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MODESTUM

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A polynomial regression model based educational software tool to interpret the internal combustion engine characteristics

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ABSTRACT

Technical education requires regular upgrades in pedagogical methodologies to keep up student's skill on par with ever demanding job market. This paves the way for creating newer e-learning concepts for classroom to replace or supplement established teaching protocols. In line with this motive, this study deals with the development of an educational software tool to understand the traits of an internal combustion engine. The core of this software tool consists of polynomial regression equations, which in turn was arrived from statistical models using real world experimental data. A MATLAB-based GUI allows the operator to effortlessly interact with the software tool. Upon installation, the software requires the user to define input variables for it to automatically compute data and represent the output data in both visual and tabulated form. The advantage of three-dimensional surface plots for visual representation allows for understating the interactive effect of multiple input parameters on any given output parameter. Overall, average relative error for the model is less than 6%, thus exhibiting a good statistical fit.

Keywords: engine, modelling, parameter estimation, e-learning, polynomial regression

INTRODUCTION

Indian Technical Education

The considerable growth of industries in India over the past few decades has increased the demand for engineers and quality technical education. Nevertheless, the employer's discontent with the skills and technical knowledge possessed by the engineering graduates has not gone unnoticed. It has affected students employability in the technical domain (Gokuladas, 2010). There are numerous engineering institutions in India. However, the quality of education provided at many institutions and the methodology adopted in training the students can be improved in order to meet industry requirements and deliver employable graduates. Hence, it is essential to take steps in order to improve the quality of technical education (Sharma, 2014). As per previous studies, India has been recognized as the third largest in terms of education. However, with regard to quality and provision of equal access to technical education, there is still scope for improvement (Tulsi & Pooni, 2015). There are numerous challenges faced by the institutions providing technical knowledge, one of them being the under-utilized spending patterns on higher education. There has been a rise in the number of educational reforms as well, especially after the independence. The country is known for experimenting with the educational system according to the advances in technologies and progress in research (Toshniwal & Yammiyavar, 2013). These established reforms aim at enhancing the quality of education provided to the people in order to increase the technical proficiency. This would help bring about socio-economic developments (Venkatram, 2016).

Methods to improve the quality of technical education that has been followed for more than 40 years has not been easy considering the hurdles in adapting to the upgraded learning methods. One example of such an arrangement was the quality-enabled model to assess the quality of technical education in Indian institutions, where comparisons were made using education quality index scores (Gambhir et al.,

Nomenclatures are listed in **Table A1** in **Appendix A**.

2016). There are many factors affecting these reforms and methods. Bridging the gap between the education and skills provided to the students and what is expected of them by their employers plays a pivotal role in improving the quality of technical education. An assessment based on the nature of tertiary education, occupation, and classifications in accordance with high technology and knowledge-intensive industries has proved useful (Unni, 2016). Another factor that affects the quality of technical education provided to the students is the lack of proficient teachers in institutions of higher education. With the inadequacy of competent and user friendly tools to explain a concept using application-based examples, clarify doubts and assess the progress of the students, it is difficult to ensure a long-term advancement in the quality of technical education (Sharma & Pandher, 2018).

Apart from the methods stated above, the Government of India with assistance from the World Bank used TEQIP to bring about several changes in the education provided to the female population and weaker sections of society over the past decades. Hence, the need for breakthrough in the quality of technical education provided by other institutions remains a work in progress (Dubey et al., 2019). Field surveys from student quality assurance surveys are paving ways to further improvement (Choudhury, 2019).

Teaching Methods

Everyone is familiar with the traditional teaching methods unlike contemporary methods. However, with the rise in innovative ideas and creative methods of learning, there has been a decline in interest in traditional teaching methods. Students use electronic devices, access the web to clarify their doubts, understand a complicated topic, or even attend daily lectures. Visualization and interactive learning methods like gamification, videos and real-life applications to explain topics or to show the working of a machine or a system are steadily gaining popularity among many others (Tretinjak et al., 2014).

Traditional teaching strengthened theoretical knowledge but infusing them with these methods could make knowledge intake enjoyable and more accessible. When a teacher explains a concept in traditional and modern teaching methods, he shows his knowledge. Clarifying doubts creatively shows the efforts of the teachers to keep the lecture interesting (Pâmîntaş, 2015). With appropriate training and motivation, teachers will have the inclination to adapt to the modern teaching methods with ease. The same goes for the technical education provided (Rüütmann & Kipper, 2012).

E-Learning

The process of learning and acquiring knowledge is complex. Numerous platforms are available to the students to make learning more effortless and inspiring. In the field of engineering, students are expected to be socio-culturally competent (Ekaterina et al., 2015). For example, in the field of engineering, computer-aided tools are being taught to make the process of understanding the subject easier (Fowler et al., 2001). Passive knowledge intake is relatively common among students in primary school as well as higher levels of education. Conceptualizing the theories learnt in classes can be tricky if the lessons are not interactive and do not push students to visualize what they are learning. Hence, by using various approaches such as Piagetian, the classroom teachings are being transformed from simple theoretical knowledge to application-based constructive knowledge (Gurses et al., 2015).

Concept-based learning can be made possible through various software available to the students. However, not every student might have access to such resources. Using an e-learning platform will ensure that students from all over the globe get equal access to educational resources. Adopting e-learning without proper research and assessment of the student's requirements may not be helpful in bringing out effective technical and primary school education quality changes. Overall, it is considered to be a complicated process but not impossible. Research to ensure the validation of the frameworks of e-learning is essential before investing (Inglis, 2008). Several factors determine whether e-learning best suits the various courses, the level of technical education the student is at, and how well the student can adapt to make the learning process less complicated (Islam et al., 2015). Factors like reluctance to adapt to innovative teaching methods, lack of extensive teacher training program, student competency, the content and design of the software, ease of access and support etc., hinder the promotion of e-learning (Selim, 2007).

For students, e-learning requires self-discipline to complete the courses within the stipulated time. Issues like reluctance to download the learning materials and take assessment tests affect the learning process (Farid et al., 2014). They would need prior training in ICT skills to get used to the e-learning environment (Navimipour & Zareie, 2015). Other factors like network bandwidth issues, lack of physical interaction and computer resources should also be improved (Wong, 2007). Therefore, e-learning is challenging for both the students and teachers. Bringing changes to traditional classroom teaching can prove difficult. There are instances, where teachers may not be as welcoming to such drastic changes as the younger generation. Though e-learning may significantly reduce the mental stress of the teachers, it is still their role to make the best use of the available resources for the students to get benefitted. Proper communication and training provided to the teachers before implementation can be helpful for the development of critical thinking and interactive learning (Laborda et al., 2014). Apart from teacher training programs, tools like sentiment analysis can help teachers understand the classroom's mood during lessons. Detecting the students' moods would assist teachers in understanding the student's requirements for the class to be more interesting, the lessons to be more understandable, and worth the time and effort (Clarizia et al., 2018).

The implementation of e-learning depends on how comfortable the students are adapting to the changes in the learning methods. Interactive e-learning tools indeed provide a better understanding approach to the subject. Nevertheless, in many cases, the students may not be confident in shifting from traditional classroom teaching. Their receptiveness, interaction with other students and teachers, and level of understanding a subject without being present in a classroom depends on the steps taken to increase their satisfaction (Sun et al., 2006). Surveys that focus on the learner's and instructor's familiarity to the platform, computer efficacy, portal interface, content quality, and support provided are essential to adjust (Mahwish & Farooq, 2009). Inputs from students and teachers are as important as the ones from the developers of interactive e-learning platforms (Abdellatief et al., 2011).

