Design and Manufacture of a Low-Cost Data Acquisition Based Measurement System for Dual Fuel Engine Researches

To cite this article: N Sinaga *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **598** 012031

IOP Conf. Series: Materials Science and Engineering **598** (2019) 012031 doi:10.1088/1757-899X/598/1/012031

Design and Manufacture of a Low-Cost Data Acquisition Based Measurement System for Dual Fuel Engine Researches

N Sinaga[1], B Yunianto[1], D Purba[1], Syaiful[1] and A Nugroho[2]

[1] Mechanical Engineering Department, Diponegoro University, Jl. Prof. Sudharto, SH, Semarang 50275, Central Jawa, Indonesia.
[2]Mechanical Engineering Department, University of Wachid Hasyim, Jl. Menoreh X/22, Sampangan, Semarang 50232, Central Jawa, Indonesia.

nsinaga.ccfed@yahoo.com

Abstract. The role of data acquisition based measurement system in the researches is essential since it delivers many advantages compared to the manual arrangement. Nevertheless, its cost is comparatively high, then it becomes an obstacle, particularly for researchers in producing nations. The purpose of the study was to obtain a low-cost data acquisition system which has good performance when used in the research of dual-fuel engines. The study included a selection of variables, components and sensors, programming, and calibration. The Arduino based data acquisition system was chosen, which was relatively cheap and easy programming. The sensors/transducers consisted of three K-type thermocouples, three load cells, one proximity sensor, and one DHT-11 sensor. Programming of data acquisition systems was facilitated by using Arduino IDE software. The display and data recording were done in Microsoft Excel software, with the help of PLX-DAQ software. In this study, a low-cost data acquisition based measurement system had been successfully developed, which had low uncertainty, low hysteresis, and excellent repeatability. It is concluded that the system is very suitable to be used in dual fuel engine researches to measure engine speed, fuel discharge, gas fraction, torque, power, brake specific fuel consumption and brake thermal efficiency.

1. Introduction

The use of data loggers, or currently often referred to as data acquisition (DAC) systems, has begun to be popular since the 1980s, along with the development of the Personal Computer (PC). This is because many data logger components are similar to PC components [1]. With the speedy growth of cyberspace and computer technology, many modern data acquisition systems have been produced and are available to evaluate the parameters and performance of the system while operating [2]. Data acquisition systems available on the market are relatively expensive. Presently, there are options to build an acquisition system based on a new platform that is simpler, cheaper and more comfortable to use **Error! Reference source not found.**.

Data acquisition is a process of taking samples data from physical phenomena and converting them into numerical values that can be manipulated by a computer **Error! Reference source not found.**. The physical magnitude measured can be in the form of temperature, flow velocity, light intensity, pressure, the force produced by an object, and so onward [5]. The data acquisition system records data very accurate, can be repeated, reliable, and fault-free, as long as it is connected and controlled according to the conditions recommended by the maker. Such conditions are the right sensor selection, the appropriate and protected cable, the right type and magnitude of the signal, the frequency and range of data, and so forth [6].

Some advantages of utilizing data acquisition systems include speeding up the measurement process, easier data retrieval and control, high accuracy, low degree of uncertainty, and being able to correlate data quickly. Particularly for applications in dual fuel gas-diesel engine tests, this arrangement makes it possible to determine the gas fraction in the mixture in real-time, which is not possible in the manual measurement system. The combination of a data acquisition system with a control system can be utilized to regulate transient engine performance tests. For instance, when using an eddy current dynamometer, where the power and torque depend on the rotational speed and excitation power given to the dynamometer.

The Arduino-based data acquisition system is the right solution because, in accession to its relatively low price, the software is also open source and is quite comfortable in programming, because many libraries can be accessed freely via the net. As well, it has high reliability and durability [7] even when employed in hostile environments such as that of the automobile. Arduino is an open-source electronics platform based on easy-to-use hardware and software. Arduino boards can read inputs and turn it into an output such as recording measurement data, activating a motor, turning on an LED, publishing something online and so forth.

