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People's Democratic Republic of Algeria

Abou Bekr Belkaid University - Tlemcen

Faculty of Sciences

Department of Computer Science

Final study thesis for obtaining a Master's degree in Computer Science

Option: Software Engineering

Subject

Permanent preheating controller system for LPG gas before injection into the engine

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Presented on July 01st, 2025 before the jury composed of

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Academic Year: 2024- 2025

بسم الله الرحمان الرحيم

”وَأَن لَّيْسَ لِلإِنسَانِ إِلاَّ مَا سَعَى ۝ وَأَنَّ سَعْيَهُ سَوْفَ يُرى “

[النجم:38-39]

First of all, We are thankful to God Almighty for granting us the health, strength, and patience to complete our graduation project. We are profoundly grateful to Almighty Allah for guiding us through this journey.

Acknowledgments

This work was possible due to the effort of many parties including :

Our team, which did put in all mind and dedication to the project, and to our supervisor Mr.BENAZZOUZ Mourtada as he was always helping from the beginning to the end and for guiding us through this academic final semester .

And to the jury members the examiner Mr.Amine BRIKCI NIGASSA, our president Mr.Mohamed MANA and I2E expert MrAbdelhak ETCHIALI, for their suggestions and remarks and their questions that reflect their dedication and care for the students to always work more and hard to provide excellent work

We also would like to acknowledge the I2E team for the guidance through various phases of our project especially to the member Mr.Abdeladim Benferhat

Faculty members including our professors and colleagues and academic staff, for providing the perfect environment to help get to this point and to achieve this work and for providing their valuable feedback and suggestions.

This research was supported by the university of ABOU BAKR BELKAID TLEMCEN and we are truly thankful for their support.

To our families, thank you for your endless patience, love and encouragement, we couldn’t have done this without them.

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List of abbreviations

CPU	Central processing Unit
DAQ	Data acquisition
DAM	Data access memory
ECU	Electronic control unit
LPG	Liquified petroleum gas
RAM	Random access memory
ROM	Random only memory

General Introduction

CONTENT

1. Project Context

In software engineering and systems engineering, providing solutions to the environment is seen as a duty for all engineers.
LPG (Liquified petroleum gas) vehicles in my country gained popularity especially among taxi drivers and many other individuals who use the LPG option due to its lower costs.

2. Problematic

We have been getting lots ofкомplaints from regular consumers of LPG vehicles and we have observed the following problems of the current LPG system :

- Damaging of the engine components by long exposure of the different temperatures leading to thermic shock.
- Ongoing pollution of the environment by the incomplete combustion leading to CO1 emissions.
- Failure to attain the maximum performance of the engine especially on climb roads.
- Increased consumption of LPG due to inefficient combustion in the engine

Having the above-mentioned context in mind, the research strives to make a contribution by a solution answering the question below:

How can a permanent LPG preheating system be integrated into existing mechanical vaporization setups to ensure consistent fuel vaporization, improve cold start performance, and protect engine components in LPG-converted vehicles?

3. Contribution

In our work we have analysed , designed and implemented a prototype that controls the heating of LPG before injection into the combustion chamber achieving optimality in the consumption of the LPG using a well studied control method and a an enhanced choose of hardware components and following systems engineering and software engineering approaches for maintaining functional and non functional qualities of the system.

4. Thesis Organization

Our master’s thesis provides a concise overview of LPG technology in vehicles,next, it presents the methodical system design that was used based on software engineering principles, finally we detail our implementation phase supported by empirical results

I. Overview of LPG technology in vehicles industry

CONTENT

Overview of LPG technology in vehicles industry

Liquified petroleum gas (LPG) is a valuable energy source used worldwide for numerous business applications in transportation and industry.

1. Definition

Liquefied petroleum gas primarily consists of propane and butane, it is a by-product of natural gas processing and petroleum crude oil refining, yielding a cleaner-burning alternative to traditional fuels like gasoline and diesel. [1] [2]

Key features making it flexible. It possesses boiling points of 42°C for propane up to 0.4°C for butane. LPG is heavier than air and holds high energy contents of approximately 25 MJ/L, is ignitable in the air in concentration ranges between 2.15% and 9.6%. LPG is odorless and colorless, with and added odorant for safety..[1] [2]

2. LPG physical and chemical properties

LPG's widespread use in automotive and domestic sectors is rooted in its unique chemical and physical characteristics, which together define its performance, safety, and versatility

Chemically, LPG is predominantly a blend of propane (C_3H_8) and butane (C_4H_{10}), occasionally containing minor amounts of other hydrocarbons such as propylene, butylenes, and traces of ethane and pentane. The mixture of hydrocarbons is highly flammable, possessing an explosive range in air from 1.8% to 9.5% by volume. The high calorific value of LPG, approximately 12,500 kcal/kg, means that it is a very effective source of energy, and clean combustion results in very little soot and sulfur emissions compared to other fossil fuels. LPG is chemically non-corrosive and non-toxic but odorless in its pure state, so mercaptan odorants are added for leak detection and safety reasons. Its auto-ignition temperature is between 410°C and 580°C, providing a safety margin against accidental ignition under normal conditions. The chemical uniformity and purity of LPG are regulated by standards to ensure engine compatibility and minimize engine deposits, especially for automotive applications..[14] [15] [16].

From a physical perspective, LPG is distinguished by its liquefaction ease at comparatively modest pressure and thus facilitating storage and transportation in the condensed form. LPG has a density of about 0.525 to 0.580 when in liquid state at 15°C, roughly half the density of water, and when released, LPG expands quite rapidly—one liter of liquid LPG will produce about 250 liters of vapor. In vapor state, LPG is 1.5 to 2 times heavier than air and will sink in low areas of ground, an important safe factor in storage and handling. The vapor pressure of LPG varies with temperature and composition from approximately 220 kPa for butane at 20°C to over 2,200 kPa for propane at 55°C.

LPG is odorless and, as mentioned, colorless except when odorized. Its boiling point is well below room temperature (propane: -42°C; butane: -0.5°C), so it evaporates very quickly when exposed to atmospheric conditions. Storage tanks are typically filled to only 80–85% capacity to allow thermal expansion and to prevent hazardous overpressure conditions.[14] [15] [16]

Property	Value(s)
Chemical Formula	Mix of C_3H_8 (propane) and C_4H_{10} (butane)
Boiling point	Propane:: -42°C ; Butane:-0.4°C
Density (liquid)	0.53-0.54(specific gravity , water = 1) [3]
Vapor Density	1.8 (air =1) [3]
Energy Content	25 MJ/L [1] [2]
Flammable range	1.5%-9.6% in air
Color/Odor	Colorless and odorless (odorant added for leak detection)

TABLE I.1 - Physical and chemical properties of LPG

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The physical and chemical characteristics of LPG—high energy content, clean combustion, ease of liquefaction, and safety features—make it a convenient and effective fuel for a wide range of applications. Its handling, however, requires careful attention to storage, ventilation, and leak detection due to its density and flammability. Understanding these characteristics is central to achieving optimum advantages of LPG while maintaining safety in its use and distribution.[14] [15] [16]

3. A brief history of LPG

3.1.Early Discoveries:

The use of natural gas dates far back to ancient times, as evidenced by discoveries in Iran between 6000 and 2000 BCE. However, the modern era of development of LPG began in the late 19th century when French chemist Pierre-Eugene-Marcellin Berthelot synthesized propane in the 1850s and '60s. [5]

3.2.20th Century Developments:

In 1910, U.S. chemist Walter Snelling identified propane as a volatile component of gasoline, which put propane into commercial service. By 1912, Snelling negotiated the first household use of propane. In 1918, the first LPG-fired blowtorch was sold. [4]

3.3. 1920s Expansion:

LPG sales grew rapidly in the 1920s, reaching 10 million gallons in the U.S. by 1929. In 1928, LPG was first used as a motor fuel in a truck

3.4.Post-WWI Growth:

Following World War I, LPG production and use expanded significantly. By 1947, the first liquefied gas tanker was built, and by the 1950s, international export contracts were established

3.5.Modern Era:

Today, LPG is widely used for cooking, heating, and as a cleaner automotive fuel. Its infrastructure has grown globally, with significant advancements in distribution and storage technologies.

The development of LPG illustrates a steady evolution from early natural gas observations to a versatile and accessible modern fuel. Initial scientific discoveries in the 19th and early 20th centuries laid the groundwork for its practical applications.

First in domestic use and later in industrial and automotive sectors. Over the decades, advancements in storage, transport, and distribution have positioned LPG as a reliable alternative energy source. [4]

LPG's cleaner combustion properties, relative affordability, and suitability with existing engines have rendered it a desirable option, particularly in nations like Algeria where reducing fuel prices and diversifying energy consumption is an ongoing pursuit. Greater transport use of LPG across North Africa reflects its role in addressing economic and environmental challenges and thus becoming a major player in the region's evolving energy landscape.

FIGURE I.1 - Frank Philips - the world's first LPG producer [5]

4. How LPG Works

LPG operates in vehicles because of a wide range of factors, hence proving to be an effective and efficient substitute fuel source. Its energy content is one of the key factors. LPG contains a lot of energy per unit volume with high energy content, hence allowing vehicles to offer the same performance as gasoline or diesel-fueled vehicles. The energy density allows LPG-powered vehicles to offer the same level of performance, which is a factor making it an effective means of everyday use.

The second critical factor is LPG's high octane rating, typically 105 to 110. LPG's high octane rating makes it resistant to engine knocking, or pre-detonation, when it is combusted. Engine knocking can cause engine damage and reduce efficiency, but LPG's knock resistance translates into smoother, more efficient engine operation. This leads to better performance, better fuel economy, and potentially longer engine life.

The vehicle's life cycle of LPG consists of a passive mechanism that relies on mechanical processes rather than active electronic management. The LPG is stored in a high-pressure tank and is fed into a reducer, where it gets heated by the engine's coolant system. This passive preheating process plays a crucial role to convert liquid LPG into a gaseous state suitable to burn. The vaporized LPG is then pumped into the engine's intake manifold, where it gets mixed with air and subsequently burns inside the combustion chambers. Car LPG systems today lack active preheating or vaporization systems but utilize the natural heat transfer from the engine's cooling system [7] . This passive approach simplifies the system and reduces the utilization of additional electrical components, hence making it cost-effective and reliable for dual-fuel vehicles to switch between LPG and gasoline [6]

To conclude, LPG works in vehicles because it has high energy content, knock resistance, clean combustion, and effective fuel supply systems. These render it an effective, low-cost, and eco-friendly source of fuel for modern vehicles.

5. Components of LPG systems in vehicles

LPG vehicles have some key components that make it possible to use it as a fuel listing them below

1. LPG tank: Usually located in the boot or spare wheel well. Contains the LPG under pressure and it has pressure release safety valves and to prevent overfilling
2. Tank valves: includes filling valve, non-return valve, pressure relief valve, manual valve and solenoid valve
3. Reducer (Vaporizer) : Converts liquid LPG to gaseous state using the heat of the cooling system of the engine
4. Gas Filter: Eliminates contaminants and oily deposits to provide a clean gas flow to the injectors
5. LPG Injectors: Injazzs the right quantity of gas into individual cylinders, as commanded by the ECU
6. Electronic control unit (ECU)**:** Manages the fuel-air mixture by calculating the quantity of gas to inject and timing of injection.
7. Fuel changeover switch**:** Allows the driver to switch between LPG and Gasoline and it has automatic switch on certain conditions (reaching specific temperature or if LPG runs out)

These components combined play to ensure proper and safe operation of LPG systems for application in motor vehicles. The technology is essentially passive, whereby preheating and vaporization occur through the process of natural heat transfer rather than through active electronic methods[8]

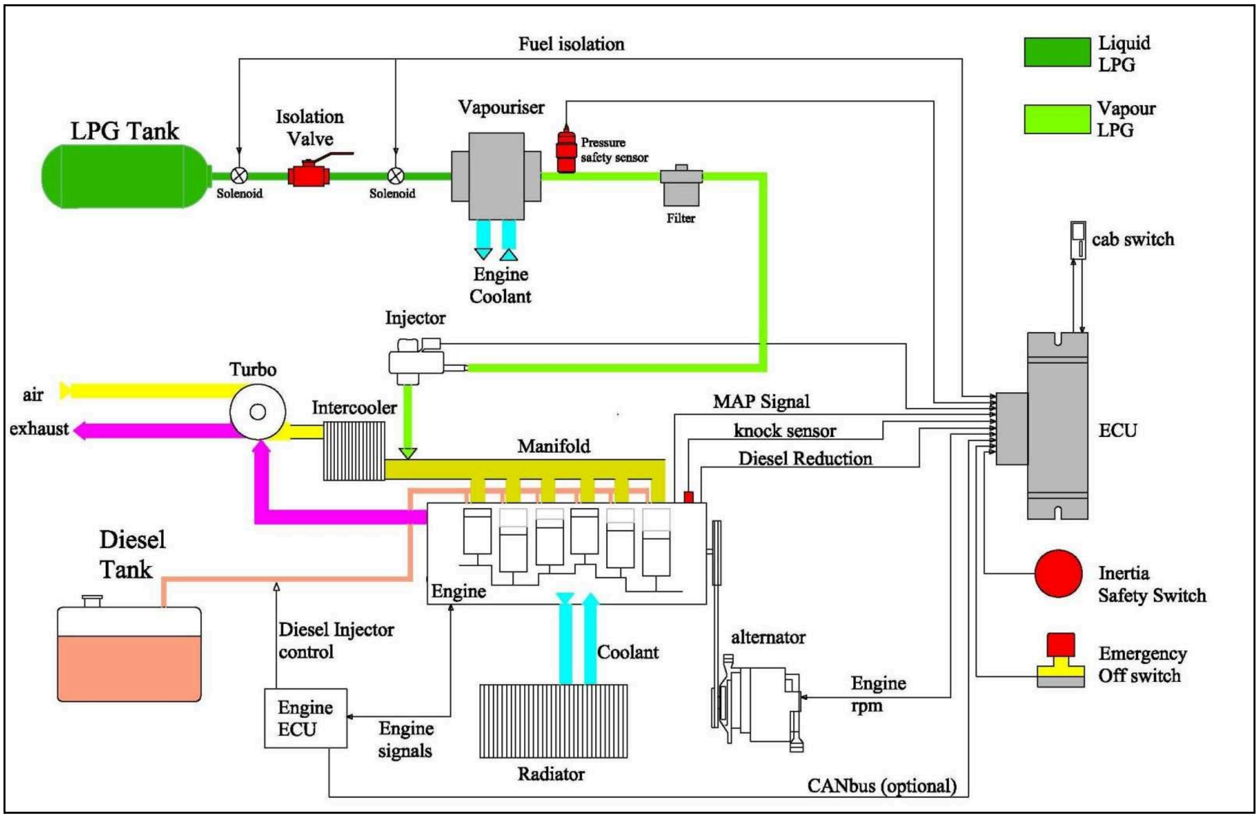

FIGURE I.2 - Schematic Diagram of LPG-Diesel Dual Fuel System in Vehicles [9]

6. From tank to combustion chamber: LPG LIFECYCLE

When the fuel is needed by the engine, LPG is first released from the pressurized tank. Through high-pressure fuel lines.