Implementing e-learning in developed countries is considered more effortless than in developing countries. A careful introspection of the aforementioned perspectives would help better understand how fast and successfully e-learning can be made accessible to students all over the globe (Ozkan & Koseler, 2009). Surveys conducted abroad have mentioned that all the dimensions of the proposed methods of e-learning are essential to determine their effectiveness (Bhuasiri et al., 2012). In many cases, it is difficult for students to understand subjects taught in their native languages. In such cases, e-learning would help them better understand and grasp a concept in a fluent language (Yanuschik et al., 2015). Indeed, executing e-learning will involve huge investments. Methods such as the Kirkpatrick model adopted by prior research studies ensure the cost-effectiveness of e-learning while maintaining its quality. Such models focus on the course content, communication, collaboration and required legislative changes to secure the rights and to avoid malpractices among participants, the teacher workload, and overall changes in the institution's atmosphere (Misut & Pribilova, 2015).

Since the investments are high, improving the e-learning environment quality is vital in ensuring that the students receive the best in terms of technical education. Focusing on factors like functionality, reliability, usability, efficiency, maintainability, and portability, the quality of e-learning can be assessed in a productive manner (Grigoraş et al., 2014). In developing countries this can be ensured based on the frameworks provided through previous research. Not only do they ensure quality enhancement but also quality assurance. Such frameworks raise awareness among students and teachers and broaden their expectations from such platforms while throwing light on the strengths and weaknesses of e-learning both at the macro and micro levels (Masoumi & Lindström, 2012). Though most subjects are application-based, close attention is paid to theoretical knowledge. Subjects based on IC engines are taught using different methods in different institutions. Using a single platform that explains all the concepts, applications and aspects of IC engines by infusing it with ICT makes it easier not only for the students by providing them with interaction-based learning but also reduces the pressure of preparation on young teachers (Shatrov et al., 2020). Virtual engineering laboratories that allow simulations such as MATLAB are gaining popularity among students. By providing virtual simulations of the real-world applications, such software assist in teaching the working principles of various instruments and devices used in the field (Ibrahim, 2011).

SURVEY ON EDUCATIONAL SOFTWARE

Educational Software

The use of software and other tools to explain concepts has made learning more enjoyable than being an arduous task (Tzur et al., 2021). Different fields of engineering, medicine, and many others have seen the integration of educational software for learning purposes. These methods have encouraged interactive learning and active participation of the students even in the technical fields, thereby improving their understanding of the subject and its real-life applications. However, not every educational software may be adequate or appropriate for students at different levels of their technical education. While some may prove to be easier to use, understand and help in putting theories to application, others may further complicate the learning process and not serve their purpose. Hence, choosing the software requires close attention and extensive research based on the software's design, development and assessment (Hinostroza et al., 2000).

Educational software can not only be used for technical education, but it can also be used for students in primary schools. Since children's attention span is far below that of adults, implementing software in classes will help promote the children's rapt attention. However, many schools do not have access to such technology. Therefore, but promoting such technology is essential to ensure that each individual gets equal access to such learning processes and methods (Stanisavljević-Petrović et al., 2015). The effectiveness of infusing educational software, computer graphics and multimedia with theory-based classes also depends upon the software used and the teacher's ability to use it to extract the best outcome. There is no doubt that the technological advancements surely help the students in visual and interactive learning. However, without the guidance of a teacher, infusing theoretical knowledge will not be as effective as was expected. Teacher training and professional development sessions that help teachers understand why it is essential to encourage visual learning and how to use the resources at hand are helpful (Niederhauser & Stoddart, 2001). Nevertheless, such software are not accessible for use and requires a student to pay hefty amounts to obtain the licensed version. It stands against the policy of providing equal access of software to all the students. Hence, several open-source software is gaining popularity. Tools can be built and shared over the web to be accessed by students all over the globe using models from various areas of learning (Prensky, 2004).

Commercial Software Tools

There are various commercial software tools available for modelling and simulation of IC engine characteristics. This section presents a survey of the same. MATLAB (matrix laboratory) (MathWorks, 2023) software was introduced at the IEEE conference in 1984. The current version of MATLAB used is R2022b. Known for performing various analyses, simulations, and user interface creation, this software can be utilized to perform simulations for IC engines and various related parameters. SIMULINK provides a programming-based graphical environment for all simulations.

Introduced in 1970 in Pennsylvania, ANSYS software uses the C language (ANSYS, 2023). The current version used by professionals and students is ANSYS 2022 R2. With the method of adaptive computation, it helps perform engine-based simulations using virtual representations of engines and their various components that can be modelled explicitly or may be available inbuilt. Various modules under the same software help understand the flow of the air-fuel mixture through the valves or the strength of the material used for the engine block. The results are known to be more innovative and reduce the product development cost.

Founded in 2008, AVL (2023) has developed software such as BOOST, CRUISE, EXCITE, and FIRE. The software predicts the engine's performance, acoustics, and exhaust gas effectiveness post-treatment. However, using AVL BOOST, virtual engine simulations are performed. With such accurate results, the development cost reduces, and so does the effort taken by the OEM and the time taken for marketing it. GT SUITE (Gamma Technologies, 2023) was released in the 1980s. The software provided by Gamma Technologies, GT SUITE, helps with various functions varying from concept designing, design optimization, and simulations to assess any aberrations in functioning. GT- Power helps predict parameters like power, torque, volumetric efficiency, and fuel consumption rate in IC engines.

Developed by Ricardo PLC (2023), VECTIS is software that focuses on computational fluid dynamics. The main applications include vehicle thermal management and in-cylinder analysis for IC engines. ENGDYN pays close attention to the engines, structure, and associated components. It provides a three-dimensional analysis of the engine development. For pre and post-processing in engine analysis, FEARCE proves helpful. It supports engine analysis, from assembling components to applying boundary conditions and receiving accurate results for further improvement. PISDYN, on the other hand, solely focuses on reducing development cost and manufacturing time by accurate piston analysis.

4stHEAD, a design software developed by Prof. Blair and Associates (2023), helps design all the components in and attached to the four-stroke engine's cylinder head. Some areas under the focus of 4stHEAD are cam profile, cam design, valve life profile, evaluating cam quality, and valve train dynamics, among many others. 4stSOFT, a software marketed by SAE, paid close attention to engine performance based on Otto and Diesel cycles, friction loss and transfer, cylinder to pipe flow, and wave reflections.

Virtual 2-stroke and Virtual 4-stroke are software developed by Optimum Power Technologies (2023), which provides an interface for powerful engine simulations. It handles the engine's design, simulation and optimization in a precise, comprehensible environment. Used for race car engine simulations, Dynomotion developed by Audie Technology (2023) is known for its sophistication. It is an advanced engineering simulation software that uses Cam Pro, Valve Pro, and Flow Quik for inputs and provides outputs based on power, port velocity curves, and volumetric efficiency.

As a full-cycle engine simulation software, DIESEL-RK (2023) provides thermodynamic analysis of dual fuel systems and thermodynamic analysis of two-stroke and four-stroke engines. The latest version of the software, 5.3.9.78, was released in 2020. Mecware (2023), a Japanese firm also provide software such as EGSIM, which can visualize engine intake/exhaust pulsation. Additionally, they provide, DRIVESIM, a drive train simulator to study the characteristics of powertrains and XCOMB, an excel addon tool to evaluate engine cylinder pressure.