The query that requires to be resolved in this study is: does this low-cost acquisition system have a quality that satisfies the requirements to be used in research, particularly in dual-fuel engine research? Thus, this research points to study some quality parameters of the measurement system, namely measurement uncertainty, hysteresis, and repeatability, which is connected with the delay time of data access. In this paper, we discuss the process of designing, manufacturing and testing a data acquisition system for use in research on dual fuel liquid-gas engines, especially for diesel-gas dual-fuel engines. The success in evolving such a product is expected to assist researchers in inducing a low price and high-quality data acquisition scheme. Thus, the researchers are expected to no longer think twice about researching because of the constraint of a limited budget.

2. Methodology

Figure 1 shows a flow diagram of designing, manufacturing and testing the data acquisition system. As stated earlier, the acquisition system would be used in dual-fuel engine researches. The design began with the selection of measurement variables and continued with the manufacturing of the layout and the acquisition program. The quality and characteristics of the system were found out by conducting several tests, including calibration, measurement uncertainty, hysteresis, and repeatability. The independent parameter on the engine measurements was the gas and diesel oil flow rate, gas fraction, engine speed, and dynamometer load.

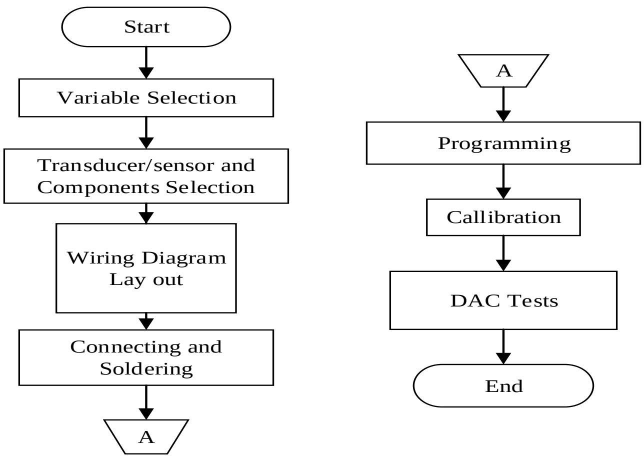

Figure 1. Flow chart of DAC system design.

The dependent parameters observed were the temperature of engine cooling water, intake and exhaust gas, air temperature and humidity, torque and engine power, brake specific fuel consumption (BSFC), and thermal brake efficiency (BTE). All these parameters were acquired so that they could be read and stored on the computer. Therefore, the measurement variables chosen were the flow of diesel and gas flow, engine speed, dynamometer load, temperature of cooling water, air intake, exhaust gas, and temperature and humidity. Explanation of measuring instrument components, wiring diagrams, programming, calibration and quality tests of data acquisition systems is discussed below.

3. Design and manufacturing of the DAC system

3.1. DAC System Arrangement

As stated before, Arduino is popular because it is open source and there are many libraries available that can be downloaded. Another essential factor to consider is that the use of an Arduino board is an excellent tool to train users in measurement procedures with relatively low but accurate costs [8]. To get a good DAC system depends on the following elements, namely personal computers, transducers, signal conditioners, the hardware and software [9]. Figure 2 shows the scheme of the work process of a data acquisition system.

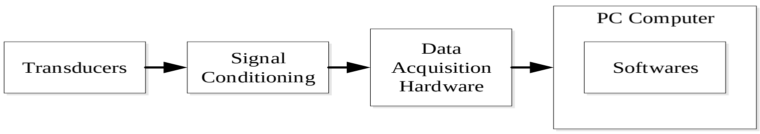

Figure 2. Element of PC-based DAC system

3.2. Characteristic of the Measurement System

Several parameters determine the character of a measuring instrument [10]. However, the most commonly used to determine its quality are measurement uncertainty, repeatability, and hysteresis. Accuracy is a measure of how close the output of the instrument is to the actual value. Repeatability shows the proximity of the output readings when the same input is applied repeatedly over a short period, with the same condition of measurement, instrument, location, and observer [11]. Hysteresis is the difference in the results of the reading when the measurement is conducted from two opposite directions, namely ascending and descending [12]. A system that has large hysteresis cannot accurately predict the system output [13]. Therefore, the smaller the hysteresis, the better the measurement system.

