American Journal of Sensor Technology, 2014, Vol. 2, No. 1, 7-12
Available online at http://pubs.sciepub.com/ajst/2/1/2

DOI:10.12691/ajst-2-1-2

Piston Data Telemetry in Internal Combustion Engines

K. M. Ebrahimi*, A. Lewalski, A. Pezouvanis, B. Mason

School of Engineering, University of Bradford, UK
*Corresponding author: m.ebrahimi@bradford.ac.uk

Received January 01, 2014; Revised January 14, 2014; Accepted January 24, 2014

Abstract Measuring piston crown temperature and pressure during engine development cycle is paramount. This paper presents a new development in short distance telemetry system which includes an on board power generation device. A mechatronic data acquisition system is developed whereby signal conditioning is performed by a module inside the piston and the signal passed to a Bluetooth transmitter module for wireless telemetry to a Bluetooth receiver located in very close proximity, connected to an external host PC. The Data Acquisition Bluetooth module integrates a microcontroller that reads the conditioned sensor signal and performs any other required functionality. The microcontroller firmware includes a server that collates the data and transmits them via Bluetooth to the host PC to display via a client interface. An independent power supply consisting of a rotor incorporating NdFeB magnets and a wire wound stator. As the crankshaft rotates the rotor induces an AC voltage into the stator. A rectifying circuit converts the AC voltage into a regulated DC output voltage that drives the signal conditioning and embedded Bluetooth circuits.

Keywords: *short distance telemetry, Bluetooth, piston, temperature*

Cite This Article: K. M. Ebrahimi, A. Lewalski, A. Pezouvanis, and B. Mason, "Piston Data Telemetry in Internal Combustion Engines." *American Journal of Sensor Technology*, vol. 2, no. 1 (2014): 7-12. doi: 10.12691/ajst-2-1-2.

1. Introduction

Automotive manufacturers endeavour to develop more efficient engines with higher power and reduced emissions due to government legislation and consumer demand. In order to achieve these goals, certain piston parameters such as temperature, forces and pressures need to be monitored, sampled and accurately analyzed [1]. Piston damage occurs mainly due to wear, temperature, thermal and mechanical fatigue, over a wide temperature range at the crown, ring grooves, pin holes and skirt [2] caused by carbon deposits on chamber wall, aluminium sticking in top ring groove and decreased oil thickness between ring and liner, resulting in reduced tensile strength and hardness of piston and increased friction between ring and liner [2]. It is the temperature distribution that affects the piston which in turn affects the overall performance of the engine [3]. The cylinder wall surface temperature had much less influence on the combustion process than the surface temperatures of the piston and the head [4]. This is particularly true at lower engine loads. Analysis of a piston can be performed by software modelling and requires the input of piston temperatures as a basis for simulation [3]. The measurement of piston temperature in a reciprocating engine aims to measure temperature inside the cylinder at the piston head surface, piston ring grooves and pin holes. Piston temperatures are especially challenging to measure because they are constantly in motion and temperature measurement in the inherently harsh operating environments of internal combustion engines has historically been a difficult, time consuming and expensive process [5]. A number of sensors are used to measure the rapid change of high temperatures and uneven distribution of heat at different positions or areas of the piston. Measurement equipment must be protected against several conditions in the engine, with acceleration forces near 2000g [6] occurring at Top Dead Centre (TDC) at rated speed. Type K thermocouples are used to measure a wide range of operating temperatures inside the engine and to allow complete mapping of piston temperature distribution, several measuring locations are required in the piston and data must be obtained under various engine operating conditions. Reported piston temperatures are 275°C on the piston crown surface [4], 382°C in the piston bowl, 225°C at the pin hole, 209°C on the top groove [7] cylinder head, liner, piston 140°C-280°C [8]. The crankcase can reach 200°C [5].