Non-Commercial Software Tools

This section presents a survey of prior studies on software tools developed by course instructors for teaching IC engine concepts. Cave (1974) used ICL 4 -50 to explain how computer models could efficiently aid in teaching courses related to ICEs. These models provided a real-life-based experience to students about the varying conditions of operation and environment on which the engine's working depends. Filipi et al. (1997) elaborated on the advantages of using graphical software MATLAB-SIMULINK to minimize the development time and provide simplified solutions for sophisticated simulations. Graphical simulations allowed manipulation of input data, real-time monitoring of output variables and visual representations for comprehensive comparative studies. Kirkpatrick et al. (1997) wrote a JavaScript website-based software to help apply the concepts of thermodynamics and heat transfer to IC engine applications. It was introduced as a part of the sophomore-level heat transfer course. The software proved helpful for the IC engine analysis and design.

Kirkpatrick and Willson (1998) developed a JavaScript website-based software to elaborate thermodynamics, fluid mechanics and heat transfer of ICEs. An online research facility based on engines was also constructed using web browsers. Huffman (2000) explained how models of ideal gas law, heat release and others could be used to demonstrate spark timing and compression ignition in IC engines for further use in undergraduate studies. To help gain a better understanding of ICE, Zeng and Assanis (2004) developed a computer-oriented tool to simulate the spark-ignition engine using embedded physical, mathematical models and control strategies governing it's working. Animations, graphics and real engine models were employed to explain the processes and equations with ease.

Vijayshree et al. (2006) formulated a GUI-based software called GANESH to solve equations governing the processes of a four-stroke spark-ignition engine. Various models were developed using this software. It used Visual C ++ and OpenGL for development. The primary purpose of creating this software was to minimize the development time and have a user-friendly interface for all simulations related to the engine. Depcik et al. (2007) describe how heat release simulations can be utilized in functioning ICEs. Models and computer simulations assisted in the detailed examination of the engine's working fluids' thermodynamic characteristics, bringing to attention the need for sub-models with a highly accurate analysis. McMasters (2011) developed a numeric-based model in Microsoft Excel for IC engines for use in an elective course. This model replaced the previously available Excel ideal gas computer, MATHCAD file. Using the one-degree rotation of the crankshaft as a differential element size gave the students a direct experience with concepts of specific entropy, enthalpy, and internal energy. This numerical model was well received and appreciated.

Zueco (2011) used different simulation cycles of the IC engines to demonstrate how good modelling of engines can be for teaching purposes. The theoretical models of engine operation, such as perfect and ideal gas, were explained for constant values of volume, pressure and temperature. Cruz-Peragón et al. (2012) set up a Microsoft Excel spreadsheet program for students to model and study IC engine. Assuming air as a perfect gas with constant specific heat capacities and temperature independent, simple models using an ideal air cycle could be modelled. Also, complex mathematical engine models can be built by considering the deviation of specific heat capacities with respect to temperature.

García et al. (2012) used MATLAB code to describe the parametric analysis of the combustion process taking place in an ICE. The need for this virtual instrument rose from the increasing need for engineers to provide mathematical models for various calculations. Use of MATLAB would give students a better understanding of how diesel combustion takes place. Burke et al. (2017) developed a MATLAB based virtual laboratory application for teaching engine calibration. The footing of this application lies on mathematical models derived from experimental research to simulate an engine test cell. This study also showed that developing educational software tools encourages the connection between teaching and research and can easily be adapted for use in training students in other disciplines.

Acevedo et al. (2020) proposed an integrated package of three computer-based programs, CombustionUA, VOLCONTROL, and CarnotCycle improve the students' skills and provide comprehensive learning of combustion, steady-state flow devices and reversible and irreversible processes. This program package enhanced the problem-solving ability of the students. Dimitrov (2020) developed a MATLAB based computational program for processing indicator diagram of SI and CI engines powered by both conventional and alternative fuels. This software suite can be used for both tutorial sessions and processing experimental research results. Gómez-de la Cruz et al. (2021) created a spreadsheet based application for undergraduate students to simulate a turbocharged engine. The models are based on engine performance curves obtained from stationary tests of three different one cycle engines. The program computes both the air-fuel cycle of naturally aspirated and turbocharged engines. The use of spreadsheet-based calculation makes complex analysis of coupling a turbocharger to an IC engine quite simple. The authors of this study would like to highlight that no prior studies were found to use open-source development software such as python for creating e-learning tools with respect to IC engine domain.

OVERVIEW OF THIS STUDY

Domain

The study of energy, work, and heat as well as their interactions with one another is the focus of the field of physics known as thermodynamics (Borgnakke & Sonntag, 2022). The origin of thermodynamics as a scientific field can be traced back to Otto von Guericke in 1650. He created the world's first vacuum pump and demonstrated the concept of a vacuum using his Magdeburg hemispheres (Partington, 1989). Thermodynamics is an indispensable subject within the mechanical engineering curriculum. Its principles permeate all aspects of engineering as every engineering activity involves the interaction between energy and matter. In our daily lives, numerous appliances and devices utilize the concepts of thermodynamics, such as heating and air-conditioning systems, refrigerators, pressure cookers, water heaters, irons, and engines in automobiles and power plants (both gas and steam). These examples illustrate importance and widespread application of thermodynamics and its necessity as a crucial component of engineering education (Handoyo, 2007).

Of the subjects covered in the field of engineering, thermodynamics plays a vital role. Industry experts agree that knowledge of thermodynamics is essential for graduate engineers despite their domain. In the automotive industry, one factor that determines a graduate engineer's employability is their knowledge of thermodynamics, especially in the technical domain. Different versions of thermodynamics simulation have proved to be helpful for the students. It includes employing simplified instructional models to promote a higher understanding of the subject (Caton, 2002). Instructional models are not the only method to explain the concepts of thermodynamics. A comparison between the actual engine cycle simulation with varying parameters and an instructional module with constant parameters and composition has demonstrated its usefulness (Caton, 2001).

Thermodynamics involves theories, graphs and concepts and several mathematical equations that can sometimes prove hard to grasp. Simplified models are helpful even in these cases. One such model is an integrated motorcycle model that manipulates parameters (Magnani et al., 2018). However, when taught in educational institutions, the subject primarily includes graphs, theories, and equations to memorize, which might prove difficult for many students despite their learning capacity and ability. Thermodynamics is a subject that needs an individual to understand the concepts and their applications instead of memorizing the related laws. However, there have been numerous types of research on methods to help students understand the subject better. Using computer graphics and multimedia can initiate interactive and visual learning methods (Mulop et al., 2012).

Motivation

In line with prior studies on developing educational software tools for thermodynamics discipline, this study aims in developing a MATLAB based GUI for students to understand the characteristics of IC engines. Prior attempts in making such educational software tools were based on mathematical models built using equations derived from thermodynamics and machine kinematics. However, in this study, the initial part of the work is primarily a comprehensive survey that identifies the experimental outcome using RSM for studying IC engine characteristics. Based on the survey results from literature, polynomial regression equations have been formulated from statistical models of the physical engine test data. This has been used as the basis for developing the software application.

METHODOLOGY

Survey on Experimental Studies Using RSM

RSM study is mostly used in applications, where many independent input variables have a potential impact on the outcome of the process.

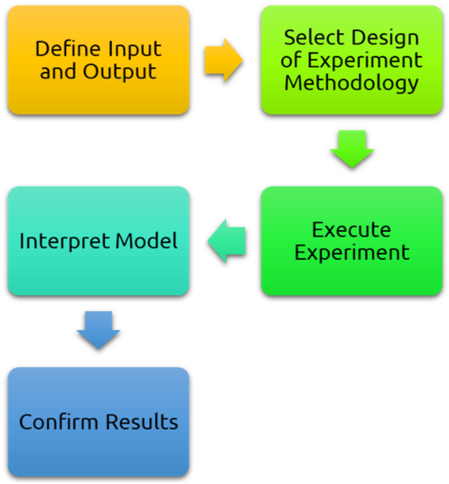


Figure 1. A flow chart on steps involved in utilizing RSM for ICE research (Source: Authors' own elaboration)

This technique has been mostly used in chemical processes (Bezerra et al., 2008). Many studies have been conducted in the past focusing on an optimization technique called RSM for investigating optimum engine operating characteristics using different fuels. A graphical illustration on the said topic is presented in **Figure 1**.