3.3. DAC Component Selection

The data acquisition system is designed using three main components, namely micro-controller, sensor and sensor module, and display. Information about each component is described below.

3.3.1. Microcontroller Selection. As described earlier, this acquisition system was designed using Arduino DAC, namely Arduino Mega 2560. This type was chosen because the number of I/O ports is more than the other types. With a higher number of ports, more sensors can be used. Also, this DAC board is easily obtained at a relatively low cost.

3.3.2. Selection of Sensors and Sensor Modules. In designing and manufacturing data acquisition systems, there are several sensors and sensor modules that are used with their respective functions. The sensors and sensor modules are as follows.

- Type-K thermocouple. This thermocouple consists of nickel and chromium on the positive side, while on the negative side consists of nickel and aluminum. This type of thermocouple is often used for general purposes because the cost is lower and more available.

- MAX 6675 module. This module is a signal conditioner that gets input from a K type thermocouple and converts analog data into digital data. MAX 6675 has been equipped with a cold/reference junction compensator and a Serial Peripheral Interface communication protocol to send the measured digital data to the microcontroller.
- Load cell. This transducer is used to produce electrical signals whose magnitude is proportional to the force measured. This sensor is widely used in electronic scales, where load cell is a series of several strain gauges.
- HX-711 module. The working principle of this module is to convert resistance changes into electrical voltages. With this module, the microcontroller can read signals from the load cell. Because this sensor only gives a very low voltage signal, an amplifier is needed to amplify the signal to be 0 - 5 V.
- DHT-11 sensor. This component can measure two environmental parameters at once, namely temperature and humidity. The advantages of this sensor compared to other sensors are the quality of data readings that are more responsive, faster and not easily interfered. The DHT-11 sensor, in general, has a reasonably accurate humidity and temperature reading.
- Proximity sensor. This sensor is used to detect an object based on the distance of objects to the sensor. The measuring distance starts from 1 mm to several centimeters. In the current design, this sensor serves to measure the rotating speed of the engine.

3.3.3. Display Selection. In designing the data acquisition system, there were two displays used, namely computer displays and pulse meter displays, which were additional components to facilitate the testing process on diesel engines later. Also, the pulse meter reading was used as a comparison with the engine speed data obtained by data acquisition.

3.3.4. Selection of Supporting Software. Arduino Mega 2560 board has an uploaded program to run the DAC system on the computer. Arduino IDE (Integrated Development Environment) software was used for writing a program, as well as to upload it into the board. Through this software, an embedded program was written to perform functions through the programming syntax. PLX-DAQ software was selected, as an open source software from Parallax Inc., to display sensor reading data into the Microsoft Excel sheets.

Figure 3 shows the results of the DAC design. These components can be reduced or added according to the test requirements. For this study, namely in testing dual fuel engines, these functions are depicted in Figure 4 The appearance of reading data on an MS Excel worksheet is shown in Figure 5.