The most common temperature sensors used within pistons are thermocouples, thermistors, and resistance thermometers and many methods have been developed for temperature measurement in running engines. It is the method of transferring the sensor signals to a stationary logging system outside the engine that is a technically demanding task using a variety of techniques [4]. A well tried scheme is the use of slip rings on the crankshaft using two rings for each parameter under consideration, but the voltages developed due to friction of the brushes on the slip rings are often of the same order as those to be measured, giving rise to excessive errors in measurement [9]. The hinged linkage system [10,11,12,13] routes signal wires down the piston connecting rod to the moving big-end bearing cap and supports the wires between the moving big-end cup and a stationary point on the engine crankcase although cyclic bending of the wires leads to wire fatigue and breakage. The contact method [14] is a simple technique for transferring the temperature sensor signals out of the engine. The signal wires are brought to a connector at a convenient position such as the bottom of the piston skirt. When the piston is at bottom dead centre (BDC), this connector makes contact to a connector on the engine crankcase. During the brief contact period, signals are transferred to a logging system outside the engine.

Early non-contact methods employed a VHF radio transmitter to transmit data to a receiver remote from the engine [15] and RF telemetry was further developed by Horler [16]. Other non-contact techniques include Infra Red telemetry where an IR transmitter on the piston skirt transmits the signals to an IR receiver on a stationary point on the engine crankcase [17,18,19]. Electronic circuits condition, multiplex and transmit the signals within the piston. IR telemetry systems require line of sight positioning and are susceptible to lens misting by engine oil. Power for the piston hardware can be provided by an on-board battery or generated by a small power generator that utilizes the motion of the piston [6]. Another non-contact method is an induction coupling technique that transfers signals and power between a moving coil on the piston skirt to a stationary coil on the crankcase when the piston is at bottom dead centre. The strength of the induction between the two coils can be related to the piston temperature. An advantage of this technique is the simplicity of the temperature sensing system carried by the piston, comprising only a thermistor and a resonator coil. However, one thermistor / resonator coil pair is needed for each temperature measuring point on the piston [20]. Another variation on the induction method has NbFeH permanent magnets placed on the counter weight circumscribed on an arc of 130° and passing by a coil bobbin, thus inducing an AC voltage. An electronic circuit power generator rectifies the AC voltage and regulates the DC voltage to drive a microcontroller and Bluetooth wireless transmitter that transmits digital signal data to a Bluetooth receiver at a host PC for logging [21].

The use of wireless transmission methods avoids the necessity of routing cables or positioning components or coils at strategic positions. Some technologies are more suited to long distances, whilst others are short distance, cable replacement technologies. The power consumption and data transfer rate of wireless technologies depend on the required applications. Long distance transmission technologies such as Wifi have high power consumption and implementation costs compared to other technologies.

ZigBee is a low data rate low power technology and spends the majority of time in sleep mode. Bluetooth technology has low power consumption, sufficiently high data transfer rate of 3Mbs (EDR) and can be formed into networks or connected directly as a P2P connection [22].

This Short Distance Telemetry system is a substitute for slip rings and their associated cabling. A slip ring also transfers power, but this cannot be achieved with the SDT system, therefore an independent power supply is required.

Chapter 2 identifies the functionality of Bluetooth and how it transmits data. Chapter 3 describes how the proposed mechatronics system acquires data values. Chapter 4 depicts the construction and electronics of the power generator. Chapter 5 outlines how the individual modules are integrated into a whole. Chapter 6 reports the results of data acquisition. Chapter 7 discusses the mechatronic telemetry system.

2. Data Communication

Bluetooth wireless technology is selected for low power consumption and is designed for cable replacement with short distance transmission and data transfer rate of 3 Mbits. A Bluetooth device comprises of two components, a radio transceiver and a driver (Stack). The Bluetooth radio uses the 2.40GHz – 2.48GHz frequency within the ISM band employing the FHSS (Frequency Hopping Spread Spectrum) transmission method whereby the transmission signal is spread over a wide band of 79 channels, each 1 MHz wide, hopping between frequencies in a psuedo random manner determined by the master device. The default number of hops is 1600 hops per second, giving 625μs per time slot for each frequency. By employing time division duplexing (TDD), data is contained within packets and transmitted in the time slots between master and slave, where the master transmits on the even clock and the slave transmits on the odd clock. Large data packets may be transmitted over 1, 3 or 5 consecutive time slots. Interference from other devices may occur on a transmitted frequency, but will occur for a short time only, and lost data retransmitted. By using adaptive FHSS, if interference on a channel occurs, then that channel is subsequently not used.