It then enters the mechanical reducer (regulator) which is tasked with converting the LPG to a gaseous state, the reducer uses heat from engine's coolant system

Noting that the conversion process only depends on

- Coolant temperature
- Ambient conditions
- Engine heat load

Thus it will have several negative effects on the engine and on the environment in the long term.

After liquid to gas conversion phase, the LPG passes through medium-pressure hoses to the intake system of the engine, and depending on vehicle type and age different injection systems can be used which are :

- **Mixer Systems (venturi type):**

In such setups, the LPG is supplied to the intake air under a simple venturi effect and without injectors, Metering of fuel depends on the utilization of the engine's natural vacuum plus a plain mechanical diaphragm, Though the systems are comparatively simple and robust, they lack precision, because this has the tendency to create an unpredictable air-fuel mixture leaning too frequently towards being either too lean or too rich

Sequential Gas injection (SGI):

Newer LPG vehicles use electronic injectors to provide vaporized fuel. While the vaporizer is still mechanical, injection timing and quantity are ECU-controlled for optimum fuel-air mixtures.[10]

In both systems , the LPG vapor mixes with incoming air in the intake manifold. The air-fuel mixture quality impacts combustion performance, power, output and emissions.

Once the mixture has been admitted into the cylinders, the burning will begin by drawing the mixture by the piston that takes place during the intake stroke stage .It is then followed by the compression stroke that squeezes the mixture for high energy release. At the ignition phase, a spark plug ignites the compressed fuel mixture.Owing to LPG's high octane rating (105–110), the combustion is knock-resistant and clean, leading to a rapid burn which pushes the piston downwards and builds mechanical power. Following combustion, even conventional systems in modern engines usually consist of oxygen sensors to monitor exhaust gases and catalytic converters to reduce toxic emissions such as NOx, carbon monoxide, and unburned hydrocarbons.[11]

The below FIGURE I.3 we see the displaying latest generation LPG system architectures called the LPI and LPDI

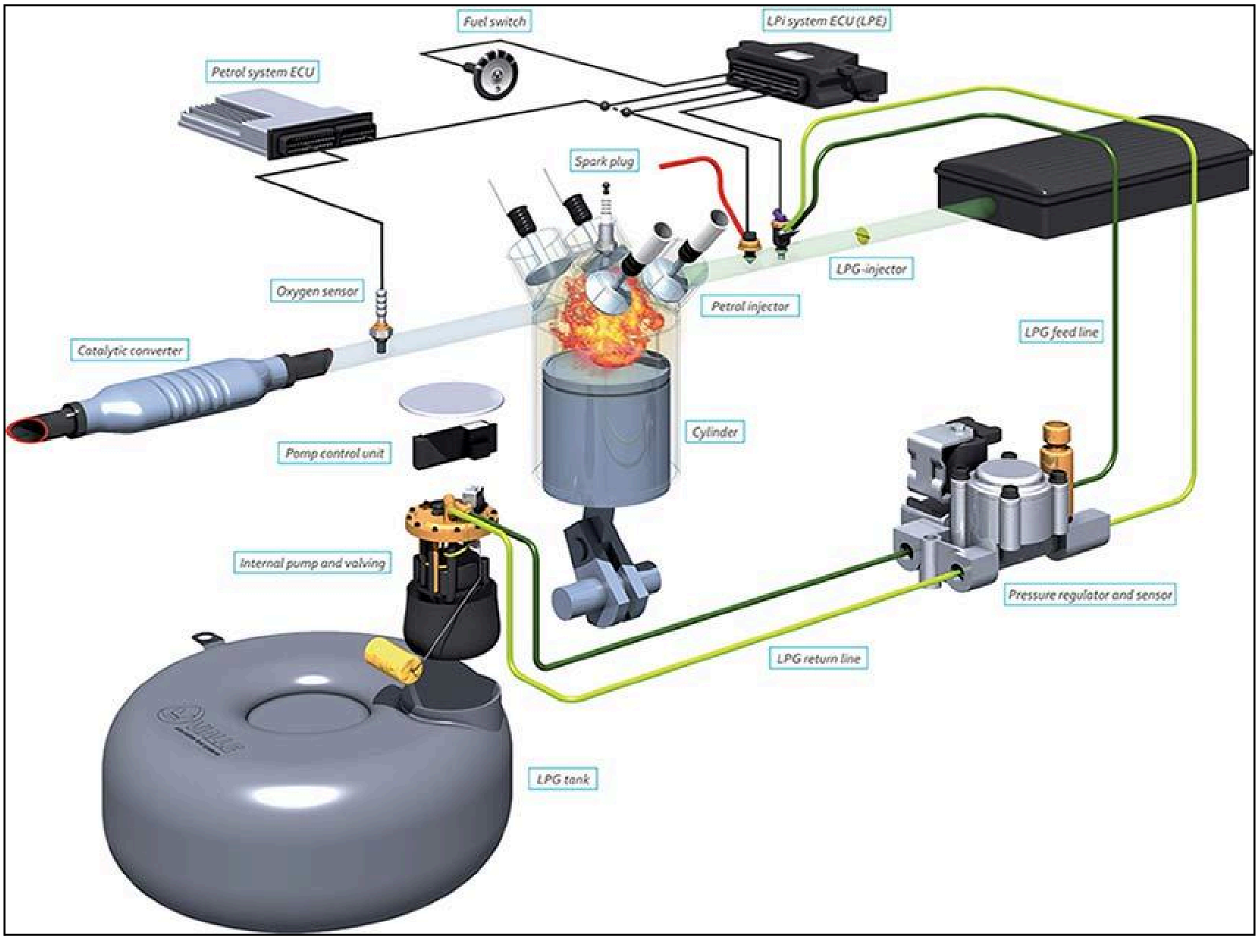

FIGURE I.3 - LPG vialle lpi system architecture [13]

The LPG refueling process of a vehicle includes a number of phases influencing engine performance and the environment. LPG is dispersed from a pressurized tank and mechanically compressed into gas, using engine coolant system heat. The process is dependent on parameters like engine load and coolant temperature, which have negative impacts on the engine and emissions in the long term.

LPG, once converted, is supplied to the engine intake system, which can utilize two forms of injections: simple mixer systems or more advanced Sequential Gas Injection (SGI) systems. SGI systems are more precise in controlling the fuel-air mixture and influence engine performance and emissions.

In burning, LPG's high octane number ensures a clean burn, increasing efficiency and reducing knocking. Modern engines make use of sensors and catalytic converters to cut down on nasty emissions, and LPG becomes an even cleaner fuel source.

7. LPG in Algeria

LPG in Algeria was used in 1983 and was led by NAFTAL. In the years that followed, NAFTAL was instrumental in the construction of more than 400 distribution stations and more than twenty conversion centers. The private sector was included to the conversion activities' purview in 1995. Currently, there are an estimated 120,000 automobiles that have been converted to LPG/C, and there are more than 100 authorized installers spread out over the country. (APURE, 2019, p 03).[Lakehal Elamine , 2024] [14]

This government program is among the largest endeavors in North Africa to adopt replacement fuels, primarily on economic grounds of fuel substitution, environmental impact reduction, and enhanced energy self-reliance. Over time, the state has also provided financial incentives to LPG conversion and helped build domestic conversion and maintenance capabilities.

Despite such a good trend, good percentages of Algeria's LPG-powered vehicle stock are fitted with older-generation systems founded on mechanical vaporization processes, particularly among poorer and rural communities. These systems usually do not include precise electronic control and are even more susceptible to inefficiency when cold starting or low ambient temperature, which is a condition that is common within Algeria's highland and steppe areas during winter.

Years	Consumption	Vehicles	Refuelling sites
2015	291	24700	604
2019	936	120 000	803
2021	1385	100000	1044
2022	1550	120000	1285
2023	1730	730 000 (01/01-30/06/2023)	131

TABLE I.2 - Local market demands for LPG [14]

The numbers presented in TABLE I.2 clearly illustrate that Algeria has made a serious and concerted effort to accelerate the conversion of automobiles to liquefied petroleum gas (LPG). During the nine-year period—from 2015 to the most recent available data—the annual rate of conversion has quadrupled, which speaks to the serious commitment and active efforts of Algerian authorities. This spectacular growth is the result of a combination of key factors, each contributing in its own measure to the general trend of LPG use in the nation.14]

8. Pricing and consumer behaviour

Algerian strategic price interventions conducted three times since 2015 have seen remarkable evolution of price in conventional fuels. Petrol prices, for instance, have increased over double from 22.60 DZD per liter in 2015 to 44.62 DZD per liter in 2020. Diesel prices also increased from 17.70 DZD per liter in 2015 to 28.6 DZD per liter in 2020. Prices of LPG surprisingly remain constant with a nominal of 9 DZD per liter. This constant price and the fact that LPG boasts of a cut-and-dried cost advantage over traditional fuels has seen it be a highly-sought and affordable product among consumers where increasing costs of fuel define the markets.[14]

The continuous governmental incentives of Algeria also assisted in the large-scale use of LPG-powered vehicles. The government has a streamlined policy system that encompasses the subsidization of 50% of the conversion price to car owners. In so far as the cost of converting a car to run on LPG is 70,000 DZD, half of which is covered by the government and which it takes 35,000 DZD per cost of conversion. Vehicle conversion rules and regulations also streamlined and prioritized safety and quality standards.[14]

The second critical component of the transition has been growth in the distribution network of the LPG. Algeria has long understood the very inherent nexus between the production and distribution and use of the fuel in the supply chain and has moved early in the construction of its distribution network of the LPG. There has been more than double growth in the fuel points of the LPG from 604 in 2015 to 1,315 in 2023. This has been complemented through a policy of strategic importance mandating the owners of fuel stations to include facilities of distribution of the LPG in their projects. Naftal, with its market share of dominance with the backing of a state support, has been a pace setter in supporting the construction of facilities to equip all the non-LPG installed stations in full. This is in accordance with the vision of Algeria in establishing a viable and sustainable energy network in its larger vision of energy transition and sustainability in the environment.[14]

Overall, Algeria has been making significant strides towards promoting the shift towards liquefied petroleum gas (LPG) vehicles, as seen through the remarkable improvement in conversion levels in recent years. This rise has largely been driven by a number of favorable factors that include the stability and low price of LPG compared to the rising costs of traditional fuels such as diesel and gasoline. Evidence of the government's backing of the program takes the shape of substantial subsidies to convert cars to run on LPG in addition to the streamlining of regulatory measures aimed at maintaining safety and quality standards. In addition to that, the country has focused on expanding its network of LPG outlets, which has seen a remarkable increase in the number of gas outlets that sell LPG. These efforts show that Algeria is serious about initiating a green energy shift in a bid to tackle the rising demand for cleaner and cheaper fuels.

9. Environmental Impact of LPG Compared to Other Fuels

LPG (Liquefied Petroleum Gas) is a prime contender as a cleaner fuel alternative to traditional fossil fuels like gasoline, diesel, and even coal.[17] [18] Its combustion properties and production processes emit less and have a smaller carbon footprint, making it a prime choice for the transition towards cleaner sources of energy. [19 [20]

8.1.Reduced Emissions

LPG vehicles can achieve an up to a 21% decrease in the emission of CO2 and an up to 95% decline in particulate matter emissions with its cleaner-burning properties [21]. Up to 20% less CO2 is released by LPG compared to gasoline, which alleviates climate change [17] . The carbon impact of LPG is more than 20% less than that of gasoline and more than 10% less than diesel [20]. Besides, LPG combustion produces minimal particulate and nitrogen oxides (NOx), major air pollutants, and zero sulfur emissions, as compared to coal and oil, reducing acid rain issues and water ecosystem destruction [17] .

8.2.Air Quality Improvements

The use of LPG in cars leads to cleaner air in particular in densely populated cities.[17] LPG cars emit less toxins in air and less greenhouse gas compared to regular diesel and gasoline cars. One diesel car emits 120 times the particulates of one equivalent car that runs on LPG, and 20 cars running on LPG will emit the same NOx of one diesel car.[18].

8.3.Well-to-Wheel Analysis

From a "Well-to-Wheel" perspective, an LPG-powered medium-sized vehicle emits less CO2 than gasoline and diesel vehicles. All fuels have a greenhouse gas (GHG) intensity value given to them, which is calculated on a life-cycle basis, comprising fuel extraction, processing, and distribution emissions, for which the EU is planning to reduce the intensity of greenhouse gases in fuels [22].

8.4.Impact on Ecosystems

LPG is nontoxic and has no influence on soil, water, and groundwater aquifers. The combustion of LPG does not release sulfur dioxide (SO2) into the atmosphere, meaning less acid rain issues and less harm to aquatic life [19].