A summary of critical research studies on IC engine using RSM is tabulated in **Table 1**.

GUI Development

Polynomial regression equations referred from an experimental study by Sakthivel et al. (2019) was used to create the mathematical basis of the software program. These equations were used for predicting the values of all responses. It was found out from the survey tabulated in **Table 1** that certain studies using RSM optimization technique present either actual or coded equations. With actual equations, the prediction for any given model becomes much simpler, where the input values can be directly inferred from the experimental design. But if the equations are presented in coded form, it needs to be converted to actual equations for it to be used as a model. The methodology for conversion can be referred from the stat ease software webpage (Statease, 2023).

Table 1. Experimental studies identified using RSM to analyze ICE characteristics

Model	Reference	Engine	Fuel blend	Factors (units)	Responses (units)
1	Hirkude and Padalkar (2014)	Kirloskar, CI, 553 cc, 16.5 CR, 1 Cyl. 3.78 kW @ 1,500 rpm	Diesel-waste fried oil methyl ester	CR IP (bar) IT (BTDC)	BTE (%) BSFC (kg/kWh) EGT (°C) SM (HSU)
2	Saravanan et al. (2017)	Kirloskar TAF1, CI, 661 cc, 17.5 CR, 1 Cyl. 4.4 kW @ 1,500 rpm	Diesel-iso-butanol	IP (bar) IT (BTDC) EGR (%)	NO_X (g/kWh) SM (%) CO_2 (kg/kWh) BSFC (kg/kWh) BTE (%)
3	Poompipatpong and Kengpol (2015)	Hino WO6D, CI, 5,759 cc, 16.5 CR, 6 Cyl. 108.12 kW @ 3,200 rpm	Diesel-waste pyrolysis oil	EL (%) ES (rpm)	BT (Nm)
4	Pandian et al. (2011)	Rocket engineering, CI, 1,105 cc, 17.5 CR, 2 Cyl. 7.5 kW @ 1,500 rpm	Diesel-pongamia methyl ester	IT (BTDC) IP (bar) NTP (mm)	BSEC (MJ/kWh) BTE (%) CO (%) HC (ppm) SM (%) NO_X (ppm)
5	Patel et al. (2018)	Apex innovations, CI, 661 cc, 12-18 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-jatropha curcas shell oil	CR EL (kg) FB (%)	BTE (%) BSFC (kg/kWh) HC (ppm) CO (%) CO_2 (%)
6	Sakthivel et al. (2019)	Kirloskar, CI, 661 cc, 16-18 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-calophyllum inophyllum oil	CR FB (%) EL (%)	BSFC (kg/kWh) BTE (%) CO (%) CO_2 (%) HC (ppm) SM (%) NO_X (ppm)
7	Yaliwal et al. (2019)	Kirlosker, CI, 661 cc, 17.5 CR, 1 Cyl. 3.7 kW @ 1,500 rpm	Diesel-honge seed oil methyl ester-neem wood producer gas	IT (BTDC) IP (bar) CR	BTE (%) EGT (°C) SM (HSU) HC (ppm) CO (%) NO_X (ppm) CPMAX (bar) ID (°CA) CD (°CA) HRR (J/°CA)

Table 1 (Continued). Experimental studies identified using RSM to analyze ICE characteristics

Model	Reference	Engine	Fuel blend	Factors (units)	Responses (units)
8	Karabas and Boran (2019)	Super Star, CI, 916 cc, 1 Cyl. 14.7 kW @ 1,500 rpm	Diesel-safflower biodiesel	FB (%) ES (rpm)	BP (kW) BSFC (g/kWh) HC (ppm) CO (%) NO_X (ppm)
9	Atmanli et al. (2015)	Land rover 110, CI, 2,495 cc, 19.5 CR, 4 Cyl. 82 kW @ 3,800 rpm	Diesel-n-butanol-cotton oil	FB-Diesel (%) FB-n-butanol (%)	BT (Nm) BP (kW) BSFC (g/kWh) BTE (%) BMEP (bar) NO_X (ppm) CO (ppm) HC (ppm)
10	Ozgur (2021)	Mitsubishi canter 4D3A-2A, CI, 3,907 cc, 4 Cyl. 89 kW @ 3,200 rpm	Diesel-waste cooking oil	FB (%) ES (rpm)	BP (kW) BT (Nm) SM (%) CO (ppm) NO_X (ppm)
11	Vinay et al. (2018)	Kirloskar, CI, 661 cc, 12-18 VCR, 1 Cyl. 3.75 kW @ 1,500 rpm	Diesel-mahua oil methyl ester	FB (%) EL (Nm)	BSFC (kg/kWh) BTE (%) CO (%) NO_X (ppm) HC (ppm) SM (%)
12	Ganji et al. (2021)	CAT-3401, CI, 2,455 cc, 15.1 CR, 1 Cyl.	Diesel	SOI (BTDC) EGR (%)	NO_X (g/kWh) ST (g/kWh) ISFC (g/kWh)
13	Patel et al. (2016)	CI, 661 cc, 18.1 CR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-biodiesel-diethyl ether	CR IP (bar) IT (BTDC)	BTE (%)
14	Singh et al. (2022)	Kirloskar, CI, 661 cc, 17.5 CR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-jatropha oil	FB (%) EL (kgf) CR IP (bar)	BP (kW) BTE (%)
15	Pote et al. (2020)	Kirloskar, CI, 661 cc, 12-18.1 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-tyre pyrolysis oil	FB (%) EL (%)	BTE (%) BSFC (kg/kWh) NO_X (ppm) CO (%) SM (%) ME (%)
16	Li et al. (2020)	T8138LCz, CI, 19,504 cc, 15.1 CR, 8 Cyl. 323.4 kW @ 1,545 rpm	Diesel-liquefied natural gas	ES (rpm) EL (%)	CO (%) CO_2 (%) NO_X (ppm) HC (ppm)
17	Mahla et al. (2020)	Kirloskar, CI, 661 cc, 16-18 VCR, 1Cyl. 3.5 kW @ 1500 rpm	Diesel-biogas	CR EL (%) FB (kg/h)	BTE (%) SM (%) CO (%) HC (kg/kWh) NO_X (kg/kWh)
18	Kamarulzaman and Abdullah (2020)	Yanmar TF120M, CI, 638 cc, 17.1 CR, 1 Cyl. 9.0 kW @ 2,400 rpm	Diesel-hermetia illucens larvae oil	FB (%) EL (%)	BP (kW) BMEP (kPa) BSFC (mg/J) BTE (%) CO (%) CO_2 (%) HC (ppm) NO_X (ppm)
19	Saidur et al. (2008)	Magna, SI, 1,468 cc, 9.2 CR, 4 Cyl. 64kW @ 6,000 rpm	Natural gas	ES (rpm) TP (%) OT (min)	HC (ppm) CO (%) CO_2 (%)

Table 1 (Continued). Experimental studies identified using RSM to analyze ICE characteristics

