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LOW-COST HIGH PRECISION FUEL CONSUMTION MEASUREMENT SISTEM

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Abstract: *Fuel consumption measurement is essential for evaluating the efficiency of thermal engines. Available methods range from low-cost manual techniques, such as graduated vessels and scales to high-precision commercial systems like the AVL 735S/753C and AIC 6004 SWISSLINE, which offer excellent accuracy but are often cost-prohibitive. More affordable alternatives based on electronic flow sensors and microcontrollers provide automated measurements but tend to lose accuracy at low flow rates. This paper proposes a cost-effective and precise solution tailored for laboratory environments, particularly under steady-state engine conditions. The system utilizes modified digital weight scales, an HX711 amplifier, and an Arduino-based microcontroller platform to measure fuel consumption through mass variation over time. The approach ensures good accuracy, low cost, and ease of implementation, making it well-suited for educational and research laboratories with limited budgets.*

Key words: *Fuel consumption, measurement, thermal engines, laboratory, weight scales.*

1. INTRODUCTION

One of the most critical performance indicators of thermal engines is their efficiency, which directly depends on accurately determining fuel consumption. Measuring fuel consumption can be accomplished through a variety of methods, whether applied to operational vehicles, heavy-duty machinery, or engines running under controlled conditions on experimental test benches. The choice of method depends heavily on the deployment environment, with each method offering different advantages in terms of accuracy, cost, complexity, and adaptability. Equipment used for measuring fuel consumption ranges widely—from sophisticated flow meters and electronic sensors to more accessible and low-cost alternatives. Among the most common and economical methods are manual systems that rely on the operator to initiate timing and take readings. These can include marked volumetric vessels, precision scales, or even simplified flow measurement setups. While these approaches may lack automation and continuous data logging, they remain valuable tools for basic measurements, educational purposes, or initial engine testing due to their simplicity, affordability, and ease of setup.

Various methods and devices for fuel consumption measurement have been extensively analysed by Pīrs V. et al. [1], who highlight that while many of the commonly used low-cost techniques come with certain limitations, such as reduced accuracy, lack of automation, and reliance on manual operation, they are, nonetheless, attractive due to their ease of integration and affordability. These methods are especially suitable for applications where budget constraints or simplicity take precedence over high precision.

At the other end of the spectrum are high-end measurement systems designed for professional or industrial use, offering excellent precision but at a significantly higher cost. A prime example is the AVL 735S/753C flow meter, which delivers outstanding accuracy, up to ±0.12%, over a broad flow range of 0 to 125 kg/h [2]. These systems are ideal for laboratory testing and engine development but are often too costly or complex for use in field conditions.

Another high-precision alternative, the AIC 6004 SWISSLINE flow meter, was employed by

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Oscar Olofsson [3] in his master's thesis for road testing applications. This device stands out for its compact design and vehicle-mounting capability, allowing on-road measurements with a deviation of less than 1% in flow rates ranging from 1 to 120 l/h, thereby providing a more practical solution than bulkier laboratory equipment.

For scenarios where a balance between cost and automation is desired, custom-built electronic systems represent a viable solution. H. Fathollahadeh et al. [4] proposed such a system, combining affordability with reasonable accuracy. Their design utilized two flow sensors, one on the fuel supply line and another on the return line, connected to a dedicated electronic board. The microcontroller on this board computed the net fuel consumption by subtracting the return flow from the supply flow in real-time. Following laboratory calibration, the system was installed on an agricultural tractor and achieved a respectable accuracy of approximately 2%, with an overall system cost below 500 USD.

A similar approach was adopted by A.M. Elsbaay and R.A. Hegazy [5], who developed a turbine flow meter-based measurement system. Using an Arduino-compatible microcontroller, they created a platform capable of reading, displaying, and logging real-time fuel consumption data. This low-cost solution was implemented across three different agricultural machines: a small engine, a tractor, and a combine harvester. The study found that while the system performed well overall, its accuracy decreased at low fuel consumption levels, with greater deviation observed in low-flow scenarios compared to high-flow conditions.

In the current work, we propose a cost-effective and precise method for fuel consumption measurement tailored for laboratory applications.

Our solution is designed specifically for engines operating under steady state conditions and relies on load cell technology integrated with a digital scale. By directly measuring the weight of the consumed fuel over time, this method eliminates the need for flow meters and allows for highly accurate, drift-free measurements, making it ideal for research, calibration, and controlled testing environments.