LPG is a green and clean source of energy compared to conventional fuel that provides significant reductions in emissions and is a source of clean air and less carbon footprint. Its attributes allow it to be easy and effective to achieve a decrease in the transport sector's impact on the environment. [19].

II.Overview of Software Engineering and control systems

CONTENT

Overview of Software Engineering and control systems

1. Requirements engineering

Requirements engineering is the procedure that aims to identify and reach consensus with stakeholders of the system requirements that must be built.
The best practices for creating the working environment of a project, both contractually and technically. [23].

The lifecycle usually englobes the following phases

1. **Creation Phase**:
   The process begins (vision, business need or opportunity, good idea, etc.). Business case, feasibility study, system scope, risks, etc.
2. **Requirements Elicitation**:
   Requirements are discovered by consulting (and sometimes even provoking) various stakeholders.
3. **Requirements Analysis and Negotiation**:
   Requirements are analyzed and conflicts resolved, often through negotiation.
4. **Requirements Specification**:
   A precise document describing the requirements is produced.
5. **Requirements Validation**:
   The requirements specification is verified for consistency and completeness.
6. **Requirements Management**:
   As needs evolve, so do requirements. [23].

Requirements engineering is mostly considered a central and fundamental activity in the software development life cycle, as it significantly influences whether a project will fail or be successful, a successful requirements engineering process allows the production of software that is well adapted to satisfy user needs appropriately, while poor requirements management is likely to lead to project delay, cost overrun, or system failure.
With the inherent volatility of requirements over time, requirements engineering remains a required discipline, providing the infrastructures needed to anticipate, manage and adapt changing needs throughout the software life cycle.

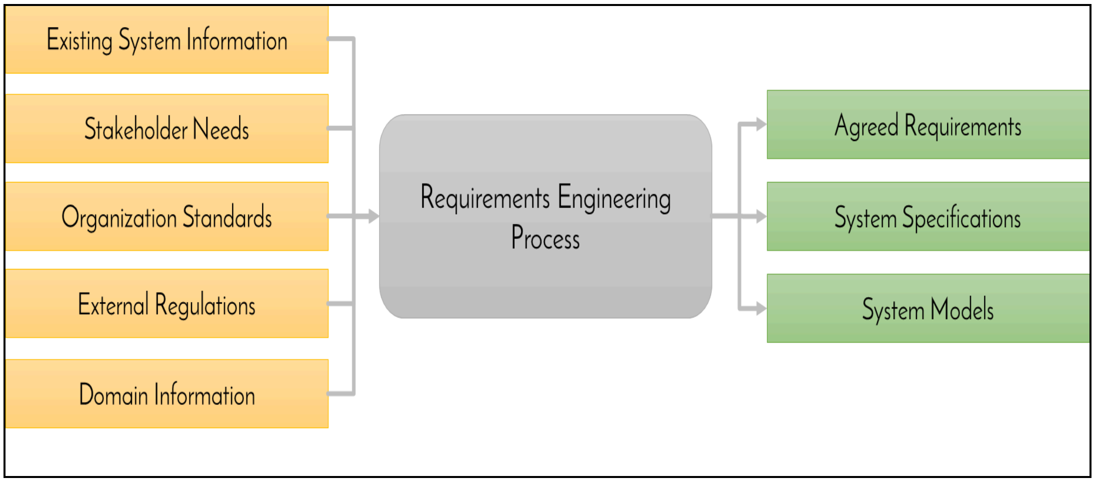

FIGURE II.1 - The overall requirements engineering process [24]

2. Software engineering

Software engineering is a systematic, structured, and measurable process for developing, operating, and maintaining software systems. Software engineering is the application of engineering methodology in software development with the final goal of developing high-quality, reliable, and scalable solutions that provide realistic solutions to intricate problems of the real-world scenario. Software engineering came into being to address the growing intricacy of software systems and the vital role played by software in contemporary society, requiring effective methodologies and frameworks for ensuring success in software projects.[25]

2.1.Software Development lifecycle (SDLC) Models

The Software Development Life Cycle, or simply SDLC, summarizes and describes the systematic and methodical stages that are required and included in the software development and creation process:

- Requirements Engineering:As mentioned above, RE is the disciplined process of elicitation, complete documentation, and careful validation of the requirements specified by different stakeholders, as discussed in detail above..

- Design: Architectural and detailed design, focusing on system structure, interfaces, and data flows.

- Implementation: This stage entails the process of converting designs into working code, while closely following proven best practices that guarantee both maintainability and scalability of the ensuing software.

- Testing: Rigorous verification and validation through unit, integration, system, and acceptance testing.

- Deployment and Maintenance: Release management, user support, and iterative enhancement based on feedback and defect resolution.

Prominent SDLC models include Waterfall, Iterative, Incremental, Agile, and DevOps. Each model offers distinct advantages and is selected based on project requirements, risk profile, and stakeholder engagement [25]

2.2 Software engineering for hardware-software integration

Embedded system design has its fundamental basis in hardware and software integration, specifically in the case of microcontroller-based systems. It ensures that the embedded code to read sensors, write to actuators, and use communication protocols is robust, synchronized, and code-efficient to talk to physical devices successfully. Integration has to be accomplished successfully by following a disciplined process involving requirements analysis, interface design, co-development, and rigorous verification and validation.

2.2.1. Hardware-Software Interface Design and Abstraction

Most crucial among these in embedded systems based on a microcontroller is the role of software engineering to design long-lasting and stable interfaces between hardware and software modules.

- Hardware Abstraction Layers (HALs): HALs allow you to isolate application logic from hardware details, making them portable and easy to maintain. [26] [27]

- Device Drivers: Developing driver modules that manage communication with sensors and actuators and other peripherals following encapsulation and separation of concerns principles.[28] [29]
- Communication Protocols: Implement and select protocols such as UART, SPI and I2C in order to support efficient data communication with external devices and the microcontroller.[26] [27]

- Interface Documentation: Providing comprehensive details and interface contracts to allow coordination and minimize the risk of integration failures. [26] [30]
- Error Handling: Developing software to identify and handle hardware failures gracefully, making the system more resilient [29]

Good hardware-software abstraction and design is key to the feasibility of embedded systems. By utilizing hardware abstraction layers, device driver modularity and communication protocol appropriateness, application logic is uncoupled from hardware detail and portability and maintainability of the system is promoted and fault tolerance is also attained. Decent interface documentation and stringent error handling also reduces faults during integration and enhances collaboration between software and hardware teams. While most of the embedded system development challenges according to literature appear at the hardware-software interface and careful interface abstraction and design is therefore good practice and even mandatory in scalable and reliable embedded solutions

3. Embedded systems

An embedded system can be defined as an isolated system, designed to perform a designated function with the help of its hardware and embedded software.

In simple terms, an embedded system is a bit like a special-purpose computer that has been built into a device that is not generally considered to be a computer.

They are named 'embedded' systems because they always function as part of a complete device. [31]

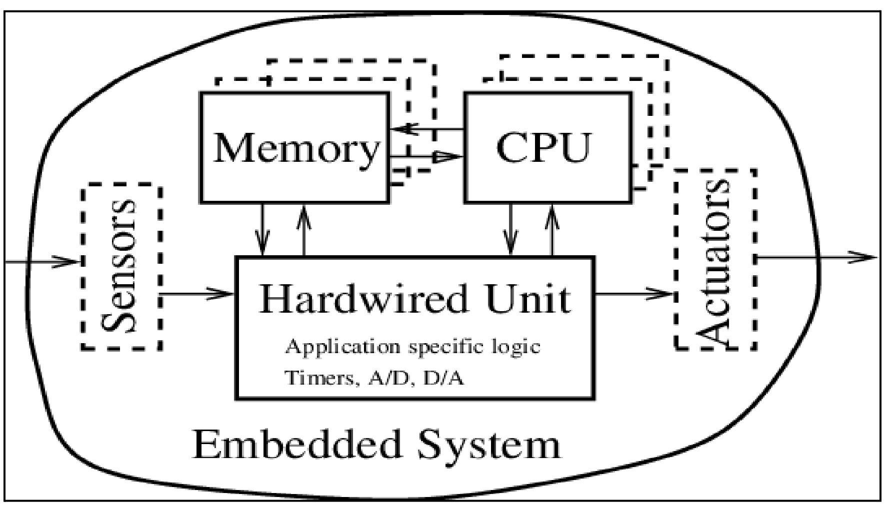

FIGURE II.2 - Embedded System Architecture.[31]

The Figure above illustrates the general internal structure that can be find in any embedded system , highlighting the interplay between it's core components such as the cpu-memory , sensors-hardwareUnit , harwareUnit-actuators …etc and thus we will define each one:

- The Sensor Interface: the first source of data, for that will be processed by CPU and saved into the memory.they can be of any type and size to serve the desired purpose and play the role of the system's input channel.
- The hardwareUnit & CPU: The application's specific intelligence that orchestrates the flow of data for different purposes , interpreting data based on programmed logic , and issues instructions accordingly.
- Memory – Short- and Long-Term: Embedded computers require processing with memory. Memory holds sensor information, system status, configuration, and program code. Volatile RAM contains transient data, and there is non-volatile ROM or Flash to store things long-term. Arrows represent transfers between the CPU and memory, and there is hardwired and memory-mapped I/O or DMA (Direct Memory Access) in advanced designs.
- Actuators – The Output Mechanism Once an embedded system has processed input information and made conclusions, it needs to act on the environment. It does this by using actuators, which translate digital information into physical motion—it rotates a motor, opens and closes a valve, or produces noise. The output to actuators illustrates the embedded system as an effector or controller of the environment.[32]

In summary.The industry for embedded systems is expected to continue growing rapidly, driven by the continued development of Artificial Intelligence (AI), Virtual Reality (VR) and Augmented Reality (AR), machine learning , deep learning, and the Internet of Things (IoT). The cognitive embedded system will be at the heart of such trends as: reduced energy consumption, improved security for embedded devices, cloud connectivity and mesh networking, deep learning applications, and visualization tools with real time data. According to a 2018 report published by QYResearch, the global market for the embedded systems industry was valued at $68.9 billion in 2017 and is expected to rise to $105.7 billion by the end of 2025.[33].

4. Data Acquisition (DAQ) Systems

DAQ is the overall process of measurement of real-world phenomena in digital form. The basic elements of an instance of a computer-based DAQ system are shown in FIGURE II.3 Most of the process equipment, i.e., transducers and sensors and final control elements, are analog and they generate or recognize analog electrical signals. DAQ hardware predominantly performs analog-to-digital (A/D) and digital-to-analog (D/A) signal translation. More and more DAQ works with a computer, i.e., the typical personal computer such as the standard PC. The computer in this figure runs DAQ software, which processes and stores the data..[34]

At the heart of the DAQ system is data conversion, that is, the conversion of analog signals to digital representations and vice versa. It is accomplished in two stages: first the signal is quantified and later it is codified. Quantifying means representing the continuous values of the analog signal by a discrete set of values, and codifying entails symbolizing these discrete values by bit sequences. The number of bits of those sequences determines the number of possible values of the conversion: 2n for n bits.[34]

A/D and D/A provide the interface between the analog world (real world) and the world of computer computation and data processing. Several of the uses of analog– digital interfaces are very prominent as we use them in our lives. Temperature controllers, computers and associated peripherals, electronic fuel injection, and compact disc music systems are merely a collection of the common applications that need analog–digital interfaces. A/D's electronic circuitry performs the quantization and coding operations. The A/D works in terms of fixed amplitude signals, say between −SV and +SV. Another electronic circuit of D/A performs conversion of digital signals into analog signals. This device converts digital codes of n bits into a signal of 2n discrete voltage or current levels. D/A will be addressed first since they are usually simpler than A/Ds and are usually used as a part of an A/D..[34]

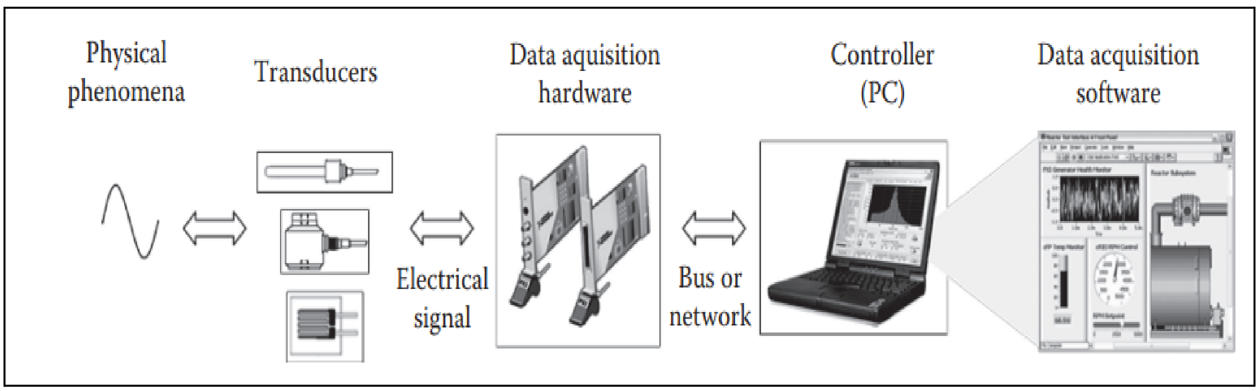

FIGURE II.3 - Basic element of a DAQ system.[34]

4.1 DAQ system architectures

- **Standalone DAQ systems**
  DAQ systems that are stand-alone are independent units containing all necessary hardware and software to acquire, process, and even store data independently. Such systems do not require a persistent connection to a computer or network to function.[36]

- **Distributed DAQ systems**
  Distributed DAQ systems consist of a number of networked modules or nodes, each of which has the responsibility for data acquisition at different locations. Nodes transfer data to a master server or computer for processing, consolidation, and storage.[36]
- **Wireless DAQ systems**

Wireless DAQ systems leverage wireless communication technologies to transmit data from sensors and acquisition modules to central processing units or cloud platforms.[36]

4.2 Temperature DAQ system

Temperature sensors are fundamental components in the implementation of the Internet of Things (IoT) and industrial automation in this era of intelligence. They can monitor environmental changes in real-time, convert temperature signals into electrical signals or other formats that can be recognized, and provide valuable data support in system control, data analysis, and prediction. This article will introduce the process of data collection of temperature sensors, including the selection of sensors, data acquisition methods, data transmission and storage, and practical application considerations.[35]

4.2.1 Selection of temperature sensors

Temperature sensors come in various types, classified according to their measuring principle into resistance temperature detectors (RTDs), thermocouples (TCs), semiconductor temperature sensors (e.g., thermistors and analog/digital output temperature sensors), etc. Consider the following while selecting an appropriate sensor:[35]

- Measurement Range:

Ensure the sensor measurement range covers the intended temperature range.