Model	Reference	Engine	Fuel blend	Factors (units)	Responses (units)
20	Simsek and Uslu (2020)	Katana KM 178 FE, CI 296 cc, 20 CR, 1 Cyl. 4.92 kW @ 3,000 rpm	Diesel-canola-safflower-waste vegetable oil	FB (%) IP (bar) EL (%)	BTE (%) EGT (°C) CO_2 (%) NO_X (ppm) SM (%)
21	Ghanbari et al. (2021)	CI, 5,818 cc, 17.1 CR, 6 Cyl. 82 kW @ 2,300 rpm	Diesel-biodiesel with alumina nanoparticles	ES (rpm) NP (ppm)	BT (Nm) BP (kW) BSFC (kg/kWh) CO (%) CO_2 (%) HC (ppm) NO_X (ppm)
22	Sharma et al. (2021)	Kirloskar, CI, 661 cc, 12-18 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-algal biodiesel	EL (%) CR FB (%)	BTE (%) BSFC (g/kWh) CO_2 (g/kWh) PM (g/kWh) NO_X (ppm)
23	Kashyap et al. (2021)	Kirloskar, CI, 661 cc, 12 – 18 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-honge seed oil Methyl ester & producer gas	EL (%) CR IT (BTDC)	BTE (%) EGT (°C) NO_X (ppm) HC (ppm) CO (%)
24	Bharadwaz et al. (2016)	Kirloskar TV1, CI, 661 cc, 17.5 CR, 1 Cyl. 5.2 kW @ 1,500 rpm	Palm biodiesel-methanol	CR FB (%) EL (kg)	BTE (%) BSFC (kg/kWh) CO (%) HC (ppm) NO_X (ppm) SM (%)
25	Lan et al. (2020)	-	Diesel	DFP (mm) DHP (mm) DHPFT (mm) PTFNS (N) DN (mm)	FIQ (mm^3)
26	Jatoth et al. (2021)	Kirloskar, CI, 625 cc, 18 CR, 1 Cyl. 6.71 kW @ 3,000 rpm	Diesel-gasoline	EL (Nm) IP (bar) IT (BTDC)	EGT (°C) BP (kW) BMEP (bar) BTE (%) BSFC (kg/kWh) NO_X (ppm) HC (ppm) CO (%) SM (HSU)
27	Khoobbakht et al. (2016)	Daimler OM 314, CI, 3,783 cc, 17 CR, 4 Cyl. 81 kW @ 2,800 rpm	Diesel-waste cooking oil Biodiesel-ethanol	FB - Biodiesel (%) FB - Ethanol (%) ES (rpm) EL (%)	CO (%) HC (%) NO_X (ppm) CO_2 (%) SM (%)
28	Khoobbakht et al. (2019)	Daimler OM 314, CI, 3,782 cc, 17 CR, 4 Cyl. 81 kW @ 2,800 rpm	Diesel-rapeseed oil Biodiesel-ethanol	FB (%) ES (rpm) EL (%)	BP (kW) BTE (%) BSFC (g/kWhr)
29	Krishnamoorthy et al. (2018)	Kirloskar TV1, CI, 661 cc, 17.5 CR, 1 Cyl. 5.2 kW @ 1,500 rpm	Diesel-waste cooking oil Biodiesel-n-pentanol/n-butanol/n-propanol	FB (Type) IT (BTDC) EGR (%)	NO_X (ppm) SM (%) HC (ppm) CO (%) BTE (%) BSFC (kg/kWh)
30	Kumar and Dinesha (2018)	CI, 1 Cyl.	Honge methyl ester	EL (%) FB (%) CR IT (°BTDC)	BTE (%) NO_X (ppm)

Table 1 (Continued). Experimental studies identified using RSM to analyze ICE characteristics

Model	Reference	Engine	Fuel blend	Factors (units)	Responses (units)
31	Ardebili et al. (2021)	Ricardo, CI, 449 cc, 13 CR, 1 Cyl. 15 kW	Diesel-fusel oil/diethyl ether	DEE (%) ES (rpm) Lambda	BT (Nm) BSFC (g/kWh) CoV_{IMEP} (%) MPRR (bar/ °CA) CA10 (°CA) CA50 (°CA) NO_X (ppm) CO (%) CO_2 (%) HC (ppm)
32	Singh et al. (2021)	Kirloskar AV1, CI, 552 cc, 16-18 VCR, 1 Cyl. 3.72 kW @ 3,000 rpm	Diesel-microalgae spirulina	EL (%) CR FB (%)	BTE (%) BSFC (g/kWh) CO_2 (g/kWh) PM (g/kWh) NO_X (ppm)
33	Katekaew et al. (2021)	RT90 Plus, CI, 487 cc, 23 CR, 1 Cyl. 6.62 kW @ 2,400 rpm	Diesel-waste cooking oil	FB (%) ES (rpm)	BT (Nm) BP (kW) BSFC (g/kWh) BTE (%) CO (%) CO_2 (%) NO_X (ppm) EGT (°C)
34	Parida et al. (2019)	Kirloskar, CI, 16-18 VCR, 1 Cyl.	Diesel-argemone Mexicana biodiesel	EL (kg) CR FB (%)	BTE (%) BSFC (kg/kWh) CO (%) HC (ppm) NO_X (ppm)
35	Khanjani and Sobati (2021)	Lombardini 3LD510, CI, 510 cc, 17.5 CR, 1 Cyl. 9 kW @ 3,000 rpm	Diesel-waste fish oil	FB (%) Water (%) Surfactant (%)	CV (kcal/g) BT (Nm) BP (kW) BSFC (g/kWh) BTE (%) CO (%) HC (ppm) CO_2 (%) NO_2 (ppm)
36	Ramachander et al. (2021a)	Kirloskar, CI, 625 cc, 18 CR, 1 Cyl. 6.7 kW @ 3,000 rpm	Diesel-methanol	EL (%) IP (bar) IT (BTDC)	EGT (°C) BP (kW) BMEP (bar) BTE (%) BSFC (kg/kWh) NO_X (ppm) HC (ppm) CO (%) SM (HSU)
37	Singh and Tirkey (2022)	Kirloskar, CI, 661 cc, 12-18 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-low-grade coal-Based producer gas	CR EL (kg)	BP (kW) BTE (%) BSFC (kg/kWh) CO (%) HC (ppm) CO_2 (%) NO_X (ppm)
38	Solmaz et al. (2021)	Lombardini, CI, 510 cc, 17.5 CR, 1 Cyl. 9 kW @ 3,000 rpm	Diesel-biodiesel with multi-wall carbon nanotube	MWCNT (ppm) EL (Nm)	BTE (%) BSFC (g/kWh) CO (%) HC (ppm) NO_X (ppm)

Table 1 (Continued). Experimental studies identified using RSM to analyze ICE characteristics