The Bluetooth stack is software that implements a Bluetooth device and has two functions: To control the Bluetooth device and communicate with other Bluetooth devices. This is achieved by implementing protocols and profiles (sets of rules) that define duties and responsibilities for how Bluetooth devices behave when communicating and defines how an application uses the Bluetooth stack.

To communicate, a Bluetooth device performs device discovery by transmitting an inquiry message, to which other devices respond. When a connection is made, the most common data transfer methods are: packet transfer (L2CAP); data streaming (RFCOMM), which emulates a serial port; and object exchange (OBEX), which transfers objects between devices. Usually the connection to another device is a master / slave configuration, but other topologies could be Client / Server, Peer to Peer, or networked as a Piconet or Scatternet. Security is not obligatory, but when used it can range from a simple pin number between devices to full data encryption [23].

The Bluetooth Stack can be hardware, firmware, or software written in a native language such as C, C++, assembler, or any other language, and only needs to implement the Bluetooth Specification. There is no requirement for standard interfaces, and this, therefore, leads to proprietary implementations of the stack. Custom applications can be developed by implementing the appropriate API to communicate with the selected stack, if available. The exception is Java, where a standard interface has been developed (Java API for Bluetooth Wireless Technology (JABWT)) [23].

3. Data Acquisition

The proposed method is to implement a mechatronic data acquisition system to eliminate the cabling of contact methods and transfer data via short distance wireless telemetry using Bluetooth. Wireless telemetry does not enable power transfer over the air, and therefore a power generator is employed to drive the electronic circuitry (Figure 1).

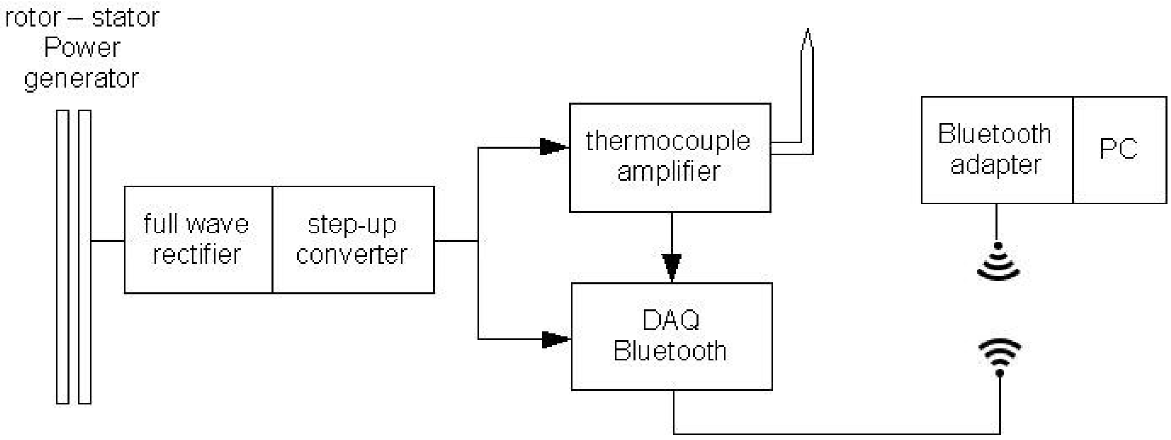

Figure 1. DAQ block diagram

The transducer is a k type thermocouple that produces 41 µV/°C output voltage that requires amplification and application of Cold Junction Compensation (CJC) to compensate for the non linear temperature coefficient of the Seebeck effect. On a PC host, CJC can be applied using lookup tables or polynomials. In the mechatronic system, analogue or digital signal conditioning is performed by a k type thermocouple amplifier device that amplifies the input signal and performs CJC. The Analog Devices AD595C [24] reads temperatures up to 300°C and outputs an analogue signal of 10mV/°C. The Maxim Dallas MAX6675 digitises temperatures up to 1024°C. The temperature has 12 bit resolution (0.25°C per bit) embedded in 16 bit read-only frame via a SPI interface [25].