- Accuracy and Stability:

Select sensors with good accuracy and long-term stability depending on application requirements.

- Response Time:

Fast response time sensors would suit applications requiring immediate temperature feedback.

- Environmental Adaptability:

Remember the moisture resistivity, corrosion resistivity, etc., of the sensor to accommodate different work environments.

- Cost and Maintainability:

Keep in mind cost-effectiveness and maintenance ease at later stages while maintaining performance.

4.2.2 Temperature data Acquisition methods

- Analog Signal Acquisition:

RTDs and thermocouples typically generate analog voltage or current signals that need to be translated into digital signals by analog input modules (e.g., ADCs, analog-to-digital converters) for computer processing.
Signal amplification, filtering, and linearization in acquisition should be taken into consideration in order to reduce noise interference and improve data accuracy.[35]

- Digital Signal Acquisition:

Most of the new temperature sensors like DS18B20 and LM75 produce digital output directly and can be directly interfaced with microcontrollers (MCUs) or computers via communication protocols like I²C and SPI.
Digital signal collection makes the circuit design much simpler and enhances the efficiency and precision of data transmission.[35]

4.2.3 Data transmission and storage

- Wired Transmission:

Adopt wired communication standards such as RS-485, CAN bus, and Ethernet to transmit sensor data to a central processor or data server.
Wired transmission is stable and reliable with higher wiring costs and lower flexibility.[35]

- Wireless Transmission:

Adopt wireless communication standards such as Wi-Fi, Bluetooth, LoRa, and Zigbee to achieve remote transmission of sensor data.
Wireless transmission is convenient for wiring and suitable for distributed monitoring systems and mobile equipment.[35]

Data can be stored on local SD cards, USB storage devices, or cloud servers.
The application of cloud computing and big data technology makes it possible to store, analyze, and mine massive temperature data.[35]

The temperature sensor data collection process is a high-technology process with multidisciplinary knowledge, i.e., sensor technology, signal processing technology, communication technology, and data processing and analysis technology. As IoT, big data, and artificial intelligence technologies continuously innovate steadily, the accuracy, efficiency, and intelligence level of temperature sensor data collection will significantly improve, providing more accurate and efficient temperature information support for intelligent manufacturing, smart cities, and environmental monitoring. In the future, temperature sensors and data acquisition technologies will be developed, promoting sustainable economic and social progress, and in the end leading to a more safe, comfortable, and efficient life for mankind.

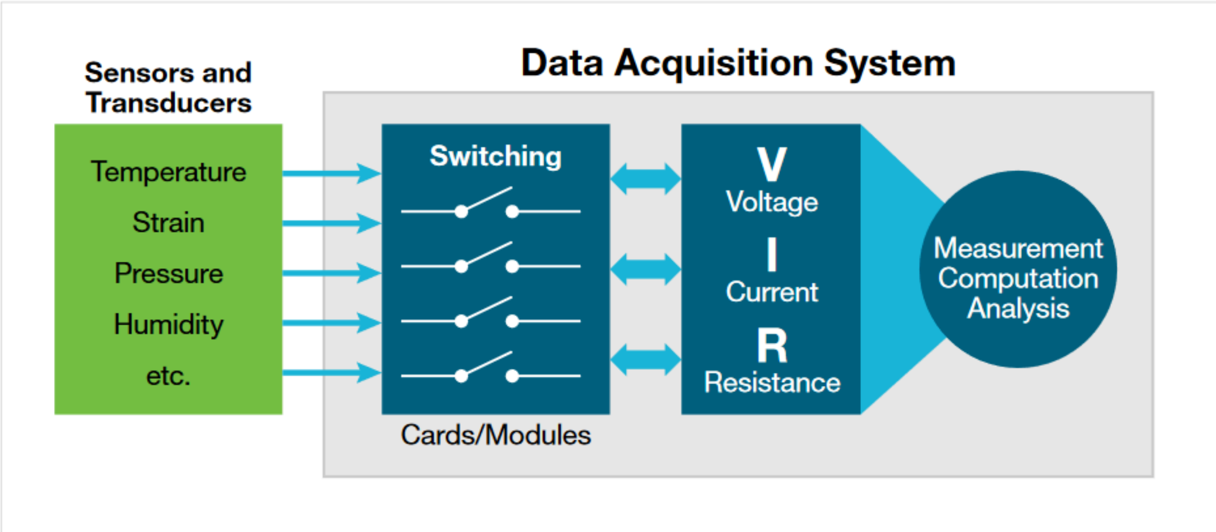

FIGURE II.4 -DAQ system architecture . [37]

5.PID Controller

PID (Proportional-Integral-Derivative) controllers are closed-loop control mechanisms widely used to regulate industrial processes such as temperature, pressure, and flow. They adjust the control output by calculating the error between a setpoint (SP) and a sensed process variable (PV) in terms of three corrective terms:

Proportional (P): Corrects for present error (difference between SP and PV).

Integral (I): Addresses past errors to eliminate offsets in steady state.

Derivative (D): Predicts future error patterns based on the rate of change.
The PID algorithm is expressed as:

$$u(t) = Kpe(t) + Ki\int 0te(\tau)d\tau + Kd\,(dt/de(t))$$

Where u(t) is the control overall output, e(t) is the error (SP - PV), and K_p , K_i , K_d are tuning grains.[38] [39]

1. Proportional tuning involves correcting a target proportional to the difference. Thus, the target value is never achieved because as the difference approaches zero, so too does the applied correction.
2. Integral tuning attempts to remedy this by effectively cumulating the error result from the "P" action to increase the correction factor. For example, if the oven remained below temperature, "I" would act to increase the head delivered. However, rather than stop

heating when target is reached, “I” attempts to drive the cumulative error to zero, resulting in an overshoot.

3. Derivative tuning attempts to minimize this overshoot by slowing the correction factor applied as the target is approached.

The purpose of a PID controller is to adjust feedback to equal a setpoint, i.e., a thermostat, which causes the heating and cooling system to turn on or off based on a set temperature. PID controllers are best used in systems that have a relatively low mass and those which react quickly to changes in energy input into the process.[40]

It is recommended in systems where the load changes often and the controller is expected to compensate automatically due to frequent changes in setpoint, the amount of energy available, or the mass to be controlled.[40]

5.1 Types of PID Controllers

- ON/OFF controllers **:**
  These are the simplest form , it switches output fully on or off when PV (processed variable) crosses SP (setpoint).[40]

- Proportional controllers:
  It doesn’t force switch on or off but it adjusts the output proportionally to error , while it reduces overshoot but it may leave residual error.[40]

- Standard PID controllers: Combines P,I and D terms for precise , stable control.They dominate industrial applications.[40]

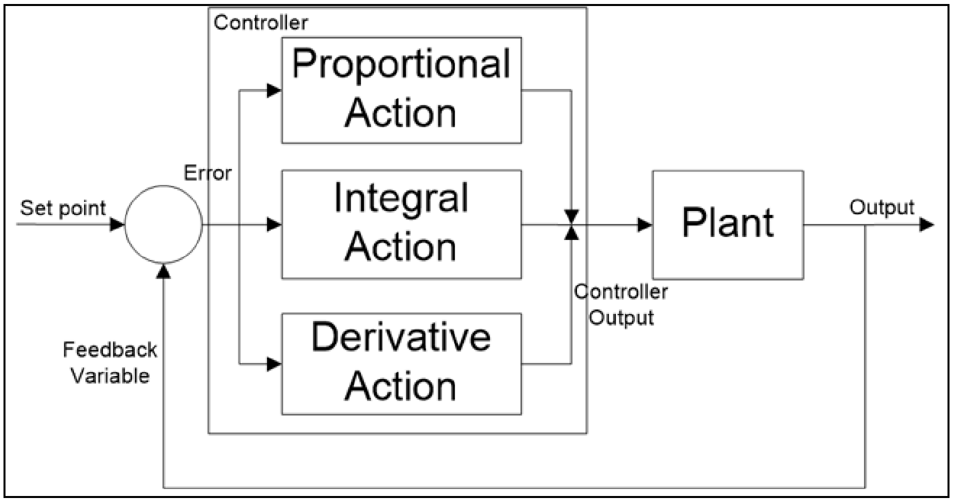

FIGURE II.5. PID Controller architecture.[41]

PID controllers are a fundamental cornerstone of automatic control systems, offering a well-proven way for the control of desired setpoints in dynamic processes. Their ability to incorporate proportional, integral, and derivative actions allows accurate correction of present, past, and future errors and makes them extremely effective for most industrial purposes. Despite their shortcomings—vibration sensitivity in the derivative term or tuning problems for nonlinear systems—PID controllers remain the first choice in most settings due to their simplicity, ruggedness, and versatility. While adding sophistication to control, PID control remains the foundation that can be augmented by more advanced methods like fuzzy logic and adaptive systems if traditional methods are too weak to stand alone.

6. Fuzzy Logic theory

Fuzzy logic, which was created by Lotfi Zadeh in 1965, is a mathematical framework for handling reasoning that is uncertain or imprecise, in effect extending the applicability of traditional binary logic. While standard logic restricts statements to being either absolutely true or false, fuzzy logic allows for a continuum of truth values between 0 and 1, mirroring how humans perceive and understand information in a gradual way. This approach is especially suitable for the representation of complicated systems where crisp boundaries are not feasible or even not possible, e.g., linguistic terms like "warm," "tall," or "fast," which do not have precise definitions in the real world.[42] [43]

At the heart of fuzzy logic are fuzzy sets and membership functions. Fuzzy sets allow elements to belong to multiple sets simultaneously, each with a degree of membership quantified by a value between 0 and 1. For example, a temperature of 25°C might be considered both "warm" and "hot" to varying degrees, depending on the membership functions defined for those categories. Membership functions can take various forms-linear, exponential, or Gaussian-depending on the modeling needs, and they enable fuzzy logic to represent vague concepts more naturally than binary logic.[42] [43]

Fuzzy logic systems operate through a sequence of stages: fuzzification, inference, and defuzzification. Fuzzification transforms crisp input values (like a measured temperature) into fuzzy values using membership functions. The inference engine then applies a set of fuzzy rules-often in the form of "IF...THEN..." statements-to these fuzzy inputs, combining them to reach intermediate conclusions. Finally, defuzzification converts the fuzzy output back into a precise, actionable value, suitable for real-world control or decision-making.[42] [43]

6.1 Architecture of a Fuzzy Logic Control System

Fuzzy logic control systems (FLCs) are designed to mimic human decision-making and are especially well-adapted to nonlinear, complex, or ill-specified systems. The default structure consists of several key components: [43] [44].

- Fuzzifier: Converts crisp numeric inputs into fuzzy values using membership functions.
- Knowledge Base: Stores the definitions of the fuzzy sets and the set of fuzzy rules that describe the system behavior.
- Rule Base: Stores a set of IF-THEN rules, typically derived from expert knowledge or empirical information, that transform input conditions to control actions.
- Inference Engine: Works on the fuzzified inputs according to the rule base, applying fuzzy logic operations (AND, OR, NOT) to the outputs of all the applicable rules to produce fuzzy outputs.
- Defuzzifier: Converts the fuzzy output back to a crisp value suitable for driving actuators or making decisions.

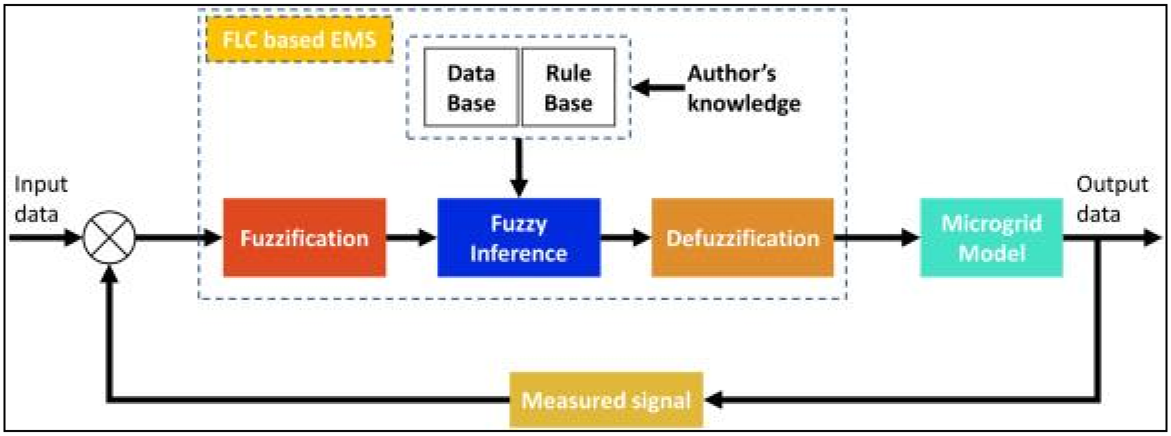

FIGURE II.6. Fuzzy logic architecture. [45]

Fuzzy logic provides an effective, versatile, and intuitive means of addressing uncertainty and complexity in control and decision-making. By bridging the gap between human thinking and machine calculation, fuzzy logic makes it possible to design robust controllers and intelligent systems that can operate in real-world, imprecise environments. As technology advances, fuzzy logic's use in hybrid and adaptive systems will extend, and hence it remains a useful tool even in the era of intelligent automation

III. Analysis,conception and implementation

CONTENT

Analysis ,conception & implementation

1. Analysis

First of all, we will be introducing the functional and non functional requirements as they are part of the analysis process followed by the assumptions and constraints and later we will be showcasing results in the form of conception and implementation.