2. MATERIALS AND METHODS

The measurement system is based on a modified kitchen scale and consists of three main components: a standard digital kitchen scale with a maximum load capacity of 8 kg, an HX711 precision amplifier module, and an Arduino Nano microcontroller. The kitchen scale was carefully dismantled to access its internal sensing elements, four strain gauge-based load cells. These load cells are typically arranged in a half-bridge or full-bridge Wheatstone configuration inside the scale. In this application, the load cells are connected in a full Wheatstone bridge, which is essential for precise and stable weight measurements.

The use of a Wheatstone bridge configuration offers several advantages. First, it significantly improves the system’s sensitivity to small changes in load, making it suitable for detecting subtle variations in fuel mass during consumption. Second, and equally important, it provides inherent compensation for common-mode disturbances such as temperature drift, mechanical stress imbalances, and uneven loading. This means that the measurement system maintains accuracy even under variable ambient conditions or minor shifts in the fuel container's position.

The electrical signals produced by the Wheatstone bridge in response to changes in weight are in the millivolt range and are too small to be directly read by the Arduino. To resolve this, the HX711 module is used as a 24-bit analog-to-digital converter (ADC) and low-noise amplifier specifically designed for load cell applications. It amplifies the differential signal from the bridge and converts it into a digital value that the Arduino Nano can process. The Arduino then reads and processes this data, allowing for real-time monitoring and calculation of fuel consumption based on the change in fuel mass over time.

By leveraging readily available and affordable components, this system provides a low-cost yet high-resolution solution for accurately measuring fuel consumption in controlled environments such as engine test benches or laboratory setups.

The amplifier is connected to the Arduino board in the configuration shown in Figure 1. In this schematic, R_C represents the strain gauges under compression, while R_S represents the strain gauges under tension.

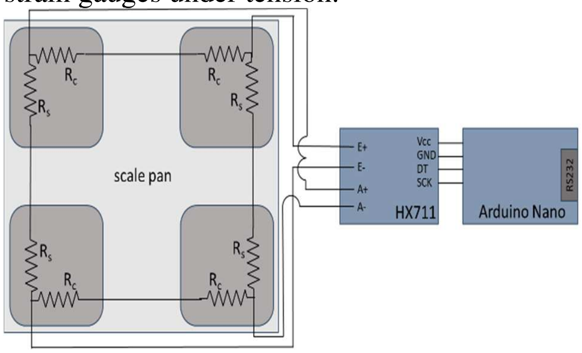

Fig. 1 Scale electrical connection

Using a dedicated software library, the scale can be calibrated with reference weights to accurately report mass in the desired measurement unit. At the time of writing, the total cost of the main components including the load cells, HX711 amplifier, and Arduino Nano was approximately 25 EURO. Even when factoring in additional installation materials such as wires, solder, and heat-shrink tubing, the total cost for building one complete measurement unit remains well under 50 EURO.

In addition to the scale itself, care must be taken to suspend the fuel inlet and return pipes, so they do not exert force on the scale and interfere with the accuracy of the measurements.

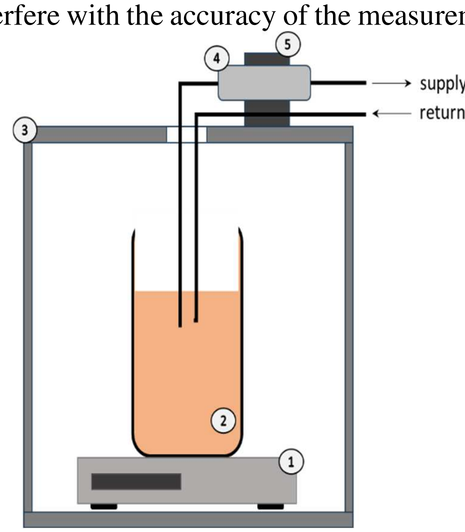

Fig. 2 Schematic representation of the proposed measurement device

The fuel and fuel vessel needs to be the only component laying on the scale, the mounting solution for the measurement device used in this paper is presented in ***Fig. 3***, where we can see the scale (1), fuel reservoir (2), pipes support structure (3), low pressure pump (4) and mounting brackets for low pressure pump and pipes (5).