Model	Reference	Engine	Fuel blend	Factors (units)	Responses (units)
39	Yaman et al. (2022)	Kirloskar TV1, CI, 661.5 cc, 6-10 VCR, 1 Cyl. 6.5 kW @ 1,850 rpm	Gasoline-1-heptanol	FB (%) CR EL (kg)	CO (%) HC (ppm) CO_2 (%) NO_X (ppm) BSFC (kg/kWh) BTE (%)
40	Simsek et al. (2022)	Katana KM 178 FE, CI, 296cc, 20CR, 1Cyl. 4.92 kW @ 3000 rpm	Diesel-animal waste fat biodiesel	FB (%) EL (W)	BTE (%) BSFC (g/kWh) CO (%) HC (ppm) CO_2 (%) NO_X (ppm) SM (%)
41	Kumar et al. (2016)	Kirloskar TAF1, CI, 661 cc, 17.5 CR, 1 Cyl. 4.4 kW @ 1,500 rpm	Diesel-dimethyl Carbonate/iso-butanol/n-pentanol	IT (BTDC) EGR (%) FB (type)	NO_X (ppm) SM (%) HC (ppm) CO (%) BSFC (kg/kWh)
42	Prasad et al. (2021)	Legion brothers, CI, 553 cc, 12-22 VCR, 1 Cyl.	Diesel-biodiesel Producer gas	CV (MJ/Nm^3) BP (kW)	BTE (%) BSEC (MJ/kWh) BSFC (kg/kWh) DRR (%) EGT (°C) CO (%) NO_X (ppm) HC (ppm) SM (%)
43	Billa et al. (2021)	Kirloskar TV1, CI, 661 cc, 17.5 CR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-biodiesel with graphene-oxide	FB (%) NP (ppm) EL (%)	BSEC (kJ/kWh) CO (%) HC (ppm) NO_X (ppm)
44	Srinidhi et al. (2021)	Rocket engineering, CI, 661 cc, 17.5 CR, 1 Cyl. 4.8 kW @ 1,500 RPM	Diesel-neem biodiesel	IT (BTDC) IP (bar) CR NiO (ppm)	BSFC (kg/kWh) BTE (%) EGT (°C) CO (%) CO_2 (%) HC (ppm) NO_X (ppm) SM (HSU)
45	Sharma and Sharma (2021)	Kirloskar, CI, 661 cc, 17 CR, 1 Cyl. 5.2 kW @ 1,500 rpm	Diesel-waste cooking oil methyl ester	EL (kg) IP (bar) IT (BTDC)	BTE (%) EGT (°C) CP_{MAX} (bar)
46	Ramachander et al. (2021b)	Kirloskar, CI, 625 cc, 18 CR, 1 Cyl. 6.6 kW @ 3,000 rpm	Diesel-compressed natural gas	EL (Nm) IP (bar) IT (BTDC)	EGT (°C) BP (kW) BMEP (bar) BTE (%) BSFC (kg/kWh) NO_X (ppm) HC (ppm) CO (%) SM (HSU)
47	Das et al. (2021a)	Kirloskar TV1, CI, 661 cc, 16-18 VCR, 1 Cyl. 5.2 kW @ 1,500 rpm	Diesel-waste plastic oil	EL (kg) CR FB (%)	BTE (%) NO_X (ppm)
48	Teoh et al. (2021)	CI, 638 cc, 17.7 CR, 1 Cyl. 7.8 kW @ 2,400 rpm	Diesel-moringa oil	EL (Nm) SOI (BTDC) IP (bar)	BSFC (g/kWh) BTE (%) NO_X (ppm) SM (%)

Table 1 (Continued). Experimental studies identified using RSM to analyze ICE characteristics

Model	Reference	Engine	Fuel blend	Factors (units)	Responses (units)
49	Das et al. (2021b)	CI, 661 cc, 12-18 VCR, 1 Cyl. 3.5 kW @ 1,500 rpm	Diesel-biofuel	EL (%) CR IT (BTDC)	BTE (%) BFR (kg/h) NO_X (g/kWh) HC (g/kWh) CO (g/kWh) CO_2 (g/kWh)
50	Yusri et al. (2017)	Mitsubishi 4G93, CI, 1,834 cc, 9.5 CR, 4 Cyl. 86 kW @ 5,500 rpm	Gasoline/2-butanol	ES (rpm) FB (%)	BP (kW) BMEP (MPa) SFC (g/kWh) BTE (%) NO_x (ppm) CO (%) CO_2 (%) HC (ppm)

Table 2. Collated data set containing predicted, RE, & average RE values

DP	Pred.	Pred.	Pred.	Pred.	Pred.	Pred.	Pred.	RE	RE	RE	RE	RE	RE	RE
Run	BSFC	BTE	CO	CO_2	HC	SM	NO_X	BSFC	BTE	CO	CO_2	HC	SM	NO_X
	kg/kWh	%	%	%	ppm	%	ppm	%	%	%	%	%	%	%
1	0.47	28.07	1.31	7.62	131.38	25.80	722.40	0.02	0.00	-0.01	0.02	0.00	0.08	0.00
2	0.60	25.24	1.49	6.23	176.19	36.47	567.43	-0.08	-0.01	0.07	-0.04	0.02	-0.15	0.03
3	0.76	22.14	1.70	4.94	226.67	46.37	426.85	0.02	0.00	0.05	0.01	0.05	-0.19	-0.02
4	0.46	28.34	1.16	7.63	111.86	22.28	829.57	0.03	0.00	0.03	-0.02	0.08	0.20	0.10
5	0.60	25.42	1.35	6.21	150.18	32.72	662.48	-0.08	-0.01	-0.02	-0.11	-0.01	0.01	0.04
6	0.75	22.23	1.57	4.88	194.15	42.38	509.77	0.02	0.00	0.05	0.00	0.03	-0.06	-0.06
7	0.46	28.41	0.97	8.13	88.00	19.48	949.10	0.03	0.00	0.14	0.01	0.12	0.35	0.00
8	0.59	25.39	1.17	6.68	119.81	29.69	769.88	-0.08	-0.01	0.03	-0.06	0.06	0.14	-0.08
9	0.75	22.11	1.40	5.32	157.29	39.12	605.05	0.01	0.01	0.00	0.01	0.02	-0.03	0.15
10	0.36	30.35	1.17	8.38	88.52	25.50	856.80	-0.07	0.01	0.03	-0.02	0.12	-0.02	0.02
11	0.49	26.94	1.30	6.92	121.61	34.33	691.11	0.05	0.00	0.08	-0.02	0.07	-0.18	0.05
12	0.64	23.25	1.47	5.56	160.35	42.39	539.80	-0.04	-0.01	0.02	-0.07	0.07	-0.25	0.11
13	0.36	30.74	0.97	8.57	83.12	20.22	948.45	-0.07	0.00	0.03	-0.07	0.06	0.16	-0.03
14	0.49	27.23	1.11	7.07	109.71	28.82	770.63	0.05	0.00	0.07	0.00	0.07	0.00	0.06
15	0.64	23.45	1.29	5.68	141.95	36.64	607.20	-0.04	-0.01	0.05	-0.05	0.05	-0.04	0.05
16	0.35	30.92	0.72	9.25	73.37	15.65	1,052.45	-0.09	0.00	0.07	0.02	-0.06	0.43	0.00
17	0.48	27.32	0.88	7.72	93.46	24.02	862.51	0.06	0.00	0.08	0.03	0.05	0.21	0.02
18	0.63	23.45	1.07	6.29	119.20	31.61	686.95	-0.03	-0.01	0.03	-0.02	0.02	0.05	-0.05
19	0.32	32.04	1.00	9.37	56.98	28.17	969.20	-0.05	0.01	-0.11	0.00	0.14	0.06	-0.06
20	0.45	28.42	1.12	7.88	86.15	36.39	799.93	0.01	0.01	-0.02	0.01	-0.03	-0.12	0.00
21	0.59	24.54	1.28	6.50	120.98	43.84	645.05	-0.02	0.00	-0.02	-0.03	0.00	-0.25	0.01
22	0.31	32.46	0.79	9.61	56.28	22.301	1,055.67	-0.04	0.00	0.03	0.02	0.06	0.24	0.01
23	0.44	28.76	0.92	8.09	78.96	30.28	874.28	0.00	0.00	0.05	0.03	0.16	0.07	0.01
24	0.59	24.78	1.09	6.67	107.29	37.50	707.27	-0.02	0.00	0.14	0.00	0.03	-0.09	0.00
25	0.30	32.68	0.53	10.35	51.24	17.15	1,154.50	-0.01	0.00	0.00	-0.05	0.13	0.32	0.04
26	0.43	28.89	0.67	8.80	67.41	24.90	960.98	-0.03	0.00	0.12	-0.05	0.14	0.13	0.06
27	0.58	24.82	0.85	7.35	89.24	31.88	781.85	-0.02	0.00	0.07	-0.05	0.11	-0.02	0.02
Average RE								**-1.71**	**-0.12**	**3.89**	**-1.72**	**5.73**	**3.88**	**1.72**

Table 2 presents the predicted data along with RE and average RE values for the model. RE and average RE were calculated using Eq. (1). The experimental data were also referred from the study Sakthivel et al. (2019). The average RE for each response is noted to be below 6% indicating a good statistical fit. An inbuilt app in MATLAB was used to build the GUI.

