A comparative study based on control system for a pulse detonation engine

Vibhanshu Dev GAUR*,[1], Mayur PATHAK[1], Tejinder Kumar JINDAL[1]

*Corresponding author
[1]Department of Aerospace Engineering,
Punjab Engineering College (Deemed to be University),
Sector 12, Chandigarh, 160012, India,
vibhanshudevgaur.mt22aero@pec.edu.in*

DOI: 10.13111/2066-8201.2024.16.2.6

Received: 09 May 2024/ Accepted: 21 May 2024/ Published: June 2024
Copyright © 2024. Published by INCAS. This is an "open access" article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Abstract: *Pulse Detonation Engine has been a point of interest in the propulsion industry for some time and the interest has been rising due to its better output and results. But any system can perform its task efficiently based on the efficiency of its control system. In this paper we have presented a comparative study between multiple control systems- one based on Bluetooth technology, the other based on infrared sensor technology and one based on wired electrical system. For the wireless system, the signal received from either of the media is passed to the various sensors and systems connected through an Arduino board that further controls the solenoid valves and ignition system. Primarily, a control system circuit is developed using Arduino board and different sensors to connect the fuel supply and ignition system. In the next stage, Bluetooth sensors are connected using an android app and then an infrared sensor based system is integrated with the Arduino to control the engine and the performance of the two systems are compared. Whereas for wired system, every sub system is controlled through optical wires including the solenoid valves, the injection system and the sensors.*

Key Words: *Pulse Detonation Engine (PDE), ignition system, Arduino, control board, Bluetooth, infrared*

1. INTRODUCTION

The energy industry has been actively pursuing the scope of alternatives to the existing ones. Along with that, the interest in using a pulse detonation engine as a new propulsion system in being explored. This paper presents a comparative study of control systems for efficient working of the entire system involving both propulsion and energy sectors. We have used the concept of pulse detonation engine and the propulsive output obtained is used in generating power. The control board is responsible for controlling the solenoid valves and fuel injectors, spark plug fuel flow rate and the operation commands. Thus the control system allows for different mechanisms to provide input commands.

With changing time and busy schedule, the need for distant controls and automation is also increasing to ease the life of the user. Wireless technology is present everywhere around us and can be easily modified based on our requirement [1]. These wireless technologies can be combined with a neural network and applied to the control and functioning of an engine using an on-board model working on a neural network propulsion system matrix. Also an improved model is proposed to improve the engine's propulsion performance using linear and physical based models [2], [3]. With rise in wireless technologies and ease of developing an android app, any control system could be designed and controlled with a smartphone from a distance [4]. Using sensors as machines to receive input signals from the user wirelessly can be done using a Bluetooth, Wi-Fi or an Infrared sensors and controlled via a smartphone or a designated remote. Similarly this technology can be used to gather the output data from the system and analysed using software. One of the applications using the Bluetooth module is the automation of home devices and controlling via an android application [5], [6], [7]. One of the applications that uses infrared module is the traffic management system [8], [9]. Thus a wireless system could be used as a substitute for existing control systems as well as to develop new control systems to solve different problems. A wireless system when compared with a wired system proves to be better in some instances but also lacks in some aspects. Various studies have been done comparing the stability of a network in a multi-scale control system. It was observed that the wireless network added complexity compared to a wired-only setup, but the control system was robust and controllable. The average steady-state error with the wireless control system grew by 20% – 30%. Similarly, at the industrial level, low- cost sensors are unable to use standard communication protocols and thus a separate communication protocol is developed that can be used by multiple coexisting sensors and a synchronised network is established between different sensor networks [11], [12], [13], [14].

2. DESIGN AND DEVELOPMENT OF PDE SYSTEM

The Pulse Detonation Engine setup has been designed and fabricated in the institute based on the various parametric studies and observations. The system uses a PDE tubes made up of SS 304 grade material which provide a thrust output in the desired direction. The tube consists of a Shchelkin spiral designed to provide optimum turbulence to the flow in the tube. The central part of the system and this paper is the control system.