Fig. 3 The proposed measurement device

One Arduino board can read multiple scales, the laboratory configuration uses two scales for two different types of fuel.

The calibration process takes time and requires patience, as better calibration results in higher precision. During the calibration phase, the digital value reported by the amplifier is correlated to a real weight.

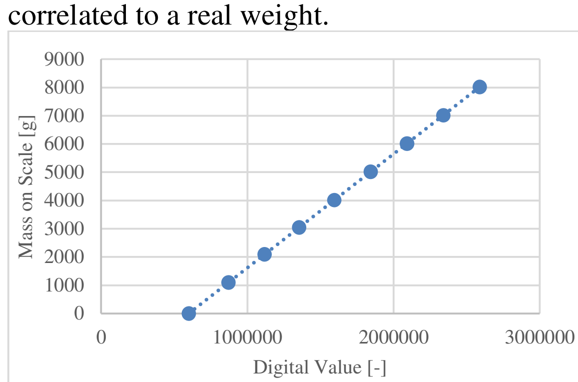

Fig. 4 Scale calibration graph

To eliminate slight drifts in measurements, calibration was performed by measuring the same weight 10 times with a 10-second pause between each measurement. Additionally, the same weight was measured while increasing and then decreasing the scale load, resulting in a matrix of values.

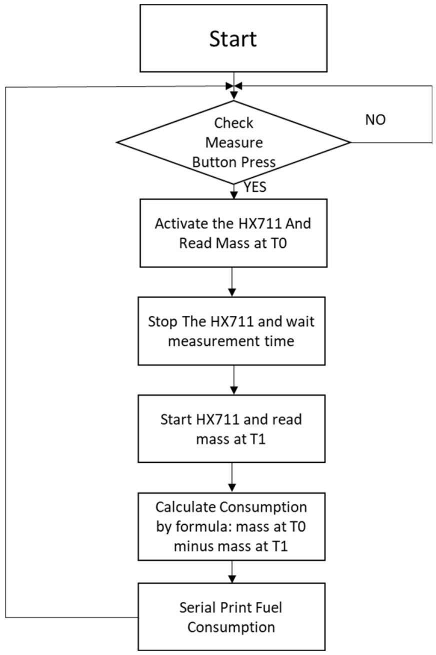

Fig. 5 Software flow chart

Based on the measurements, the graph in the **Fig. 4** above was plotted. From this graph, it can be observed that the variation of the measured mass versus the digital value is linear. Therefore, a linear equation was derived to describe the correlation between the mass on the scale and the digital value. Besides enabling a good calibration, the large dataset obtained was also used to calculate the deviation.

$$y = 0.0040288 * x - 2412.41641641 \quad (1)$$

Where:
x – digital value reported by the amplifier.
y – measured mass on scale.

After the calibration was performed, the equation (1) presented above was introduced in the software to measure mass.

The flowchart shown in **Error! Reference source not found.**, describes a process for measuring fuel consumption using an HX711 load cell sensor. It begins by waiting for a measurement button press, after which the system reads the initial mass (T_0) of the fuel. The HX711 is then paused for a defined measurement interval to allow fuel to be used. After the waiting period, the sensor is reactivated to read the final mass (T_1). The fuel consumption is calculated by subtracting T_1 from T_0, and the result is printed via serial communication. This allows precise tracking of fuel usage over time.

3. RESULTS AND DISCUSSIONS

With the software and calibration done, the accuracy of the measurement was check. This was performed by two methods. In the first step, calibration data was converted to mass by using equation obtained previously. Each mass point was calibrated using 20 digital values, this allowed us to determine the standard deviation for each point, in ***Fig. 6*** it can be observed that the real value and the measured values coincide and the standard deviation is almost constant until high loads, average value being around 1.5 grams.

After the baseline deviation was determined the time for fuel consumption reporting was set to 5 minutes, this was chose based on previous measurements to ensure a good deviation in our application, the time can be adjusted based on the fuel flow rate and desired maximum deviation in percent's.