The DAQ Bluetooth module integrates a Microchip PIC18LF6722 microprocessor and has the input and output pins required by data acquisition devices, namely, AIO, DIO, ADC and PWM. Also multiple serial data transfer methods are available, namely, SPI, I2C and UART. The firmware is written in C or assembler and includes Bluetooth services and a client interface server [26]. The Bluetooth transceiver is a CSR BlueCore 4.0 Class 1 Bluetooth radio incorporating the Bluegiga iWRAP interface to the Bluetooth stack. The maximum over the air radio transmission frequency of the radio is 50Kbs [27]. On the PC host, the Bluetooth receiver is an Ezurio USB Bluetooth adapter incorporating the Bluegiga stack [28]. The PC host displays a Flexipanel client interface that is updated with data values transmitted by the DAQ Bluetooth module. A client interface can also be designed for PDA's or other mobile devices [29]. The firmware can also include a simple html page that can be transmitted to the host and made available via the web.

4. Power Generator

The present system components require a 5V regulated supply. The power circuit transforms the induced AC voltage from the rotor – stator generator into 5.0V DC, which is supplied to the thermocouple amplifier and DAQ circuits. The conversion to DC is performed by a full wave bridge rectifier and 5v step-up voltage regulator.

The telemetry components require a power source and this is provided by an induction power generator. The power generator consists of a rotor incorporating 12 permanent magnets (NdFeB) located circumferentially around a disc and a stator with 12 coils located circumferentially around a disc. (Figure 2). The magnets increase in axial flux density with increase in length, but a compromise is made, due to space limitations, to use 10 mm diameter x 4 mm length magnets. The coils are positioned in a planar configuration, again due to space limitations, against the disc face with 5 mm centre diameter and 18 turns of 26 gauge enamelled copper wire and each coil is wound in the opposite direction to the previous.

As the rotor rotates, the flux cuts the coil inducing an AC voltage. A bridge rectifier circuit performs full wave AC – DC rectification and ripple smoothing, and a step-up converter circuit provides a 5V regulated voltage output.

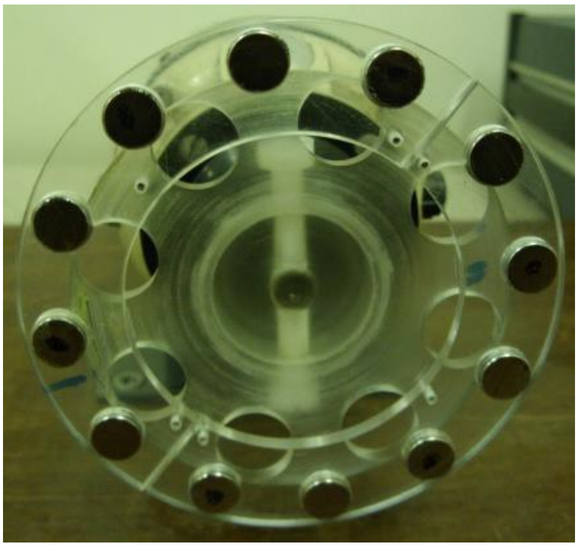

Figure 2. Power generator rotor test rig

5. Overall System

The A common method for installing thermocouple probes involves the drilling of holes to just below the piston crown surface. It has been calculated [4] that 1mm beneath the piston crown has a temperature drop of 2°C [30], so a temperature drop through 0.5mm can be estimated at less than 1°C.