1.1 Functional Requirements:

Active Preheating Capability

The system should be able to guarantee constant preheating of LPG (Liquefied Petroleum Gas) in all vehicle operating modes, both stationary (idle) and dynamic (driving) modes. It needs close interaction with the electrical and thermal domains of the vehicle in order to maintain a constant energy supply and effective heat management under any driving condition.

PID-Based Temperature Control

The system needs to operate with maximum LPG temperature through a closed-loop Proportional-Integral-Derivative (PID) control algorithm. The PID controller needs to monitor temperature feedback continuously and dynamically control heating power to minimize error margins and prevent overheating or underheating, guaranteeing fuel efficiency and combustion stability.

Extreme Climate Resilience

The preheating system should be able to function effectively in extreme environmental conditions of very low (sub-zero) and very high ambient temperatures. This requires the careful selection of the right thermal insulation, heating elements, and durable sensors that can withstand and operate safely across a broad thermal range.

Fuzzy Logic Temperature Optimization

In addition to PID control, a fuzzy logic-based control module needs to be present for enhancing responsiveness and adaptability. The fuzzy layer has to be capable of enabling the system to handle non-linearities, uncertainty, and time-varying LPG flow dynamics so that temperature can be regulated smoothly under varying load and ambient conditions.

Fail-Safe Mechanism (Fallback System)

The system will incorporate a failure detection and fallback mechanism within itself to prevent unsafe operation. In case of sensor failure, heater malfunction, overheating, or abnormalities in LPG flow, the system must automatically turn off the heating process, shut off the LPG supply, and provide an alert, thereby ensuring passenger and vehicle safety.

Optimized Preheating Timing

The system must have the capability to intelligently determine and carry out the preheating operation within optimum time ranges so that LPG will be at the ideal temperature right before it enters the combustion chamber. This conserves energy and maximizes combustion efficiency.

Thermal Insulation
To avoid loss of energy, the system must be thermally insulated with high-efficiency insulating materials so that the heat gets entrapped in the heating chamber. The insulation would increase the energy efficiency, reduce the burden on the heating element, and maintain a stable temperature.

LPG-Specific Electrovalves
The system will be equipped with custom-designed and LPG service-certified electrovalves. The valves must ensure fast response, high sealing tightness, and corrosion resistance to LPG, with the aim of safe and controlled LPG flow while preheating.

LPG-Specific Copper Coils Heating and transporting fuel lines for LPG must use copper coils made for LPG systems. These coils must have maximum heat conductivity, pressure resistance, and chemical resistance for LPG.

Compact and Vehicle-Friendly Design
The preheating system must be designed with a compact and flexible form factor to enable it to be fitted within the fuel line system of the vehicle. It must enable modular installation, space-saving routing, and be mechanically stable to resist vehicle movement and vibration.

High-Precision Data Acquisition (DAQ)
The system needs to employ credible and accurate Data Acquisition (DAQ) methods for collecting real-time information from control units, flow meters, and temperature sensors. The information should be sampled at high rate and resolution to enable timely control and proper performance evaluation.

1.2Non Functional Requirements:

- Reliability & Robustness: system must operate reliably under various conditions (vibrations , mountains , extreme temperatures..)
- Real-Time Responsiveness: System must respond to the various internal conditions ensuring no perceptible lag in fuel supply.
- Low Cost and ease of integration: the use of algerian-market available components
- Energy-efficiency: system must minimise power consumption and avoid overshooting temperature

- Safety and compliance: system must comply with automotive standards including emergency cut-off and emergency-switching

1.3 System Constraints and Assumptions:

- The design assumes a typical automotive LPG system of the first 3 generations containing a pressure regulator that exists in most algerian vehicles with LPG-system
- The heating process must be supplied by a reliable power source (12V) and fit near the engine & placed after the regulator
- The copper heating coil must withstand high temperature exposures of LPG flow (60°/70° hot & -30°/-40° cold)
- An appropriate LPG-purpose sensor is assumed to be used & placed in contact with fuel line
- The controller's fuzzy logic must respect & comply with the arduino's computational limits (16Mhz clock speed, 1 IPC ie instruction per cycle, 16 MIPS(Million instructions per second))
- Power consumption is limited to the vehicle's power source (12V battery) and must withstand it's maximum support
- Real-time temperature data is sent to the dashboard via a python script in a time that doesn't exceeds 2ms
- Control response of the heating process is initiated in a time that doesn't exceeds 2ms

2.Conception

We have developed a block diagram describing the architecture of our system , as well as we'll be showing a screenshots of the dashboard that will receive the values of the sensor

2.1 Flow chart diagram

Flow chart of LPG Preheating System of Automotive Engine The below figure FIGURE III.1 is a typical block diagram of the implemented LPG Preheating System for car application. The system preheats controlled Liquefied Petroleum Gas (LPG) before its intake into the combustion chamber, improves combustion efficiency, reduces engine wear, and makes engine starts smoother during cold climatic conditions. The system is designed as a functional demonstrator model and an educative demonstration model.

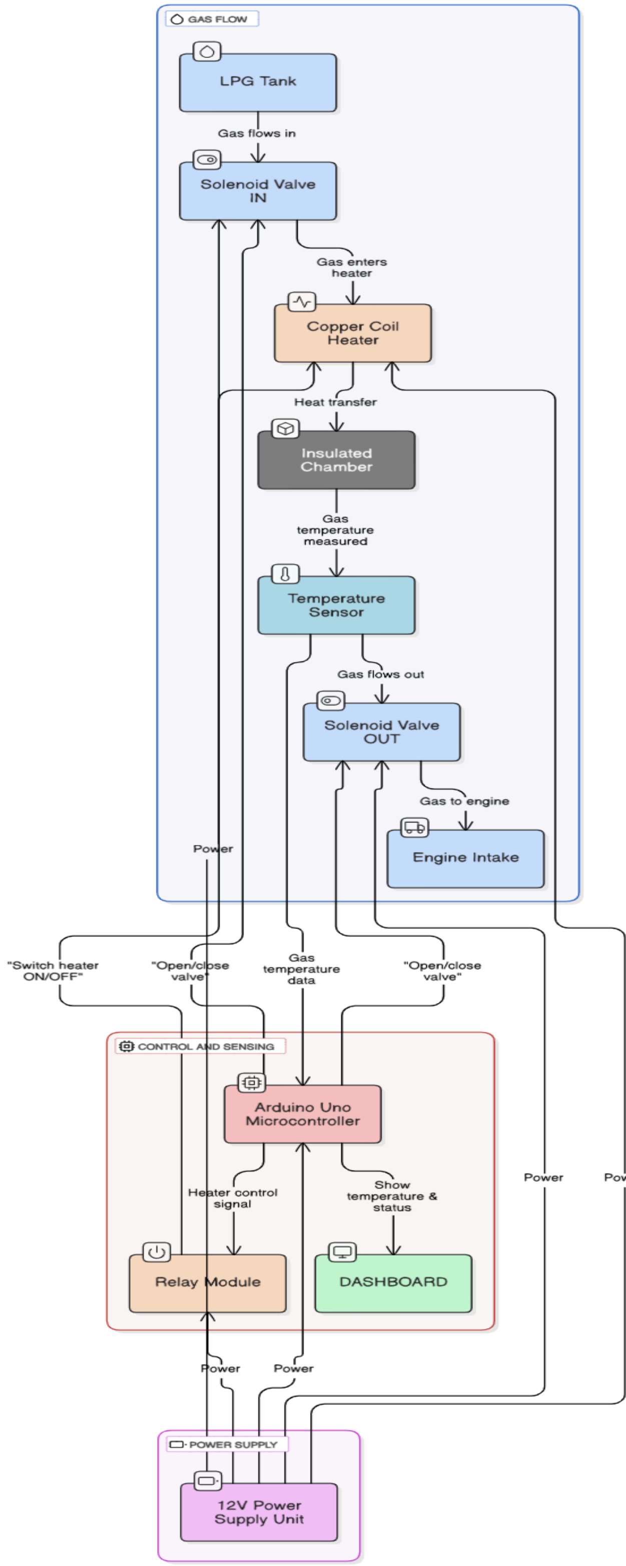

FIGURE III.1. Detailed schematic of the proposed LPG Preheating System.

The figure FIGURE III.1. is divided into different functional zones, beginning with the Gas Flow Section (blue shaded). LPG from a pressurized LPG Tank is supplied through an IN Solenoid Valve, which regulates gas inlet depending on control signals received from the microcontroller. The gas passes through a Resistor Heater, or copper coil heater as it is otherwise known. This thermal-conductive route is enveloped in a resistor heater contained within an Insulated Chamber, minimizing heat loss while providing effective thermal conduction.

With the heating of the gas, it is made to flow through a Temperature Sensor (such as LM35), which senses the gas temperature round-the-clock. On the basis of this measurement, the OUT Solenoid Valve opens or shuts to make the gas exit from the system to the Engine Intake, where it is supplied to the combustion chamber to get mixed up for ignition purposes.

Control and Sensing Subsystem The Control and Sensing Section (red) is regulated by an Arduino Uno Microcontroller, which provides temperature reading and control signals. It communicates with:

- The Relay Module to turn the heater ON/OFF.
- The IN and OUT Solenoid Valves to manage gas flow.
- A Dashboard Display, a graphical representation of system status, temperature readings, and operating modes.

Modularity of the relay and sensor feedback create a closed-loop real-time control system. Power Supply Unit

The entire system is powered using a 12V Power Supply Unit (purple color), supplying regulated power to the solenoid valves, heater, microcontroller, and auxiliary electronics. This makes the system stable and prevents electrical failure while in operation.

- Materials and Realism : All the blocks in the diagram have been assumed realistically:

- Copper has been used as heater conductors and tubing gas has been used for optimal thermal conductivity.

- The Insulated Chamber is shown as a clearer-to-view transparent casing to facilitate gas flow to be simpler to view for demonstrations.

- Electric connections are color-coded by blue and black wires to facilitate viewing and noting wiring.
- Solenoid valves and mechanical elements are identified and to-scale sketched for precise physical prototyping.

This graph on FIGURE III.1 illustrates graphically the path of LPG gas functionally in a preheating loop but integrates sensing, control, and power systems into an infinitely small educational model. It presents a real-world application of embedded system concepts and ideas of thermal engineering towards optimizing fuel control in motor systems from gaseous fuel. The modular and labeled structure is optimized for demonstration and practical prototyping.

2.2 Sequence diagram

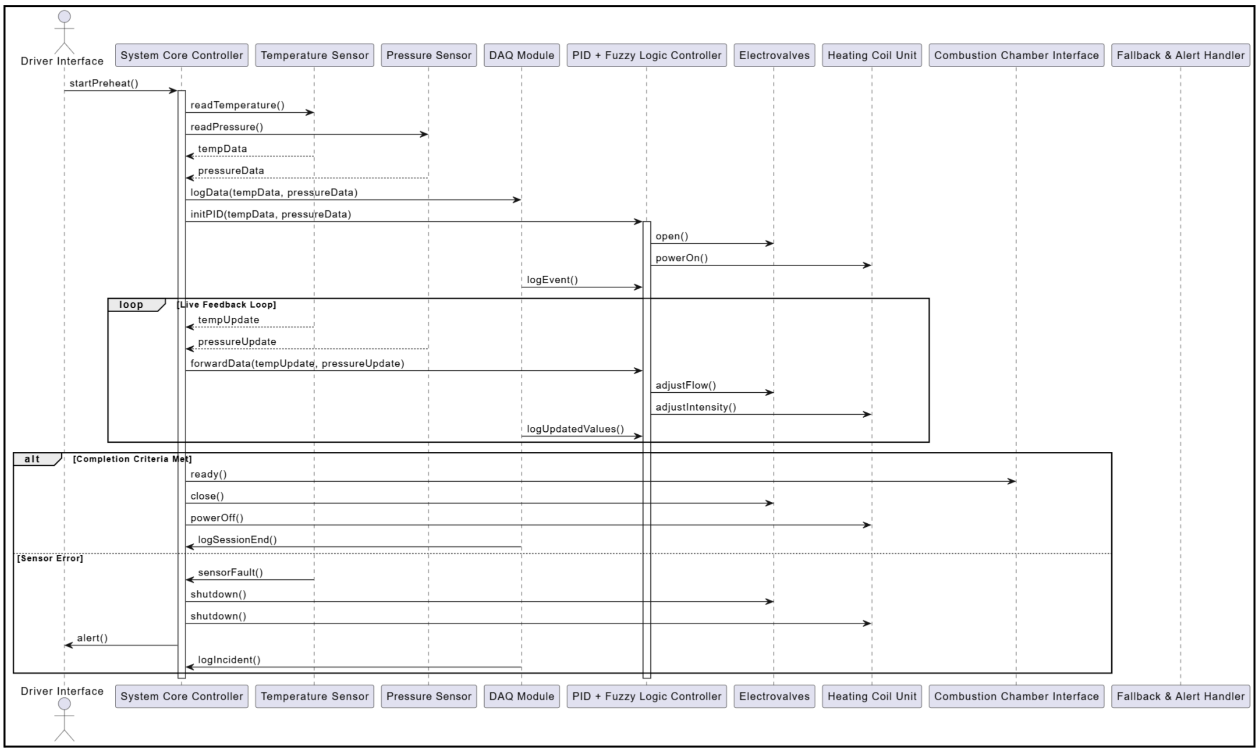

FIGURE III.2. Sequence diagram of the preheating lifecycle.