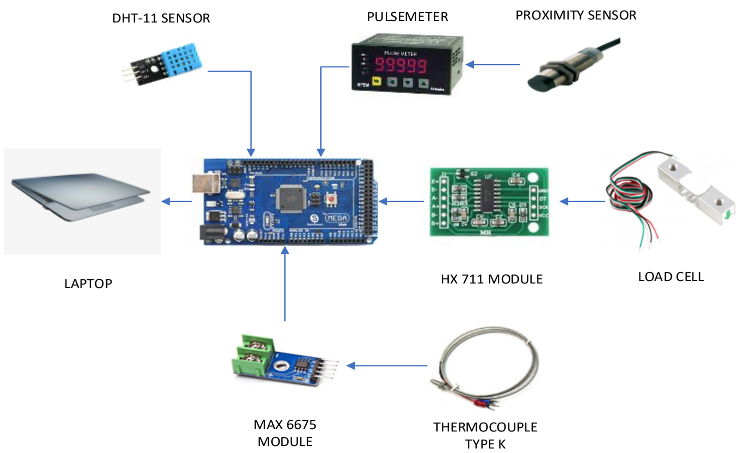

Figure 3. The DAC layout of a dual fuel engine measurement system

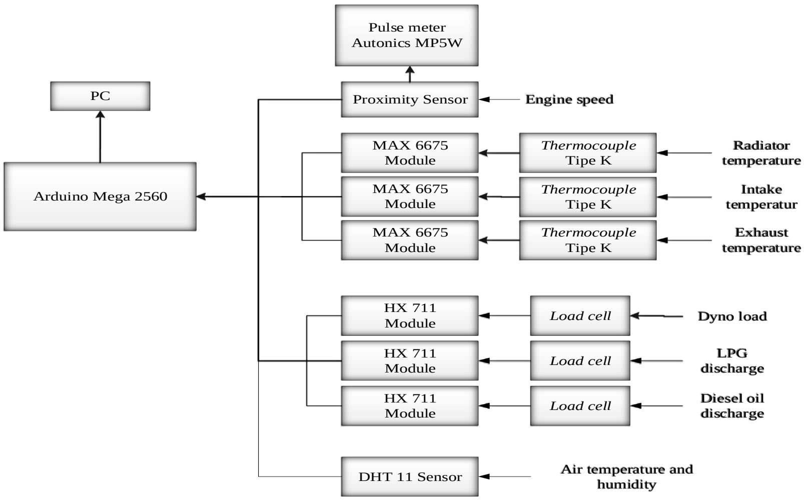

Figure 4. The component function of dual fuel engine measurements

EFFICIENCY AND ENERGY CONSERVATION LABORATORY
MECHANICAL ENGINEERING DEPARTMENT OF DIPONEGORO UNIVERSITY
DUAL FUEL Diesel-LPG TEST at TPS-50%
Wednesday, Oktober 23, 2018

Date	Time	Δt (s)	Environ. Temp (C)	RH (%)	Radiator Temp. (C)	Inlet Temp. (C)	Exhaust Temp. (C)	Dyno Load (Kg)	LPG Mass (g)	Oil Mass (g)	FC LPG (g/s)	FC Oil (g/s)	LPG Fraction (%)	Engine Speed (rpm)	Engine Torque (Nm)	Engine Power (KW)	BSFC (Kg/KWH)	BTE (%)
23/10/2018	7:19:01 AM	4	29	72	105.92	39.43	128.79	7.52	9.49	9.14	0.13	0.12	50.51	1668	18.80	3.29	0.27	31.92
23/10/2018	7:19:05 AM	4	29	72	106.01	38.97	130.96	7.57	10.01	9.63	0.13	0.12	51.49	1668	18.93	3.31	0.27	31.44
23/10/2018	7:19:09 AM	4	29	72	106.1	39.85	133.67	7.46	10.53	10.14	0.13	0.13	50.49	1668	18.65	3.26	0.28	30.44
23/10/2018	7:19:14 AM	5	29	72	106.19	40.6	137.46	7.49	11.18	10.78	0.13	0.13	50.39	1668	18.73	3.27	0.28	30.51
23/10/2018	7:19:18 AM	4	29	72	106.28	41.31	142.04	7.48	11.67	11.27	0.12	0.12	50.00	1668	18.70	3.27	0.27	32.11
23/10/2018	7:19:30 AM	4	29	72	106.55	41.27	152.75	9.21	8.39	13.42	0.17	0.16	50.38	1588	23.03	3.83	0.31	28.14
23/10/2018	7:19:35 AM	5	29	72	106.64	40.93	155.54	9.19	9.24	14.24	0.17	0.16	50.90	1588	22.98	3.82	0.31	27.50
23/10/2018	7:19:39 AM	4	29	71	106.73	41.35	159.25	9.23	9.89	14.87	0.16	0.16	50.78	1588	23.08	3.84	0.30	28.83
23/10/2018	7:19:43 AM	4	29	71	106.82	39.77	163.13	9.22	10.53	15.49	0.16	0.16	50.79	1588	23.05	3.83	0.30	29.26
23/10/2018	7:19:47 AM	4	29	72	106.91	39.93	167.88	9.16	11.19	16.14	0.16	0.16	50.38	1588	22.90	3.81	0.31	27.98
23/10/2018	7:19:52 AM	5	29	71	107	39.47	172.63	9.2	12.03	16.95	0.17	0.16	50.91	1588	23.00	3.83	0.31	27.86
23/10/2018	7:20:04 AM	4	29	71	107.27	39.39	183	8.73	14.14	18.73	0.17	0.16	50.38	1486	21.83	3.40	0.35	24.58