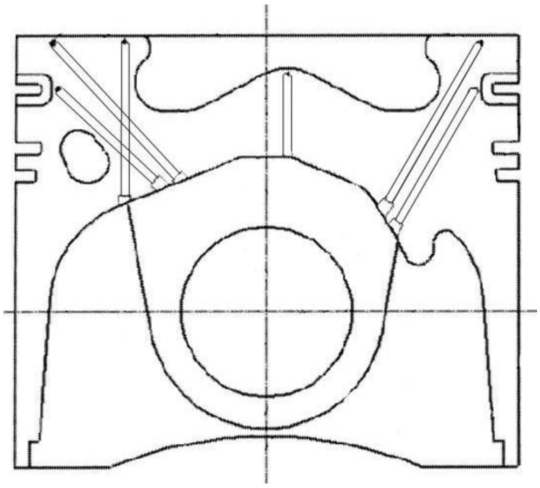

Figure 3. Instrumented Piston with Bluetooth

A piston has one or more holes drilled at desired angles to within 0.5mm of the piston crown surface (Figure 3). This hole is of sufficient diameter to accommodate the k type thermocouple probe. The thermocouple leads are taken to a signal conditioning IC. This is an AD595C thermocouple amplifier that reads the µV output of the thermocouple, applies amplification and cold junction compensation and outputs an analogue signal of 10mV /°C at temperatures up to 300°C. A DAQ Bluetooth module accepts the analogue temperature signal at an ADC input pin where it is converted to a digital value and passed to the Bluetooth radio for transmission.

The induced voltage from the power generator can be varied by amending the magnet size, coil size/turns, rotational speed or combination of. The size of magnets, coils and air gap were calculated to generate 5V at 6000 rpm, the maximum engine speed required. The generator produces 0.7V at below 1000 rpm, where 0.7V is the minimum activation voltage of the step-up converter, providing 5V for the electronics in a 1000 rpm to 6000 rpm speed range. The power generator rotor is fastened to the crankshaft and the stator is attached to the piston big end so that it is static (Figure 4), with respect to the rotor, as the crankshaft rotates (Figure 5).

Figure 4. Coil ring and magnet disc a) individually b) adjacent. Telemetry electronics positioned on big end

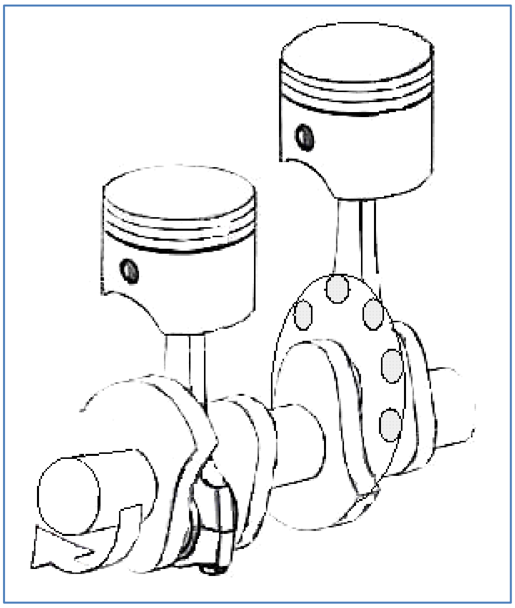

Figure 5. Power Generator attached to crankshaft

The PIC microcontroller is controlled by firmware that is developed with the Microchip MPLAB IDE and C18 compiler [31], as MPLAB is configured not to overwrite the Bluetooth services and client interface server on the DAQ Bluetooth module. The client interface is developed with the Flexipanel Designer module. Firmware can be uploaded to the PIC microcontroller by Wireless Field Programming via Bluetooth or with a TEAclipper programming clip [32]. The firmware reads the input data, performs any signal processing required and then updates specified client interface control values. These control values are then passed to the Bluetooth radio for transmission to the PC host, where they are displayed on the client interface.

6. Results

In traditional temperature data acquisition, temperature data is processed to convert temperature to voltage values and allow transmission to a host. At the host the data is then processed to convert voltage values back to temperature values and then further processed by applying cold junction compensation. In this mechatronic system, all signal processing is performed at the piston end of the signal path, and therefore, the host is required only to display data. The firmware sends control values to the client where the data is displayed as a graph plot or as a column of data values. There is also an option to save the data values to an excel file (Figure 6).