The control system is divided into two sub-systems. The first sub-system consists of solenoid valves set up just before the combustion chamber so as to maintain the amount of fuel supplied and the duration for which it is supplied. The next component is the fuel injectors and the spark plug, which provides atomised fuel into the chamber along with the required ignition energy. The second sub-system is the electrical circuit consisting of different sensors connected with the rest of the components using an Arduino board. The 5 V DC Supply is used to supply power to V_{in} of the Arduino, and the ground of the supply is connected to the other 12V DC Supply. The input command to the board is provided via Bluetooth or Infrared or Wi-Fi sensors. The Arduino controls the solenoid and spark plug as per the commands. The next section discusses the alternatives for providing input commands.

The entire control system was programmed using the open source IDE or the Integrated Development Environment developed and provided by Arduino Company. This IDE provides a user friendly environment to write a code for the functioning and uploading it to the electronic physical board.

The open source software is available for all operating systems including Windows, Linux and Mac OS and thus can be used to program all types of Arduino boards including UNO R3, Mega and Nano. To program a board, the IDE can be downloaded online and directly be used to write a code as per requirement based on the coding syntax already provided in the software and can be uploaded to manage different sensors. For our experiment, we have preferred the Arduino UNO R3 model.

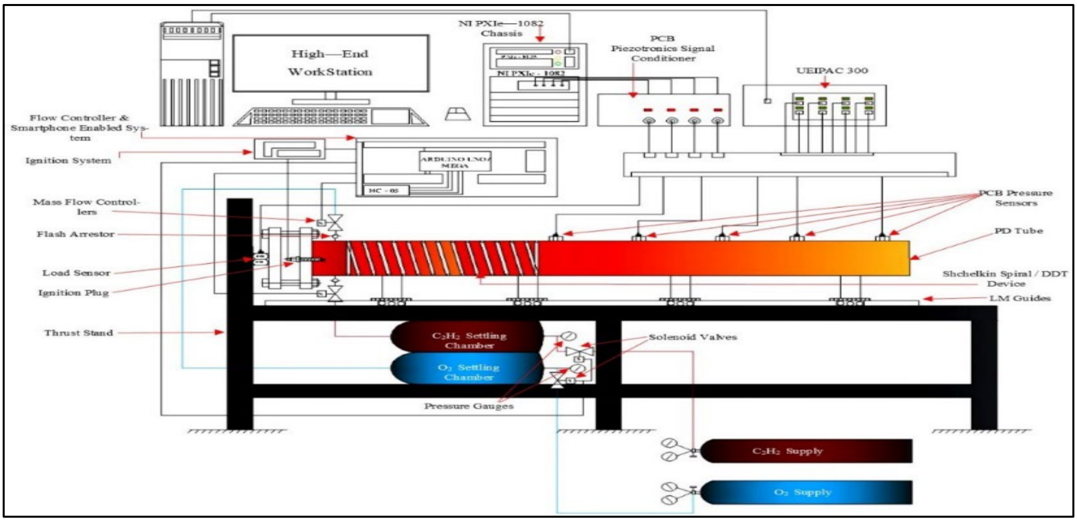

Figure 1. PDE model of PEC

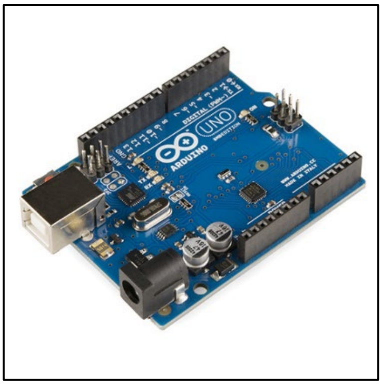

Figure 2. Arduino UNO board (Source: Wikipedia)