Figure 5. Example of data displayed in a Microsoft Excel worksheet

4. Results and Discussion

4.1. Calibrations

According to ISO/IEC Guide 17025:2017 calibration is a series of activities that form a relationship between the value indicated by a measuring instrument or a measurement system, or a value represented by a measuring material, on known values, which are related to the measured quantity in specific condition [14]. In other words, calibration is an activity to determine the truth of the value of the appointment of measuring instruments and measuring materials by comparing them to traceable standards, both nationally and internationally certified standards. Calibration aims to determine the standard deviation of the measurement or deviation of the truth value indicated by a measuring instrument. This calibration process is carried out before testing or at the preparation stage of the tool. At this stage, the acquired data are calibrated using other comparable test equipment that has been known to be accurate. In this study, calibration was carried out on data measured by a load cell, proximity sensor, and thermocouple.

There are three load cells to be calibrated, namely for measurement of dynamometer load, gas, and solar mass discharge. Calibration is performed by giving a specific load and comparing with the results of the measurement of calibrated digital scales. A digital calibrated tachometer is used to perform engine speed calibration of the proximity sensor, and then the results are compared with the speed data displayed by the MP5W pulse meter. The calibration results are seen in Table 1.

Table 1. The calibration results of load cells and proximity sensor

Scale Calibrator (gr)	Load Cell-1 (gr)	Scale Calibrator (gr)	Load Cell-2 (gr)	Scale Calibrator (gr)	Load Cell-3 (gr)	Speed Calibrator (rpm)	Proximity Sensor (rpm)
29.350	29.320 - 29.390	29.350	29.320 - 29.390	0.500	0.540 - 0.580	1148	1140 - 1152
54.430	54.380 - 54.460	54.430	54.380 - 54.460	1.030	1.010 - 1.050	1790	1780 - 1794
109.010	108.909 - 109.050	109.010	108.909 - 109.050	1.740	1.730 - 1.770	2180	2172 - 2186
149.060	149.020 - 149.090	149.060	149.020 - 149.090	1.740	2.370 - 2.420	2448	2438 - 2452

4.2. Characteristic Test Results of the DAC System
Although the calibration tests show good results, the data acquisition system must have a good performance. This character determines whether the data acquisition system is feasible to use and under what conditions can this data acquisition system be used optimally. The characters tested are measurement uncertainty, hysteresis, and repeatability.

4.2.1. *Uncertainty Test Results.* Since the purpose of manufacturing of the DAC system is to study the dual-fuel engines, the uncertainty tests are carried out on the engine used, both with single fuel mode and in dual fuel mode. To determine the uncertainty, the measurement is conducted several times in the same measurement range. The relative uncertainty value is calculated by comparing the standard deviation value to the average one [11]. Please note that the uncertainty is influenced by the engine operating conditions, namely the position of the Throttle Position Sensor (TPS). The value is influenced by the speed of data retrieval or delay-time too. Therefore, the tests are performed at TPS 33% to 100% with a delay of 1 second to 5 seconds.

It is found that, at various TPS positions, the lowest value of uncertainty is achieved at a delay time of 4 seconds. Therefore, the dual fuel engine tests are conducted at this delay time. From the value of the sensor uncertainty, as shown in Table 2, it can be determined the value of uncertainty for each parameter of the dual fuel engine tests. The parameters are torque, power, BSFC, BTE, and LPG fraction. Table 3 shows the uncertainty values for the engine parameters.