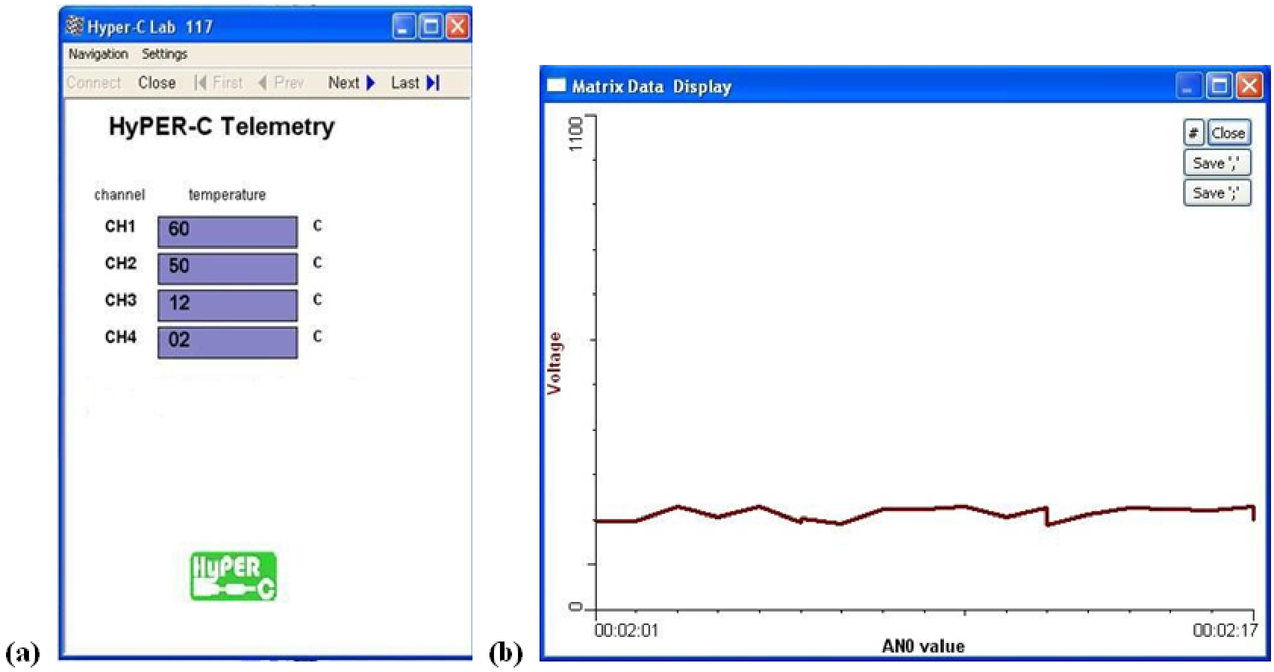

Figure 6. Client Interface (a) analogue DAQ (b) data plot

7. Conclusions

A telemetry system using an embedded Bluetooth module has been presented to measure temperatures within a piston. A short distance telemetry piston temperature system has been designed using a data acquisition Bluetooth telemetry module**,** composed of piston parts and data acquisition parts.

The DAQ circuit is installed in the piston allowing the telemetry system to measure signals captured by the sensor and the signal conditioning circuit. Due to the operating temperature limitations of the electronic components and the temperature of the telemetry system location may rise up to 150°C, the modules are encapsulated at a lower temperature by using thermo insulation.

If the telemetry system proposed in this paper is applied to a commercial engine, it is expected that efficiency in piston temperature measurement will increase. In addition, it is expected to facilitate the accuracy of thermal analysis through the measurement of multipiston temperature.

References

[1] Yamada Y., Emi M., Ishii H., Suzuki Y., Kimura S., Enomoto Y., "Heat loss to the combustion chamber wall deposit in D.I. diesel engine: variation of instantaneous heat flux on the piston surface with deposit", 2002.

[2] A. Torregrosa, P. Olmeda, B. Degraeuwe, M. Reyes, **"**A concise wall temperature model for DI Diesel engines", 2005.

[3] Papadopoulos P., "Piston temperature Measurement", MSc Dissertation, University of Bradford, 2006.

[4] N Ladommatos, Z Xiao, and H Zhao, 2004 "The effect of piston bowl temperature on diesel exhaust emissions".

