following preprogrammed instructions. This will make it possible to complete various wind tunnel testing procedures faster, more accurately and also make various complex procedures, i.e. continuous velocity profiling possible.

5. ACKOWLEDGEMENT

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