MATLAB driver code is provided in **Appendix B** and screenshots of the developed GUI are illustrated in **Figure 2**, **Figure 3**, and **Figure 4** for reference. To use the GUI, the user has to enter the minimum and maximum values for each factor, say CR, FB (%), and EL (%) for this particular case. Then the user has to set the resolution for calculation.

By default, a minimum resolution value of two, produces a model with a rough curve profile but increasing it up to 10 gives a smoother curve profile. Then the user has to click on the plot button for the GUI to display the surface plot and the table containing the predicted values for various responses. The interactive effect of EL (%) for a given range of factors such as CR and FB (%) on various responses can be visually seen by altering the EL (%) value in the bottom pane of the GUI.

$$Relative\ error\ (\%) = \frac{Y-X}{X} \times 100, \quad (1)$$

where X is experimental value and Y is predicted value.

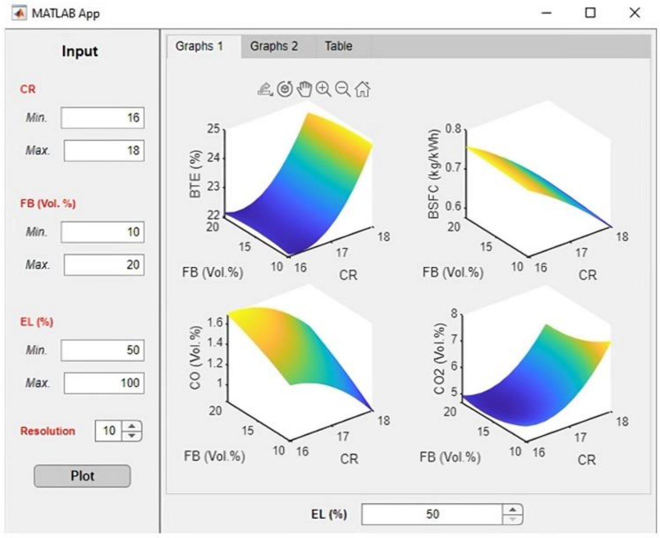


Figure 2. Screenshot of GUI showing interactive effect of various factors on responses (Source: Authors' own elaboration)

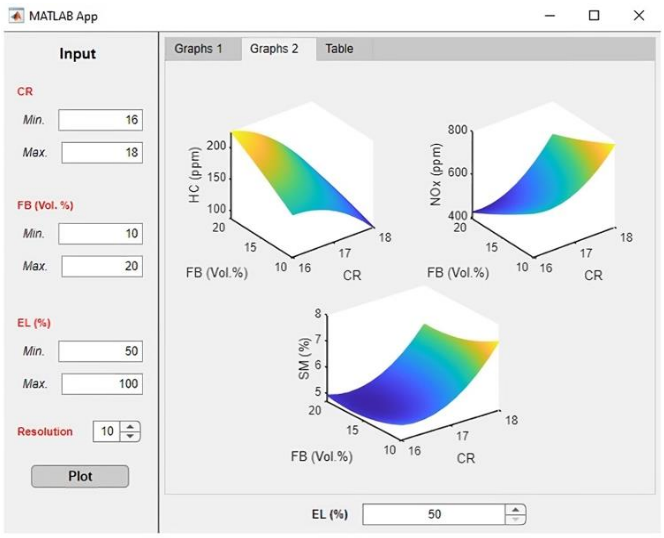
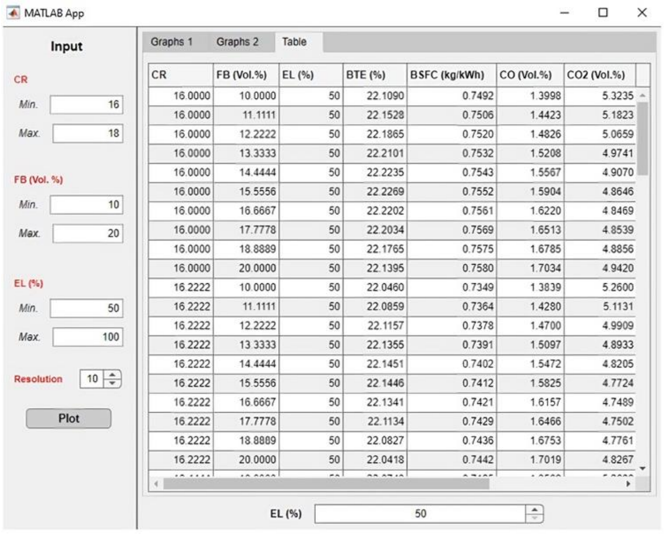


Figure 3. Screenshot of GUI showing interactive effect of various factors on responses (Source: Authors' own elaboration)



CR	FB (Vol.%)	EL (%)	BTE (%)	BSFC (kg/kWh)	CO (Vol.%)	CO2 (Vol.%)
16.0000	10.0000	50	22.1090	0.7492	1.3998	5.3235
16.0000	11.1111	50	22.1528	0.7506	1.4423	5.1823
16.0000	12.2222	50	22.1865	0.7520	1.4826	5.0659
16.0000	13.3333	50	22.2101	0.7532	1.5208	4.9741
16.0000	14.4444	50	22.2235	0.7543	1.5567	4.9070
16.0000	15.5556	50	22.2269	0.7552	1.5904	4.8646
16.0000	16.6667	50	22.2202	0.7561	1.6220	4.8469
16.0000	17.7778	50	22.2034	0.7569	1.6513	4.8539
16.0000	18.8889	50	22.1765	0.7575	1.6785	4.8856
16.0000	20.0000	50	22.1395	0.7580	1.7034	4.9420
16.2222	10.0000	50	22.0460	0.7349	1.3839	5.2600
16.2222	11.1111	50	22.0859	0.7364	1.4280	5.1131
16.2222	12.2222	50	22.1157	0.7378	1.4700	4.9909
16.2222	13.3333	50	22.1355	0.7391	1.5097	4.8933
16.2222	14.4444	50	22.1451	0.7402	1.5472	4.8205
16.2222	15.5556	50	22.1446	0.7412	1.5825	4.7724
16.2222	16.6667	50	22.1341	0.7421	1.6157	4.7489
16.2222	17.7778	50	22.1134	0.7429	1.6466	4.7502
16.2222	18.8889	50	22.0827	0.7436	1.6753	4.7761
16.2222	20.0000	50	22.0418	0.7442	1.7019	4.8267

Figure 4. Screenshot of GUI showing predicted results (Source: Authors' own elaboration)

CONCLUSIONS

In this study, a survey comprising 50 research articles within IC engine domain using RSM optimization technique was conducted.