The UML sequence diagram in FIGURE III.2 provides a detailed view of the dynamic system behavior of the LPG preheating system for an automotive application. It illustrates the time-based interaction of the internal system components, including temperature and pressure sensors, the central control logic, heat elements, and safety devices. The diagram displays the step-by-step process from system initialization to preheating activation, real-time monitoring, and secure shutdown. One of the standout features of the system is the adaptive control logic that is carried out using PID and fuzzy logic algorithms to maintain optimal temperature and pressure regardless of the changes in environmental parameters. Incorporation of a DAQ module makes sure that all sensor readings and actions undertaken by the system are traceable. In addition, the fallback and alert handler plays a critical role in enhancing system safety by responding to abnormalities, such as sensor failure or unsafe operating ranges. This modeling approach emphasizes modularity of design, sensor incorporation, and fail-safe, thus providing the foundation for determining the system's reliability and real-time responsiveness prior to deployment. The sequence diagram effectively defines the operation timeline and logical consistency of the system, thereby enabling the validation of the design as well as the following simulation stages.

3.Implementation

3.1 Sensor model

FIGURE III.3.Sensata 81CP17-02 sensor model.[46]

This replacement air pressure and temperature sensor switch demonstrates high compatibility with a variety of models, including 81CP17-02, 110R-000095, 67R-010179, and others such as 09917C and MX19. Designed to address and resolve system malfunctions resulting from sensor damage, the product ensures reliable and consistent performance. Manufactured using high-quality materials and advanced production standards, the sensor maintains operational stability and efficiency under diverse working conditions, contributing to its extended service life. Furthermore, its user-friendly, plug-and-play design allows for straightforward installation without the need for specialized tools or technical expertise, making it an accessible solution for both professionals and non-specialists.[46]

3.2 Dashboard overview

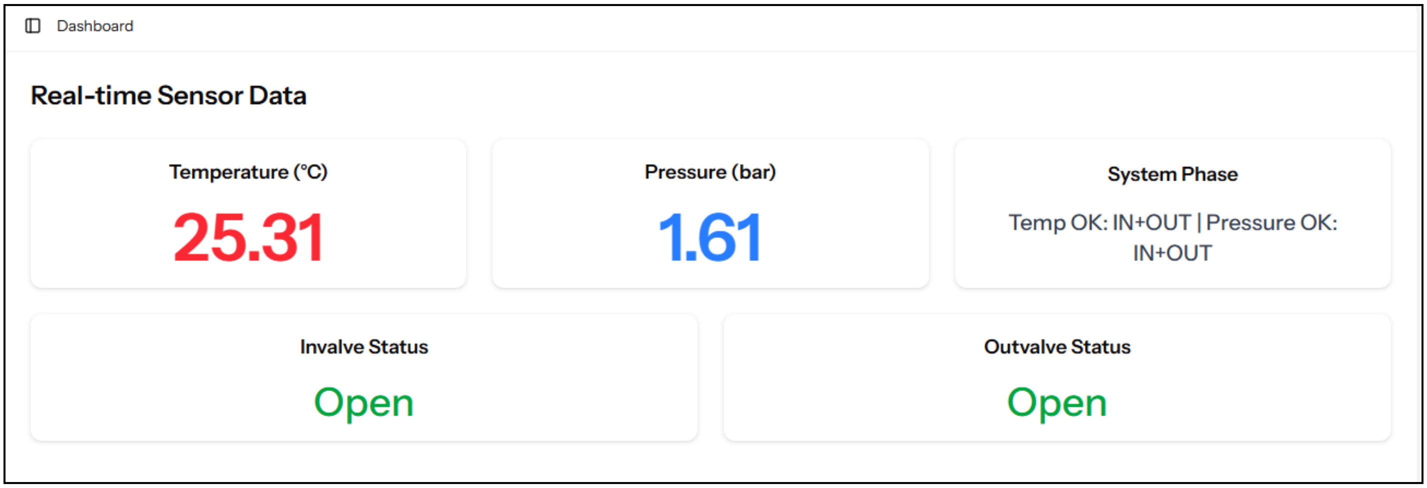

FIGURE III.4.Temperature & pressure presented in dashboard

As we can see in FIGURE III.4 the temperature and the pressure values are presented and sent to the laravel dashboard via a python script using HTTP/Serial libraries to connect to the arduino corresponding COM port and then send to the laravel API which will receive this data and later use it for statistical purposes

the script is written as follows:

```
import serial
import requests
import json
import time

SERIAL_PORT = 'COM11'
BAUD_RATE = 9600
API_URL = 'http://127.0.0.1:8000/api/sensor-data'
def open_serial_connection():
    try:
        connection = serial.Serial(SERIAL_PORT, BAUD_RATE, timeout=1)
        print(f"[INFO] Connected to {SERIAL_PORT}")
        return connection
    except Exception as e:
        print(f"[ERROR] Failed to open serial port: {e}")
        return None
def read_and_send_serial_data():
    ser = open_serial_connection()
    if not ser:
        return
    while True:
        try:
            raw_line = ser.readline().decode('utf-8').strip()
            if not raw_line:
                time.sleep(1)
                continue
            print(f"[SERIAL RAW] {raw_line}")
            try:
                parsed_data = json.loads(raw_line)
                print(f"[PARSED JSON] {parsed_data}")
                send_data_to_api(parsed_data)
            except json.JSONDecodeError:
                print(f"[ERROR] Invalid JSON format: {raw_line}")
        except Exception as e:
            print(f"[ERROR] Error while reading from serial: {e}")
        time.sleep(1)
def send_data_to_api(data):
    try:
        response = requests.post(API_URL, json=data)
        if response.status_code == 201:
            print(f"[SENT] {data}")
        else:
            print(f"[API ERROR] {response.status_code} - {response.text}")
    except requests.exceptions.RequestException as e:
        print(f"[ERROR] Failed to send data: {e}")
if __name__ == '__main__':
    read_and_send_serial_data()
```

This Python program serves as middleware between the Arduino hardware as the data source and the Laravel back-end as the data destination. The program creates a serial connection to COM11 with a default baud rate of 9600 and keeps reading data packets from the Arduino continuously. The program assumes that each line read is a JSON string with sensor data like temperature and pressure. The program unescapes and checks the JSON format and sends the same data via the HTTP POST method to a Laravel API endpoint (/api/sensor-data) that is assumed to be responsible for committing the data to the database.

The script includes minimal error handling for malformed JSON, serial errors, and HTTP request failure. It includes diagnostic logging to monitor raw serial data, parsed JSON, and the outcome of every API request. The time.sleep(1) prevents the script from bombarding the serial interface or backend with queries too rapidly and gives the script a light-touch polling feel.

This approach effectively isolates the hardware and backend, and the system is now testable and modulatable. The script itself could be made easy to modify to capture the failed transmissions, implement retry behaviors, and cache the data offline for sync later, if needed. Overall, a lean and sound pipeline for capturing sensor data and delivery in a real-time environment.

3.3 Raw sensor values

pressure (bar)	temperature (°C)	created_at	updated_at
1.07	24.25	2025-05-25 12:10:25	2025-05-25 12:10:25
1.07	24.17	2025-05-25 12:10:26	2025-05-25 12:10:26
1.07	24.25	2025-05-25 12:10:28	2025-05-25 12:10:28
1.07	24.17	2025-05-25 12:10:29	2025-05-25 12:10:29
1.07	24.25	2025-05-25 12:10:30	2025-05-25 12:10:30
1.07	24.17	2025-05-25 12:10:31	2025-05-25 12:10:31
1.07	24.17	2025-05-25 12:10:33	2025-05-25 12:10:33
1.07	24.17	2025-05-25 12:10:34	2025-05-25 12:10:34
1.07	24.25	2025-05-25 12:10:35	2025-05-25 12:10:35

TABLE III.1 - Raw temperature & pressure values (retrieved from local database)

Data presented in the TABLE III.1 were the raw temperature and sensor values retrieved from the database , the pressure presents its normal atmospheric value which is approximately 1 BAR and temperature values ranging from 23°C to 25°C on that day.

The inclusion of raw temperature and pressure measurements (TABLE III.1) in this research is significant for the validation of the operational reliability and response characteristics of the system in actual conditions. The presentation of raw data promotes transparency and provides a reference point for testing and interpretation of sensor accuracy, resolution, and stability. Raw metrics enable a preliminary assessment of environmental variations, sensor drift, and data acquisition framework anomalies. Data examination prior to the application of any filters, scaling, and controls provides important information about the dynamic behavior of the system, especially during startup, steady state, and transition modes. Raw data are important to the development of systems like PID or fuzzy logic controllers, where instantaneous changes in inputs significantly condition heating efficiency and safety mechanisms. Overall, the recording of the measurements increases reproducibility, assists in system diagnosis, and provides the basis for future developments in models or algorithms.

3.4 Fuzzy logic applied

In this project, fuzzy logic was used to handle the uncertainty and non-linearity associated with the LPG preheating process, especially under dynamic environmental conditions. The fuzzy logic controller was implemented to regulate the temperature of the LPG as it flows through the heating chamber. The fuzzy logic system consists of the following components:

- Input Variables:
    - *Temperature Error (E):* The difference between the desired setpoint temperature and the actual temperature.
    - *Rate of Change of Temperature (ΔE):* Represents how fast the temperature is rising or falling.
- Output Variable:
    - *Heater Power (HP):* The level of power to be delivered to the heater (expressed as a percentage).
- Fuzzification:
  The inputs were converted into fuzzy linguistic terms using triangular membership functions:

- *Temperature Error (E):* {Negative Large, Negative Small, Zero, Positive Small, Positive Large}
- *Rate of Change (ΔE):* {Decreasing Fast, Decreasing, Stable, Increasing, Increasing Fast}
- *Heater Power (HP):* {Off, Low, Medium, High, Maximum}

- Rule Base:
  The fuzzy rule base was created using expert knowledge and control logic. A sample of the fuzzy rules:
  - IF (E is Negative Large) AND (ΔE is Decreasing Fast) THEN (HP is Off)
  - IF (E is Positive Small) AND (ΔE is Stable) THEN (HP is Medium)
  - IF (E is Positive Large) AND (ΔE is Increasing) THEN (HP is High)
  - IF (E is Zero) AND (ΔE is Stable) THEN (HP is Low)
- Inference Engine:
  Mamdani inference method was used to evaluate the fuzzy rules and generate the fuzzy output set.
- Defuzzification:
  The centroid method was applied to convert the fuzzy output set into a crisp value for the heater power. This output was then mapped to PWM values controlling the relay responsible for switching the heater on or off.

This fuzzy control approach ensures a smooth and adaptive regulation of the LPG temperature by continuously adjusting the heating based on feedback, making it highly suitable for unpredictable environmental conditions. The use of fuzzy logic also simplifies the development of the control algorithm, avoiding the need for complex mathematical models of the system.

3.5 Thermodynamic Calculations

This part of the thesis discusses a thermodynamic analysis and mathematical study of permanent preheating of LPG, not merely for cold start but for all phases of vehicle operations like idling, cruising, and accelerating — and across all climatic conditions from sub-zero winter to tropical conditions. The intention is to illustrate how permanent preheating of LPG significantly improves combustion efficiency, protects engines, and reduces emissions.

As previously discussed LPG must be vaporized before entering the combustion chamber. The vaporization process requires energy input, specifically the latent heat of vaporization, typically around:

$$\Delta H_{vap} \approx 350 \text{ KJ /kg}$$

In standard systems this energy is taken and drawn from the engine coolant system or intake manifold,which is inconsistent especially during start-up and during low-load operation? This delay in proper vaporization leads to poor combustion , increased HC (Unburned hydrocarbons), and CO emissions, and in some cases, liquid fuel enters the chamber, causing engine knocking or thermal stress

The Arrhenius equation governs the rate of chemical reactions:

$$K = Ae^{\frac{-Ea}{RT}}$$

Where:

- K is the reaction rate constant
- Ais the frequency factor
- E_a is the activation energy
- R is the universal gas constant (8.314 J/mol·K)
- T is the absolute temperature in Kelvin

As the value of T increases due to preheating, the exponential term increases, enhancing the rate of combustion reaction

For example, increasing the intake from 293K (20°C) to 323 K (50°C) can increase the reaction rate by up to 15–25%, depending on fuel composition and engine design. This not only improves thermal efficiency but also promotes complete oxidation of hydrocarbons, reducing emissions.
For the energy balance , let's assume:

- Vehicle uses 10 kg LPG per 1000 km

- Latent heat of vaporization $\Delta H_{vap} \approx 350$ KJ /kg
- Combustion efficiency without preheating: 92%
- Combustion efficiency with permanent preheating: 98%

Energy required for vaporization is calculated as follows:

$$Q_{vap} = m^* \Delta H_{vap} = 10*350 = 3500 \text{ kJ}$$

Preheating supplies this energy using our system. If we supply 100% of this energy externally, the combustion chamber doesn't waste energy vaporizing fuel, thus preserving that energy for power output.

And for the combustion energy gain we have:
LPG energy content ≈ 46 MJ/kg
Total energy = 460 MJ per 1000 km

Improved combustion efficiency gain is calculated as follows:

$$\Delta\eta = 0.98 - 0.92 = 0.06 = 6\%$$

$$\text{Energy Gain} = 460 \cdot 0.06 = 27.6 \text{ MJ}$$

This 27.6 MJ surplus can be translated into either fuel savings, power increase, or reduced emissions.

For the exact emission reduction calculations:

Each kg of LPG burned produces ~3 kg of CO_2.

With 10 kg of LPG:

- Normal CO_2 = 30 kg
- With improved efficiency (6% fuel saved):
  Saved LPG = 0.6 kg → 1.8 kg CO_2 reduction

$$\text{Yearly Reduction} = 1.8 * \frac{20000}{1000} = 36\ kg\ CO2/\ year$$

Moreover, complete combustion reduces CO, NOx, and particulate matter due to better flame propagation and lower flame quenching.