Table 2. Measurement uncertainty of sensors

TPS (%)	Diesel Oil Load Cell (%)	LPG Load Cell (%)	Dyno Load Cell (%)	Proximity Sensor (%)	Radiator Thermocouple (%)	Intake Thermocouple (%)	Exhaust Thermocouple (%)
33	2.990	2.920	0.210	0.600	0.160	0.190	0.150
50	2.680	2.270	0.170	0.500	0.140	0.180	0.150
67	2.540	1.160	0.240	0.460	0.120	0.170	0.130
83	2.280	1.110	0.250	0.370	0.120	0.170	0.120
100	1.750	0.910	0.200	0.190	0.120	0.160	0.120

Table 3. Measurement uncertainty of engine parameters

TPS (%)	Torque (%)	Power (%)	Fuel rate (%)	BSFC (%)	BTE (%)	LPG Fraction (%)
33	0.600	0.621	2.928	2.993	2.993	2.935
50	0.500	0.519	2.276	2.335	2.335	2.283
67	0.460	0.475	1.185	1.276	1.276	1.209
83	0.370	0.389	1.138	1.202	1.202	1.165
100	0.190	0.225	0.932	0.958	0.958	0.953

4.2.2. Hysteresis Test Results.
Hysteresis is a deviation appears at two opposite directions, namely ascending and descending measurements. The test results of the hysteresis of dual fuel mode at TPS 50% are shown in Figure 6. It can be seen that the hysteresis is quite small. For measurement of dynamometer load, it is clear that the two curves coincide, which indicates that no hysteresis in this measurement. Whereas in the hysteresis of fuel consumption (FC) of diesel oil and LPG is very small, only around 0.010 g/s. Thus, it can be concluded that the hysteresis of the DAC system can be ignored.

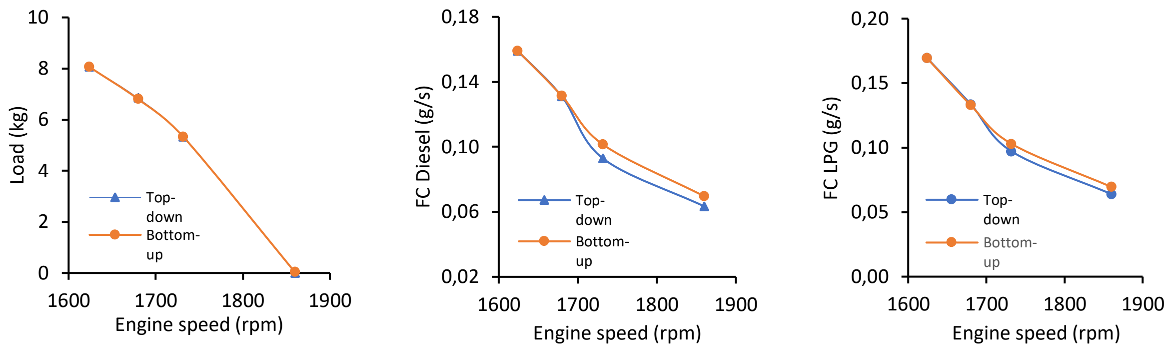

Figure 6. Hysteresis of dynamometer load, diesel oil, and LPG fuel discharge

4.2.3. Repeatability Test Results. Repeatability is the ability of an instrument unit or measurement system to obtain the same data when repeated measurements are made under the same conditions. Repeatability tests are performed on dual-fuel engines at TPS 50%. Figure 7 shows the measurement results, where there was no significant change between the first and second tests. It indicates that the measurement system has good repeatability. It also means that the measurement system has a good level of precision.