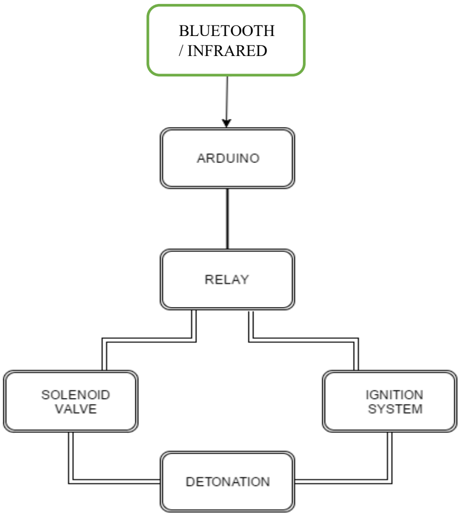

Figure 3. Block diagram of the system

3. INFRARED SENSOR BASED CONTROL SYSTEM

"Infrared" is a type of electromagnetic radiation on the EM spectrum which is used to transfer data safely and securely from a closely placed source to a receiver. Infrared light has been in use for a long time in different applications ranging from thermal imaging to telescopic analysis to controlling small devices like a television using a remote. Based on the same principle, we have used an infrared remote control connected to an infrared receiver module working at a frequency of 38 KHz, connected to the Arduino board.

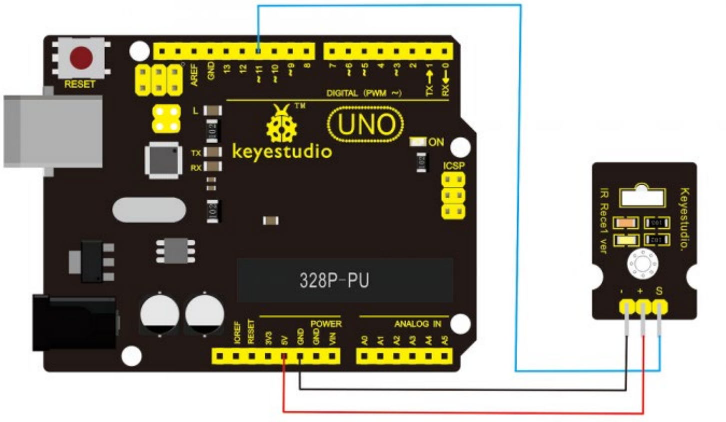

Figure 4. Connection between Arduino and Infrared module

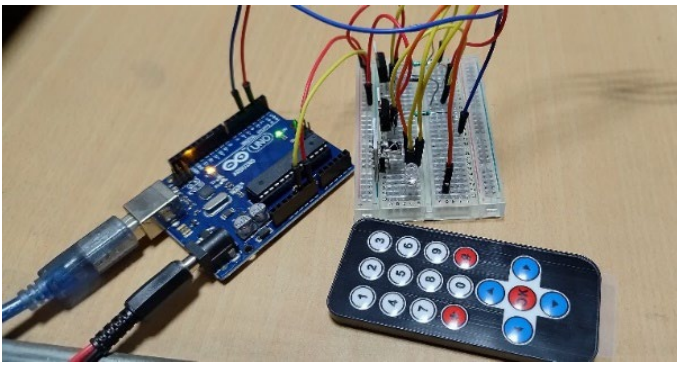

Figure 5. Control Board with Arduino connections

4. BLUETOOTH BASED CONTROL SYSTEM

For the next section, a Bluetooth based system has been designed using Arduino platform to control the ignition and various sensors of Pulse Detonation Engine via the use of an Android Mobile application [10]. The Arduino UNO R3 board and Open-Source IDE platform is used to do experimental as well as Real-time control. The app named "PDE-PEC" controls the fuel flow through timed valves and ignition system supported by Arduino Uno board. The app communicates with Arduino board through Bluetooth receiver. The app has been developed in PEC with the help of an open source tool. The buttons of the programmable app are used for respective function as mentioned below.

The android application has different control tabs, for example, the Connect tab to connect the Arduino System to the Android application, Launch tab to launch the Pulse Detonation Engine, Fill oxygen/acetylene to fill oxygen and fuel, respectively, into the settling chamber, Oxygen/Acetylene (on & off) to switch on and off the oxygen/acetylene supply to the respective settling chamber and finally, the tabs to control the number of shots at a time controlled by 10/20 tabs.