The thermodynamic rationale that supports permanent implementation of an LPG preheating system in cars is, beyond any doubt, compelling and very convincing. This new approach touches upon a very significant number of important issues because not only does it resolve the critical problem of improving startup efficiency, but it also provides good fuel vaporization under a very wide and varied range of driving conditions. Through this, this new system greatly improves overall engine performance while, all at once, helping significantly reduce noxious emissions, which inevitably translate into a greater overall longevity of various car components. If one considers the dual viewpoints of thermodynamics and energy economy, then it stands out very vividly that permanent preheating is not a mere add-on comfort feature but is, instead, an inevitable necessity for the progressive advancement of new-generation LPG automotive technologies. The firm mathematical bases that support this new technology coupled with its quantifiable and computable benefits irrevocably put it forward as a breakthrough technology in alternative fuel technology.

3.6 Prototype

In prototype development, the emphasis was on the fabrication of a working and scalable experimental setup that can represent the entire working life of the LPG permanent preheating system. We did not want to test isolated components but rather create an environment that could reproduce realistic driving scenarios with varying environmental temperatures, controlling the entering and Outgoing LPG with sufficient fidelity.

The first primary aim is the demonstration of the practicability and thermodynamic effectiveness of the LPG preheating system on the vehicle. Some of the other functions of this prototype are:

- Cold start and warm start cycles with and without LPG preheating are simulated.
- Rate of vaporization and temperature stability of LPG are measured before injection.
- Evaluation of emission differences and the fuel consumption pattern
- System evaluation for sudden throttle changes
- Thermal and electrical loading behavior study for the preheater

The prototype was designed with components that are readily available in order to provide full functionality as would exist in a permanent LPG preheating system in vehicular applications. The system architecture combines thermal, mechanical, and electronic elements in a synergistic manner in an attempt to replicate real working conditions of an engine being pre-treated on the actual fuel and flow regulation. The major components and their functions are summarized below:

1. 12V DC Power Supply Station

A 12V regulated power supply is utilized to power the whole system. It provides stable voltage and current to all the active components of the system, such as the heating element, electrovannes, and microcontroller. The selection of 12V provides compatibility with the automobile electrical system, which is the standard.

FIGURE III.5.12V DC Power Supply Station

2. Preheating Chamber (Chauffe-eau Core)

The central thermal processing module is a standard domestic water heater (chauffe-eau) that has been adapted. The unit includes a metal heating chamber that was originally designed to heat water. In our prototype, we've adapted it to preheat the LPG by passing it through a spiral copper or steel tubing inside the chamber. The heater is capable of heating the LPG to vaporization point (typically 40–60°C), which is the perfect phase transition before injection.

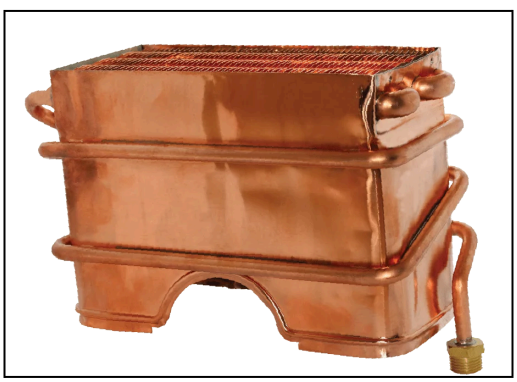

FIGURE III.6.Preheating Chamber (Chauffe-eau Core)

3. Electric Heating Element (coil heater)
The electrically controlled resistive heater fitted within the preheating chamber is utilized for heating the LPG to a consistent vaporization level. It is connected through a relay and controlled dynamically according to temperature feedback from the system and logic dictated by the microcontroller.

FIGURE III.7.Electric heater

4. Electrovannes (Solenoid Valves) – Inlet and Outlet
Two 12V electrovannes are placed at the inlet and outlet of the preheating system for LPG. They are used to regulate the inlet and outlet of fuel according to control signals from the Arduino. Precise timing of fueling and safe management of the heating process are therefore guaranteed. The inlet valve opens after the system is started, and the outlet valve only when LPG is at the required temperature, guaranteeing full vaporization prior to combustion.

FIGURE III.8.Electrovannes (Solenoid valves)

5. Arduino UNO Microcontroller
An Arduino UNO board acts as the central controller. It accepts sensor inputs, operates the relay switches of the heating element and electrovannes, and performs real-time decision logic according to a preloaded program. The Arduino is programmed with fuzzy logic to:

- Open/close electrovannes
- Turn the heater on or off
- Initiate safety shutdown when temperatures or pressures have reached preset levels

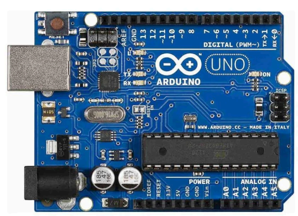

FIGURE III.9.Arduino Uno microcontroller

6. Temperature and Pressure Sensors (Checkout FIGURE III.3)
There is a pressure and temperature sensor at the exit of the LPG preheating chamber. The sensor provides real-time feedback to the Arduino, which then processes it to determine whether the LPG has achieved the necessary vaporization condition. The sensor is crucial in the provision of stable operation and avoiding under- or over-heating. 7. Relays for Power Control To safely switch high current and shield the Arduino from inductive loads, electromechanical relays are utilized. One relay switches power to the heater, and another relay is dedicated to the two electrovannes. The relays are triggered by low-power digital Arduino signals and supply robust control of the high-power devices. (

Throughout the development and prototyping phase of our LPG preheating system, several technical and safety challenges emerged that required iterative rectification and adaptation of both the design and the selected components.

Initially, our approach included the fabrication of a custom stainless steel (inox) chamber to serve as the LPG preheating vessel. However, this solution proved impractical. The primary issue lay in the difficulty of controlling and maintaining LPG flow within this enclosed chamber during static and dynamic conditions. The construction complexity and poor thermal response time made it unfit for reliable preheating, prompting a complete reevaluation.

Another critical challenge involved our intent to utilize glow plugs (bougies de chauffage) — commonly found in diesel engine cold-start systems — as the primary heating element. While glow plugs offer rapid heat generation and are compact, their direct exposure to LPG created a severe safety risk. The ignition potential due to direct contact between LPG vapors and the high-temperature surface of the plugs posed a serious combustion hazard, especially under confined conditions. This forced us to abandon this idea in favor of safer and more thermally controlled alternatives, such as external resistance-based heating components and relay-controlled activation logic for regulated heat delivery.

In parallel, we encountered challenges in terms of electromechanical integration. The LPG valves (electrovannes) required stable 12V current, and their control via relays had to be carefully synchronized with sensor readings. The calibration of temperature and pressure sensors also required multiple iterations due to analog signal noise and ambient condition variations.

These challenges underscored the complexity of developing a safe, real-time, embedded thermal control system for LPG, especially when aiming for a permanently active preheating strategy and not just cold-start mitigation. The lessons learned informed significant design corrections and validated the importance of a modular prototyping process with constant testing under controlled conditions.
Below are two pictures of the prototype we built. They show how we assembled the main components and connected everything together.

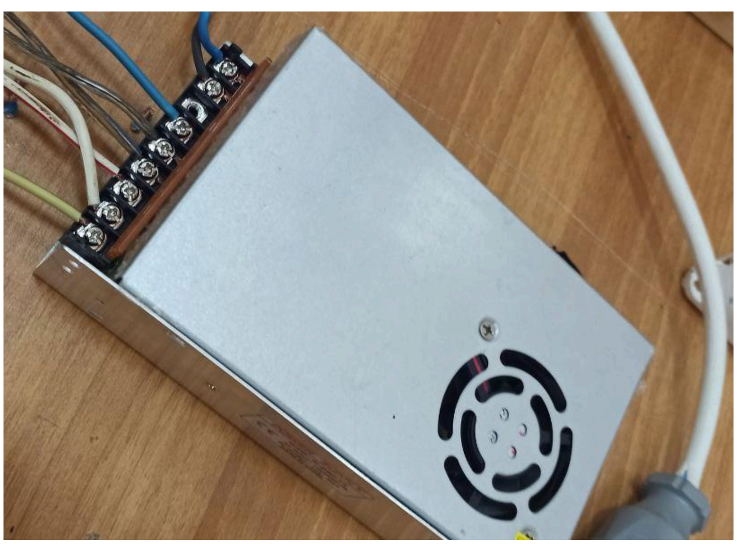

FIGURE III.10.Prototype image (power station)

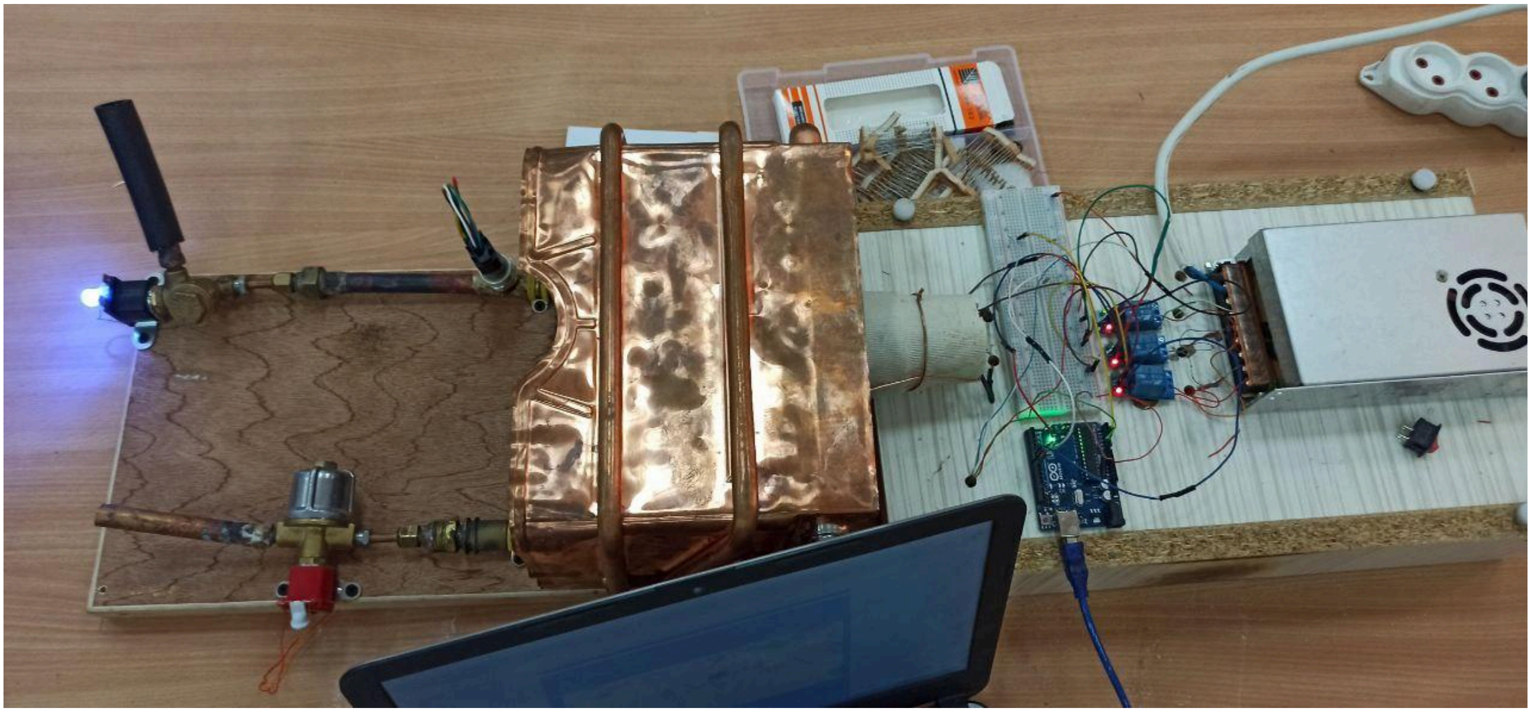

FIGURE III.11.Prototype assembled

This prototype was our attempt at bringing the concept to life and to demonstrate how our idea could work. It allowed us to explore the challenges involved in the field, test the approach we had taken, and in doing so, take an actual step toward a solution.

3.7 Algorithm data

The fuzzy logic algorithm was applied to the prototype which concluded to the list of chosen data acquired for the database showcasing the different use cases we managed to test.

id	pressure	temperature	status_message	pressure_status	invalve	outvalve	created_at
903	1.5	27.89	Temp High: OUT only	Pressure OK: IN+OUT	1	1	2025-06-19 15:13:59
904	1.94	27.8	Temp High: OUT only	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:01
905	2.1	27.71	Temp High: OUT only	Pressure High: OUT only	0	1	2025-06-19 15:14:03
906	1.54	27.53	Temp High: OUT only	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:05
907	1.24	27.62	Temp High: OUT only	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:07
908	1.18	27.62	Temp High: OUT only	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:10
909	1.27	26.99	Temp OK: IN+OUT	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:12
910	1.6	25.48	Temp OK: IN+OUT	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:14
911	1.61	25.31	Temp OK: IN+OUT	Pressure OK: IN+OUT	1	1	2025-06-19 15:14:16
855	1.33	27.35	Temp High: OUT only	Pressure OK: IN+OUT	1	1	2025-06-19 15:12:19
856	2.71	28.25	Temp High: OUT only	Pressure High: OUT only	0	1	2025-06-19 15:12:22

TABLE III.2 - Algorithm applied data (retrieved from local database)

The data presented in the table TABLE III.2 are time-series readings from the system controlled by Arduino. Every value is one cycle of reading from pressure and temperature sensors, and system state decisions by the control logic. Describing each column as follows :

The pressure (bar) is an analog reading converted to pressure based on calibrated sensor values.
The temperature (°C) is derived from thermistor voltage through the Beta parameter equation.
status_message: The logical reasoning of the control system at that point in time.
invalve, outvalve: 1/0 binary indicators of valve actuation states (active LOW relays).
created_at: Timestamp of the measurement, as precise as possible.

Fuzzy logic is applied in the Arduino code to control temperature and pressure, and results of decisions are stored in the status_message field. Steps include:

Startup Stage: Starts heating and intake to reach minimum operating temperature.

The temperature control goes as follows:
Temp Low: IN+HEAT: Activates intake valve and heater.

Temp OK: IN+OUT: Operates the intake and exhaust in proportion to stabilize the environment.

Temp High: OUT only: Exhaust-only operation to reduce the risk of overheating.