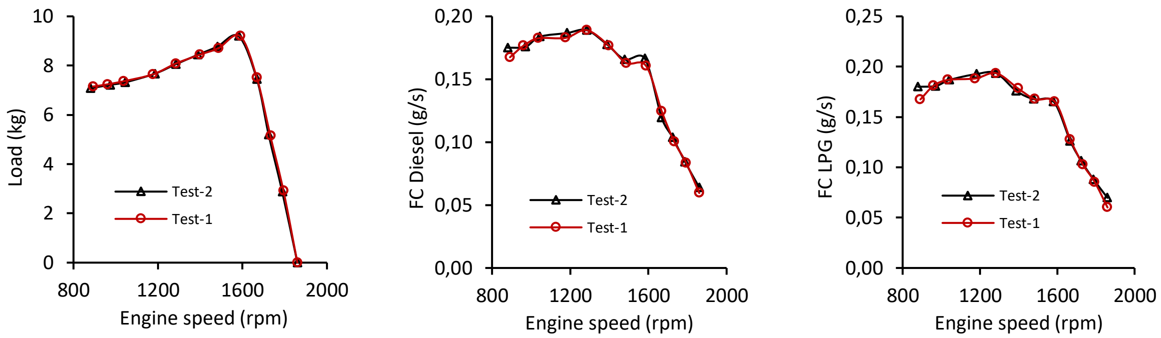

Figure 7. Repeatability of dynamometer load, diesel oil, and LPG discharge

5. Conclusion

In this study, an Arduino-based data acquisition system has been successfully developed, which has low uncertainty, low hysteresis, and excellent repeatability. The DAC system provides optimal measurement results if used with a delay time of 4 seconds, where the measurement uncertainty has the lowest values. The sensor/transducer used in this measurement system consists of three K-type thermocouples (to measure the temperature of the radiators, intakes and exhaust gas), three load cells (to measure dynamometer loads, solar discharge and LPG discharge), a proximity sensor (for measuring engine speed), and a DHT-11 sensor (for measuring temperature and humidity). Programming of data acquisition systems is facilitated by using Arduino IDE software. The display and data recording are performed in Microsoft Excel software, with the help of PLX-DAQ software. So, the DAC system is very suitable to be used in dual fuel engine study, to measure engine speed, fuel discharge, gas fraction, torque, power, BSFC, and BTE.

References

[1] Shinde P A, Joshi K V and Rajgade SC 2014 *Int. J. Electronics, Communication & Instrumentation Engineering Research and Development* (IJECIERD) **4** 163-70.
[2] Viral R and Bahar T 2013 *Proc. 2nd National Conf. on Advances in Heat Transfer and Fluid Dynamic* Aligarh.

IOP Conf. Series: Materials Science and Engineering **598** (2019) 012031 doi:10.1088/1757-899X/598/1/012031

[3] Misiruk I O, Timoshenko O I, Taran V S and Garkusha I E 2016 *2016 2nd Int. Young Scientists Forum on Applied Physics and Engineering* (YSF) Kharkiv 128-31.
[4] Agrawal S, Kumar V, Anand N, Agarwal V K and Islam A 2016 *2016 World Conf. on Futuristic Trends in Research and Innovation for Social Welfare (Startup Conclave)* Coimbatore.
[5] Bhutto J K, Chaudhary B S and Khatri P 2016 *Int. J. on Recent and Innovation Trends in Computing and Communication* 4 537-38.
[6] Measurement Computing Corp 2012 *Data Acquisition Handbook: A Reference for DAQ and Analog & Digital Signal Conditioning 3rd Ed* (Massachusetts: Measurement Computing Corporation).
[7] Fuentes M, Vivar M, Burgos J M, Aguilera J and Vacas J A 2014 *Sol. Energ. Mat. Sol. C.* **130** 529–43.
[8] Vidal-Pardo A and Pindado S 2018 *Sensors* **18** 1-20.
[9] National Instrument 1999 *Data Acquisition (DAQ) Fundamentals Application Note* 007 (Texas: National Instrument Corporation).
[10] Morris A S and Langari R 2012 *Measurement and Instrumentation: Theory and Application* (London: Elsevier).
[11] Meyer V R 2007 *J. Chromatogr. A.* **1158** 15–24.
[12] Kaufman K R, Wavering T, Morrow D, Davis J and Lieber R L 2003 *J. Biomech*. **36** 283-87.
[13] Chou J C and Hsia W L 2009 *International Scholarly and Scientific Research & Innovation* **3** 1116-19.
[14] ISO/IEC 2017 17025: *General Requirements for the Competence of Testing and Calibration Laboratories International Organization for Standardization*.