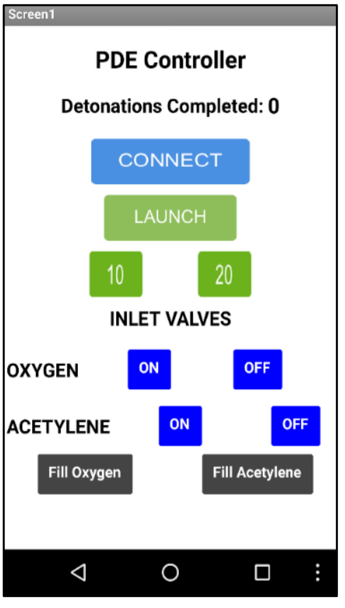

Figure 6. Mobile Application developed to control engine using Bluetooth module

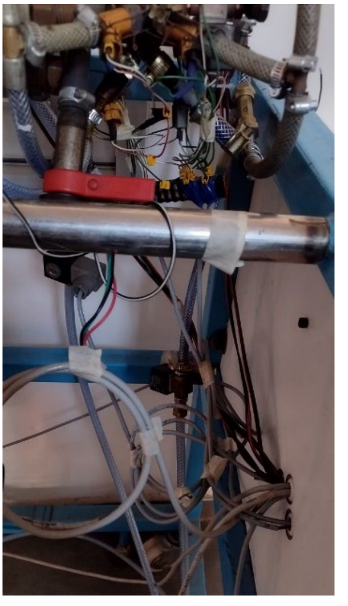

Figure 7. Wiring for a control system

5. WIRE BASED CONTROL SYSTEM CIRCUIT

The next control system is based on connections using electric wires and optical cables. The wired connections have been the primary preference in electronics and electrical circuits due to their immunity to interference, speed, reliability and security. Since the wired system sustain higher voltage and currents, a new separate control system is designed to fulfil the tasks. Similarly to replace the Arduino board, a new control tool is used using LabView software. The input commands to control the solenoid valves and ignition system along with the controls to fill the settling chambers are provided using the LabView software.

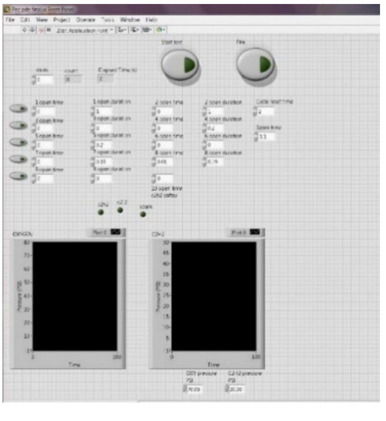

Figure 8. LabView System Layout

Figure 9. LabView System and Control tabs

6. COMPARATIVE ANALYSIS AND DISCUSSIONS

This section provides a comparison among the above discussed control systems based on different parameters:

Parameter	Infrared Based	Bluetooth Based	Wi-Fi Based	Wired system
Ease of use	Initial setup is moderately difficult but once system is designed control is easier			Wire entanglement and wear with use
Security and Interference	Works only in line of sight	Multiple device connectivity possible and thus higher interference		No interference and highest safety
Range	8 meters	100 meters	Worldwide	No limit
Input Power	Battery powered (DC)	Battery powered (DC)	AC or DC	AC input
Feasibility	Possible	Possible	Possible	Possible
Cost Effectiveness	One-time initial cost but comparatively lower			Comparatively higher initial cost
Reliability and Stability	Reliable system but there exist possibility of disturbance and loss of control	Suffers a possibility of disconnection during use hence operation becomes unstable	Highly reliable and provides most stable connection from long distances	Most stable and reliable connection until any physical damage to the system

Hence it was observed that both wired and wireless connections have high initial investment but comparatively, wired connections are more expensive. On one hand, the wired connection is secure, stable, consistent and reliable but at the same time requires higher control hardware which increases the cost along with the chances of wear and tear and difficulty with entanglement of wiring. On the other hand, wireless connections are gaining interest due to their easy operation, low cost, ease of use and availability but the level of reliability and safety reduces.