Then a suitable experimental article containing required polynomial regression equations was chosen to form the mathematical basis of the GUI. In order to verify the soundness of the statistical model, a comparison between experimental and predicted values was performed to know the average RE. It was computed and found that the average RE for responses such as BSFC, BTE, CO, CO_2, HC, SM, and NO_X are -1.71%, -0.12%, 3.89%, -1.72%, 5.73%, 3.88%, and 1.72%, respectively.

Overall, the average RE is less than 6%, thus exhibiting a good statistical fit. MATLAB software was used to create GUI. The driver code of the software provided in this study can serve as the basis for any future variations. This GUI package can be considered suitable for studying engine parameter analysis. Experimental studies employing RSM optimization technique could also provide polynomial regression equations in terms of actual factors along with coded factors. This would help in creating statistical model-based GUIs simulating the actual experiment thus reducing the reliance on physical laboratory instruments and consumables for demo lecture sessions. Unlike physics-based models, which allows a higher degree of freedom in terms of input variables, statistical models are constricted to the limitations of test data. Utilizing open-source software such as python instead of MATLAB to create GUI enhances the reach of educational tools.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

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APPENDIX A: NOMENCLATURES

Table A1. Nomenclatures

ANSYS	Analysis system	ISFC	Indicated specific fuel consumption
BFR	Biogas flow rate	IT	Injection timing
BMEP	Brake mean effective pressure	ME	Mechanical efficiency
BSEC	Brake specific energy consumption	MPRR	Maximum pressure rise rate
BSFC	Brake specific fuel consumption	MWCNT	Multi-wall carbon nanotube
BP	Brake power	NiO	Nickel oxide nanoparticles
BT	Brake torque	NP	Nano particle
BTE	Brake thermal efficiency	NTP	Nozzle tip protrusion
CA10	Crank angle for 10% combustion	NO_X	Oxides of nitrogen
CA50	Crank angle for 50% combustion	OEM	Original equipment manufacturer
CCD	Central composite design	OT	Operation time
CD	Combustion duration	PM	Particulate matter
CO	Carbon monoxide	PTFNS	Pre-tightening force of needle spring
CO_2	Carbon dioxide	RE	Relative error
CoV_{IMEP}	Coefficient of variation	RSM	Response surface methodology
CP_{MAX}	Maximum cylinder pressure	SM	Smoke opacity
CR	Compression ratio	SOI	Start of injection
CV	Calorific value	ST	Soot
DEE	Diethyl ether	TEQIP	Technical education quality Iimprovement program
DFP	Diameter of fuel plunger	TP	Throttle position
DHP	Diameter of hydraulic piston	BTDC	Before top dead center
DHPFT	Diameter of high pressure fuel tube	g/kWh	Gram per kilo watt hour
DRR	Diesel replacement rate	HSU	Hartridge smoke unit
DN	Diameter of nozzle	J/°CA	Joules per degree crank angle
EGR	Exhaust gas recirculation	kcal/g	Kilo calorie per gram
EGT	Exhaust gas temperature	kg	Kilogram
EL	Engine load	kg/kWh	Kilogram per kilo watt hour
ES	Engine speed	kJ/kWh	Kilo Joule per kilo watt hour
FB	Fuel blend	kPa	Kilo pascal
FFD	Full factorial design	kW	Kilo watt
FIQ	Fuel injection quantity	MJ/kWh	Mega joules per kilogram
GANESH	Graphical & numerical engine software hub	mg/J	Milligram per joule
GUI	Graphical user interface	mm	Millimeter
HC	Hydrocarbon	mm^3	Cubic millimeter
HRR	Heat release rate	MPa	Mega pascal
IC	Internal combustion	Nm	Newton meter
ICE	Internal combustion engine	ppm	Parts per million
ICT	Information & communication technology	rpm	Revolutions per minute
ID	Ignition delay	%	Percentage
IEEE	Institute of electrical & electronics engineers	°C	Degree celsius
IP	Injection pressure	°CA	Degree crank angle

APPENDIX B: MATLAB CODE FOR CREATING GUI

```
% Driver Code Start
%%% Taking inputs from user %%%
minCR = app.MinEditField.Value; % CR range
maxCR = app.MaxEditField.Value;
minFB = app.MinEditField_2.Value; % FB range
maxFB = app.MaxEditField_2.Value;
minEL = app.MinEditField_3.Value; % EL range
maxEL = app.MaxEditField_3.Value;
r = app.ResolutionSpinner.Value; % Resolution
%%% Initializing the input values %%%
app.ELSpinner.Limits = [minEL,maxEL]; % Setting the limits for IT Spinner
Cr = linspace(minCR,maxCR,r);
Fb = linspace(minFB,maxFB,r);
el = app.ELSpinner.Value;
%%% Calculation %%%
CR=[]; FB=[]; EL=[]; BTE=[]; BSFC=[]; CO=[]; CO2=[]; HC=[]; NOX=[]; SM=[];
for k = 1:length(Cr) % First loop for generating CR values
        cr=Cr(k);
        for j = 1:length(Fb) % Second loop for generating FB values for each CR values
                fb=Fb(j);
                for i = 1:length(el) % Third for generating EL values for set of each CR and FB values
                        % Insert BTE equation
                        bte(i) =
                        % Insert BSFC equation
                        bsfc(i) =
                        % Insert CO equation
                        co(i) =
                        % Insert C02 equation
                        co2(i) =
                        % Insert HC equation
                        hc(i) =
                        % Insert NOX equation
                        nox(i) =
                        % Insert SM equation
                        sm(i) =
                        % Saving the results
                        CR(end+1)=cr; FB(end+1)=fb; EL(end+1)=el(i); BTE(end+1)=bte(i); BSFC(end+1)=bsfc(i);
                        CO(end+1)=co(i); CO2(end+1)=co2(i); HC(end+1)=hc(i); NOX(end+1)=nox(i); SM(end+1)=sm(i);
                end
        end
end
%%% Displaying Results %%%
% Table Generation and Print
T = table(CR',FB',EL',BTE',BSFC',CO',CO2',HC',NOX',SM');
app.UITable.Data = T;
% Plotting the surface graphs
% Plot 1 – BTE
[CRi,FBi] = meshgrid(linspace(min(CR),max(CR),101),linspace(min(FB),max(FB),151));
F = scatteredInterpolant(CR(:),FB(:),BTE(:),'linear');
BTEi = F(CRi,FBi);
mesh(app.UIAxes_6,CRi,FBi,BTEi);
% Plot 2 – BSFC
G = scatteredInterpolant(CR(:),FB(:),BSFC(:),'linear');
BSFCi = G(CRi,FBi);
mesh(app.UIAxes_2,CRi,FBi,BSFCi);
% Plot 3 - CO
H = scatteredInterpolant(CR(:),FB(:),CO(:),'linear');
COi = H(CRi,FBi);
```

```
mesh(app.UIAxes_7,CRi,FBi,COi);
% Plot 4 - CO2
I = scatteredInterpolant(CR(:),FB(:),CO2(:),'linear');
CO2i = I(CRi,FBi);
mesh(app.UIAxes_11,CRi,FBi,CO2i);
% Plot 5 - HC
J = scatteredInterpolant(CR(:),FB(:),HC(:),'linear');
HCi = J(CRi,FBi);
mesh(app.UIAxes_9,CRi,FBi,HCi);
% Plot 6 - NOX
K = scatteredInterpolant(CR(:),FB(:),NOX(:),'linear');
NOXi = K(CRi,FBi);
mesh(app.UIAxes_8,CRi,FBi,NOXi);
% Plot 4 - SM
L = scatteredInterpolant(CR(:),FB(:),SM(:),'linear');
SMi = I(CRi,FBi);
mesh(app.UIAxes_10,CRi,FBi,SMi);
% End of Driver Code
end
```