[5] Kajiwara H., Fujioka Y., Susuki T., Negishi H., "An analytical approach for prediction of temperature distribution in diesel engines", 2002.

[6] Burrahm, R. W., Davis, J. K., Perry, W. D., and Santos, A. D.-L., "Development of a piston temperature telemetry system", SAE paper 920232, 1992.

[7] F.S. Silva, "Fatigue on engine pistons – A compendium of case studies ", 2004.

[8] V. Esfahanian, A. Javaheri, M. Ghaffarpour, "Thermal analysis of an SI engine piston using different combustion boundary condition treatments", 2005.

[9] Piston Technology, Hepworth & Grandage Ltd., 1969.

[10] Miyamoto, N., Ogawa, H., Iemura, A., and Reksowardojo, I. K., "Cycle-to-cycle transient characteristics of exhaust gas emissions from diesel engine with different increasing and decreasing load patterns", SAE paper 970750, 1997.

[11] Jeon, Y. J., Kim, S. I., Park, S. I., Kim, J. S., Choi, K. H., and Jin, J. H., "Thermal load in a heavy duty diesel engine with EUI system", SAE paper 2002-01-0492, 2002.

[12] Assanis, D. N. and Syrimis, M., "Piston heat transfer measurements under varying knock intensity in a spark ignition engine", SAE paper 971667, 1997.

[13] Assanis, D. N. and Friedmann, F., "A telemetry linkage system for piston temperature measurements in a diesel engine", SAE paper 910299, 1991.

[14] Takamatsu, H. and Kanazawa, T. "Piston temperature measurement method for high- speed gasoline engines", *Soc. Autom. Engrs Japan, JSAE Rev*., 1999, 20(2), 259-279.

[15] Lightfowlers P., Piston Telemetry System (1962), Piston Technology, Hepworth & Grandage Ltd., 1969.

[16] Horler G.D., Picken D.J., "A Digital Electronic Solution to Piston telemetry", SAE paper 2000-01-2032, 2000.

[17] Russ, S., Kaiser, E. W., and Siegl, W. O., "Effect of cylinder head and engine block temperature on HC emissions from a single cylinder spark ignition engine", SAE paper 952536, 1995.

[18] Upris, M. C., Jason, R. R., and Anderson, C. L., "Comparison of time-averaged piston temperatures and surface heat flux between a direct-fuel injected and carburetted two-stroke engine", SAE paper 980763, 1998.

[19] Wiczynski, P. D., Varo, R. G., Archuleta, S. A., Galarno, M. J., "New piston telemetry applied to spherical joint piston development", SAE paper 960056, 1996.

[20] Kato, N., Moritsugu, M., Shimura, T., and Matsui, J., "Development of a piston temperature measuring technology using electromagnetic induction", SAE paper 2001-01-2027, 2001.
[21] Lee H-W, C-HO, Kauh S K, and Ha K-P, "Development of a multipiston temperature telemetry system using Bluetooth networks", 2600.
[22] www.bluetooth.com.
[23] Kumar C.B., Kline P.J., Thompson T.J., "Bluetooth Application Programming with the Java APIs", Morgan Kaufmann, 2004.
[24] AD595A datasheet, www.analog.com.
[25] MAX6675 datasheet, http://datasheets.maxim-ic.com.
[26] Toothpick 2.1 manual, www.flexipanel.co.uk.
[27] Linkmatik datasheet, www.flexipanel.co.uk.
[28] Ezurio Bluetooth adapter datasheet, http://www.lairdtech.com/Products/Wireless-M2M-and-Telematics-Solutions /Bluetooth-Module/.
[29] flexipanel designer manual, www.flexipanel.co.uk.
[30] Ogawa, H., Kimura, S., Koike, M., and Enomoto, Y., "A study of heat rejection and combustion characteristics of a low-temperature and pre-mixed combustion concept based on measurement of instantaneous heat flux in a direct-injection diesel engine", SAE paper 2000-01-2792, 2000.
[31] www.microchip.com
[32] www.flexipanel.co.uk