Pressure Control:
Pressure Low: IN+HEAT: Similar to low-temperature startup, promoting fluid inflow and warming up.

Pressure High: OUT only: Reverses overpressure buildup by opening the exhaust valve alone.

Pressure OK: IN+OUT: Balanced normal condition.

Observations from Data:
Initial data (e.g., ID 855) show overheat situations with temperatures > 30°C, with the out valve being opened only for cooling.

As the process stabilizes, temperatures decrease to ~27°C, as seen from 'Temp High: OUT only' and 'Pressure OK: IN+OUT' messages.

Finally, normal operating states are established (e.g., IDs 909–911), with 'Temp OK: IN+OUT' at decreased temperatures (~25°C) and properly balanced valve operations.

General Conclusion

In this master's thesis we have embraced many disciplines and fields startçng from our own skills in software engineering to our closed field the automation and mechanical engineering and all the way to LPG carburant in vehicles, we have presented the basic functionalities of the preheating system, beginning from wide definitions of the LPG industry in the automotive field and presenting many statistics considering the LPG usage and prices in Algeria to discussing the different approaches of engineering methods used to implement this system like software engineering, requirements engineering and we have seen how DAQ and fuzzy logic can highly contribute to give precise information and deliver exact data for controlling the temperature, of course, any work can and will open more and more work later, as of our system, we hope this project will later lead to other innovative systems in the domain of LPG automotive field and integrating more enhancements and features to this like the inclusion of an AI model that is trained for engine data and ambient values of temperature and different environments to predict precise values of LPG enhancing the combustion and that will promote and open more questions and ideas later to contribute more to science and to the economy and the innovation sector in Algeria.

References

[1] EPCM holdings.What is the future of LPG?, consulted on 09/04/2025. URL: https://epcmholdings.com/what-is-the-future-of-lpg/

[2]. The Editors of Encyclopaedia Britannica and Melissa Petruzzello.Liquified petroleum gas : Description , uses and processing. Consulted on 25/05/2023. URL: https://www.britannica.com/science/liquefied-petroleum-gas

[3] FOX Petroleum.Liquified petroleum gas (LPG) : physical properties and characteristics. consulted on 10/10/2025. URL: http://www.foxpetroleum.net/LPG.php

[4] Piotr Złoty.History of autogas -Europe. consulted on 13/04/2025. URL: https://gazeo.com/up-to-date/news/2014/History-of-autogas-Europe,news,7767.html

[5] Piotr Złoty.LPG : the first 100 years. consulted on 13/04/2025. URL: https://gazeo.com/up-to-date/news/2013/History-of-LPG-the-first-100-years,news,6662.html

[6] Eric Hahn.LPG Gas Car & LPG Conversion: How an LPG Gas Car Works - Autogas. consulted on 13/04/2025. URL:https://www.elgas.com.au/elgas-knowledge-hub/residential-lpg/autogas-lpg-car-conversion-how-work/

[7] Korea LPG Association.LPG vehicles technology .consulted on 13/04/2025 .URL : https://www.klpg.or.kr/_ENG/html/dh/Industry01_2

[8] LPGain.LPG components .consulted on 14/04/2025 .URL : https://lpgain.ie/lpg-components/

[9] Stefan Unnasch and Love Goyal.Life Cycle Analysis of LPG Transportation Fuels under the Californian LCFS .consulted on 14/04/2025 .URL : https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/workshops/10242017_wpga.pdf

[10] altenergy.WB/HVS NatGas Backup System Water Bath Vaporizer with Venturi-Type Mixing System Naturally Aspirated - No Compressed Air Required consulted on 14/04/2025 , URL : https://altenergy.com/media/1065/wbhvs-dec-2021.pdf

[11]EPA.Liquefied Petroleum Gas Combustion .consulted on 14/04/2025 .URL : https://www3.epa.gov/ttnchie1/old/ap42/ch01/s05/final/c01s05_oct1996.pdf

[12] 111otonic.LPG Lpdi system .consulted on 14/04/2025 .URL : https://nitoautogas.com/w/p/s/2/en

[13] 111otonic.LPG Lpi system .consulted on 14/04/2025 .URL : https://nitoautogas.com/w/p/s/2/en

[14] Lakehal Elamine.Economic Analysis of Algeria's Transition to LPG .consulted on 14/04/2025 .URL : https://asjp.cerist.dz/en/downArticle/277/19/2/259570

[15] NRL.LIQUEFIED PETROLEUM GAS (LPG) .consulted on 16/04/2025 .URL : https://www.nrl.co.in/upload/nrlLPG-Specifications.pdf

[16] FOX Petroleum.LIQUEFIED PETROLEUM GAS .consulted on 16/04/2025 .URL : http://www.foxpetroleum.net/LPG.php

[17] gogas.The Environmental Benefits of LPG: A Cleaner Fuel for a Greener Future .consulted on 16/04/2025 .URL :https://gogas.co/media/blogs/blog-details/environmental-benefits-of-lpg

[18] liquid gas UK.Why is LPG considered to be environmentally friendly? .consulted on 16/04/2025 .URL :https://www.liquidgasuk.org/faqs/why-is-lpg-considered-to-be-environmentally-friendly

[19] autogas italia.What is the impact of the LPG on the environment? .consulted on 16/04/2025 .URL :https://www.autogasitalia.it/en/faq/gpl/what-is-the-impact-of-the-lpg-on-the-environment/

[20] gogas.LPG-Powered Vehicles: A Sustainable Transportation Solution .consulted on 16/04/2025 .URL :https://gogas.co/media/blogs/blog-details/lpg-powered-vehicles

[21] gogas.EVs vs LPG-Fueled Cars: Can LPG Be Part of a Zero-Emission Future? .consulted on 16/04/2025 .URL :https://www.opisnet.com/blog/evs-vs-lpg-fueled-cars/

[22]AEGPL. AEGPL response to Commission's consultation Strategy to reduce CO2 emissions from cars .consulted on 16/04/2025 .URL :https://climate.ec.europa.eu/system/files/2016-11/aegpl_en.pdf

[23] Chikh Azeddine. *Ingénierie des Besoins*, Chapitre 1: Ingénierie des exigences, p. 19.

[24] Adam M. Sandman.Principles of requirement engineering or requirement management .consulted on 28/04/2025 .URL :https://www.inflectra.com/Ideas/Whitepaper/Principles-of-Requirements-Engineering.aspx

[25] GERARD O'Regan.Concise guide to software engineering .consulted on 30/04/2025 .URL :https://books.google.dz/books/about/Concise_Guide_to_Software_Engineering.html?id=rPuLEAAAQBAJ&redir_esc=y

[26] Hardware/Software Interface Design .consulted on 30/04/2025 .URL :Hardware/Software Interface Design

[27] GIOVANNI DE MICHELI.Hardware software interface .consulted on 30/04/2025 .URL :Hardware Software Interface - an overview | ScienceDirect Topics

[28]citeseerx.Synthesis of the Hardware/Software Interface in Microcontroller-Based Systems .consulted on 30/04/2025 .URL :Synthesis of the Hardware/Software Interface in Microcontroller-Based Systems

[29] Grady Andersen & MoldStud Research Team.Understanding the hardware-software interface in embedded systems .consulted on 30/04/2025 .URL :Understanding the Hardware-Software Interface in Embedded Systems | MoldStud

[30] ARTERIS.Electronic design : navigating the hardware-software interface in Chip Design..consulted on 30/04/2025 .URL :Electronic Design: Navigating the Hardware-Software Interface in Chip Design - Arteris

[31] Emma Ashely.Definition of embedded system..consulted on 01/05/2025 .URL :https://www.rs-online.com/designspark/what-is-an-embedded-system

[32] Tammy Noergaard. *Embedded SystemsArchitecture: A Comprehensive Guide for Engineers and Programmers* , Chapter3: Embedded Hardware Building Blocks and the Embedded Board, p. 77.

[33] heavy.ai.Embedded systems..consulted on 01/05/2025 .URL :https://www.heavy.ai/technical-glossary/embedded-systems#:~:text=An%20embedded%20system%20is%20a%20microprocessor%2Dbased%20computer%20hardware%20system,part%20of%20a%20large%20system.

[34] Halit Eren and David Potter. Data Acquisition fundamentals..consulted on 01/05/2025 .URL :https://www.researchgate.net/publication/294885079_Data_Acquisition_Fundamentals?enrichId=rgreq-74005e44dc8f67ce9d6f47464ffe8bb0-XXX&enrichSource=Y292ZXJQYWdlOzI5NDg4NTA3OTtBUzo4MzcwMDEzODk1NTk4MjBAMTU3NjU2ODA5MDg2NQ%3D%3D&el=1_x_3&_esc=publicationCoverPdf

[35]besteetech. How does temperature sensors collect data..consulted on 04/05/2025 .URL :https://besteetech.com/news/Data-collection-of-temperature-sensor-e.html

[36] Aimil Ltd.Understanding the types of DAQ systems : processes , Examples and applications in AI ..consulted on 04/05/2025 .URL :https://www.aimil.com/blog/uses-and-types-of-daq-systems/

[37]tektronix. DAQ Data Acquisition Primer: An Introduction to Multi-Channel Measurement Systems..consulted on 04/05/2025 .URL :https://www.tek.com/en/documents/primer/daq-data-acquisition-primer-introduction-multi-channel-measurement-systems

[38] zurich instruments.Principles of PID Controllers..consulted on 05/05/2025 .URL :https://www.zhinst.com/americas/de/resources/principles-of-pid-controllers

[39] .Muhammad Sufyan.Principles of PID ControllersPID Explained: Theory, Tuning, and Implementation of PID Controllers..consulted on 05/05/2025 .URL :https://www.wevolver.com/article/pid-explained-theory-tuning-and-implementation-of-pid-controllers

[40] dwyeromega.What is a PID Controller?..consulted on 05/05/2025 .URL :https://www.dwyeromega.com/en-us/resources/pid-controllers

[41] Ravi Kansagara.PID Controllers: Working, Structure and Tuning Methods..consulted on 05/05/2025 .URL :https://circuitdigest.com/article/what-is-pid-controller-working-structure-applications

[42] fujielectric.The Fundamentals of Fuzzy Logic..consulted on 05/05/2025 .URL :https://www.fujielectric.fr/en/blog/the-fundamentals-of-fuzzy-logic/

[43] Josep Ferrer.Fuzzy Logic in AI: Principles, Applications, and Python Implementation Guide..consulted on 05/05/2025 .URL :https://www.datacamp.com/tutorial/fuzzy-logic-in-ai

[44] tutorialspoint.Fuzzy logic - control system..consulted on 05/05/2025 .URL :https://www.tutorialspoint.com/fuzzy_logic/fuzzy_logic_control_system.htm

[45] sciencedirect.Fuzzy logic - control..consulted on 05/05/2025 .URL :https://www.sciencedirect.com/topics/engineering/fuzzy-logic-contro

[46] amazon.Air Pressure/Temperature Sensor.consulted on 29/05/2025 .URL:https://www.amazon.com/Temperature-Replacement-Compatible-110R-000095-67R-010179/dp/B0D4H7KR11

ملخص

لقد اكتسبت صناعة غاز البترول المسال في المركبات الآلية شعبية منذ طرحها لأول مرة، ومن ذلك، بذلت عدة محاولات لتحقيق الأمثلية من حيث البيئة والأداء بمساعدة أنواع مختلفة من العمليات الهندسية، وفي هذا المشروع، نجحنا في تحقيق هدفنا الرئيسي المتمثل في تحقيق منتج يساهم في هذا المجال باتباع عملية هندسة البرمجيات التي انتهت إلى نظام تحكم دائم في التسخين المسبق لغاز البترول المسال قبل الحقن.

تقدم هذه الأطروحة تصميم وتنفيذ نظام ذكي مدمج لتنظيم حرارة الغاز باستخدام متحكم متصل (Arduino Uno). ويستخدم النظام أجهزة استشعار ذكية، ويتيح المراقبة في الوقت الفعلي، ويهدف إلى تحسين السلامة وكفاءة الطاقة في البيئات الصناعية.

الكلمات المفتاحية:

الأنظمة الحرة، متحكم مايكرو، أجهزة الاستشعار الذكية، تنظيم الغاز، الأمن الصناعي، البيانات المؤقتة الحقيقية,تطوير الويب

Abstract

The LPG industry in automotive vehicles has gained popularity since it was first introduced , going from that , several attempts to achieve optimality in terms of environment and performance with the help of different types of engineering processes , in this project , we have successfully achieved our main goal of developing a product that contributes to this field following software engineering process which concluded in a permanent preheating controller system for LPG gas before the injection

This thesis presents the design and implementation of an intelligent embedded system for gas temperature control before entering the engine using a connected microcontroller (Arduino Uno). The system uses smart sensors, enables real-time monitoring, and aims to improve safety and energy efficiency in industrial environments.

Keywords:

Embedded system, microcontroller, smart sensors, gas regulation, industrial safety, real-time data, web development.

Résumé

L'industrie du GPL dans les véhicules automobiles a gagné en popularité depuis son introduction, à partir de là, plusieurs tentatives ont été faites pour atteindre l'optimalité en termes d'environnement et de performance à l'aide de différents types de processus d'ingénierie. Dans ce projet, nous avons atteint avec succès notre objectif principal de réaliser un produit qui contribue à ce domaine en suivant un processus d'ingénierie logicielle qui a abouti à un système de contrôleur de préchauffage permanent du gaz GPL avant l'injection.

Ce mémoire présente la conception et la mise en œuvre d’un système embarqué intelligent pour la régulation du débit de gaz avant d'entrer dans le moteur à l’aide d’un microcontrôleur connecté (Arduino Uno). Le système utilise des capteurs intelligents, permet une surveillance en temps réel, et vise à améliorer la sécurité et l’efficacité énergétique dans des environnements industriels.

Mots-clés:

Système embarqué, microcontrôleur, capteurs intelligents, régulation de gaz, sécurité industrielle, données temps réel, développement web