Thus, the selection of a perfect control system is a matter of requirement. For an application requiring higher safety and reliability of operation, wired control system would be preferred. But for a simple low-cost operation which does not have the risk of security, a wireless system must be preferred without any range of operation disadvantage. Also, the choice between a Bluetooth based device and an infrared based device will depend on the further requirement. For example, a Bluetooth module has a range of about 100 meters and can be connected to multiple devices simultaneously but an infrared module has a range of just 8 meters with an operation capability in line of sight but can be connected to one control device at a time which increases the safe control of the system. But for a Wi-Fi enabled system, the operation becomes most efficient as it can be operated from anywhere remotely, thus improving ease of operation and cost-effectiveness.

REFERENCES

[1] Shinde, S. Kanade, N. Jugale, A. Gurav, R. A. Vatti, M. M. Patwardhan, Smart Home Automation System using IR, *Bluetooth, GSM and Android,* 2017 Fourth International Conference on Image Information Processing (ICIIP).

[2] Q. Zheng, D. Xiang, C. Chen and H. Zhang, Research on aero-engine performance seeking control based on the NN-PSM on-board model, *Proc IMechE Part G: Journal of Aerospace Engineering 2022*, Vol. **236**(16) 3505–3517.

[3] Q. Zheng, Y. Wang, F. Sun, J. Fang, H. Zhang and Z. Hu, Research on aero-engine steady model based on an improved compact propulsion system model, *Proc IMechE Part I: J Systems and Control Engineering 2020*, Vol. **234**(6) 726–733

[4] D. Sullivan, W. Chen and A. Pandya, Design of Remote Control of Home Appliances via Bluetooth and Android Smart Phones*, 2017 IEEE International Conference on Consumer Electronics - Taiwan (ICCE-TW)*.

[5] Y. Rahayu and M. I. Hidayat, Bluetooth Based Home Control and Real-Time Energy Consumption Monitoring System through Smartphone, *International Journal of Electrical, Energy and Power System Engineering (IJEEPSE*), Vol. **2**, No. 3, pp. 5-9, October 2019.

[6] T. Vidas, C. Zhang and N. Christin, Toward a general collection methodology for Android devices, *Elsevier: digital investigaton* **8**, 2011, S14 - S24.

[7] T. K. Sai Manikanta Chari and S. T. Tutika, Density Based Traffic Control Signaling Using IR sensors, *International Journal of Engineering and Information Systems*, Vol. **3**, Issue 3, March – 2019, Pages: 51-56.

[8] D. Patel and Y. Rohilla, Infrared Sensor based Self–Adaptive Traffic Signal System using Arduino Board, *12th International Conference on Computational Intelligence and Communication Networks*.

[9] * * * *IR module Control*, https://vayuyaan.com/blog/ir-sensor-module-infrared-sensor-complete-guide/

[10] * * * *Android developer guide*, https://developer.android.com/codelabs/basic-android-kotlin-compose-first-app#0

[11] Mohd. Tabbara, D. Neˇsic´ and A. R. Teel*,* Stability of Wireless and Wireline Networked Control Systems, *IEEE TRANSACTIONS ON AUTOMATIC CONTROL*, VOL. **52**, NO. 9, SEPTEMBER 2007.

[12] J. Dong and W. J. Kim, Experimental Analysis and Implementation of a Multiscale Wireless/Wired Networked Control System, *International Journal of Control, Automation, and Systems* (2014) **12**(1):102-110

[13] A. Flammini, P. Ferrari, D. Marioli, E. Sisinni and A. Taroni, Wired and wireless sensor networks for industrial applications, Elsevier: *Microelectronics Journal* **40** (2009) 1322–1336.

[14] V. P. Patil, U. Gohatre, S. Matey, R. Jadhav, A. Kantekar, DESIGN AND DEVELOPMENT OF BLUETOOTH CONTROL CAR BASED ON ARDUINO UNO, *International Research Journal of Modernization in Engineering Technology and Science*, Volume: **04**/ Issue:08/ August-2022