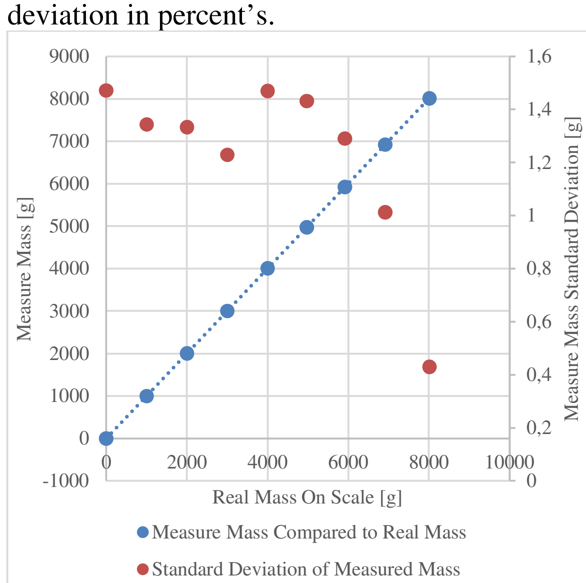

Fig. 6 Measured value compared to real value and standard deviation of each measured point

Since the measurement system relies on mass differences over time, the accuracy of the results is influenced by both the flow rate and the duration of the measurement interval. At lower flow rates, the quantity of fuel consumed over a short period is relatively small, which means that even minor noise or fluctuations in sensor readings can lead to a higher percentage deviation in the calculated fuel consumption. Therefore, in such cases, it is advisable to extend the measurement duration. A longer time interval allows the system to average out short-term variations and improves the signal-to-noise ratio, resulting in better overall precision.

Conversely, when fuel flow rates are higher, the system registers larger mass changes over shorter periods, making the relative impact of noise and resolution limitations less significant. In these scenarios, shorter measurement intervals may be used without significantly compromising accuracy, which is particularly useful in time-sensitive testing or when a high level of precision is not critical.

The relationship between measurement deviation, flow rate, and wait time is illustrated in **Fig. 7**. As shown, longer durations lead to reduced deviation, especially at low flow rates, while at high flow rates the deviation remains low even with shorter intervals. This observation highlights the importance of adjusting the measurement interval based on the specific operating conditions and accuracy requirements of the test scenario.

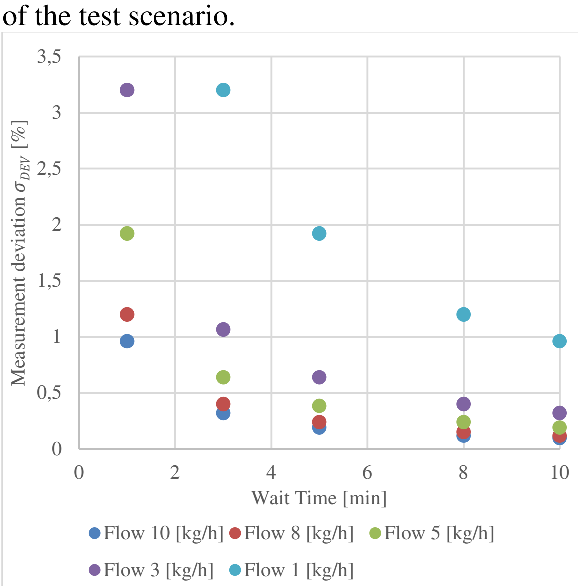

Fig. 7 Deviation of measured flow rate influenced by fuel flow and wait time between measurements

The values in ***Fig. 7*** were obtained by following formulas:

$$\Delta m = \frac{H_f}{M/_H} \tag{2}$$

Where:
Δm - Mass difference between measurements.
H_f – Hourly fuel flow rate.
$M/_H$ – Measurement per hour.

Using the maximum deviation from the calibration matrix we can determine the deviation percent based, σ_{DEV}, on fuel flow and wait time with formula. Where 1.4 is the observed deviation in grams.

$$\sigma_{DEV} = \frac{1.4}{\Delta m} * 100\ [\%] \tag{3}$$

A final verification procedure was carried out to ensure the reliability and precision of the system. This validation involved placing a static load of 6 kg on the scale, simulating approximately half the capacity of a typical fuel tank under test conditions. Subsequently, a series of known masses were incrementally removed from the scale to emulate fuel consumption.

This approach allowed for controlled observation of the system's response to decreasing load and the accuracy of mass detection. The results showed that the reported fuel consumption closely matched the actual mass removed, with a maximum deviation of only 0.4%. This low margin of error confirms the system's capability to deliver precise measurements even under dynamic weight variations, making it suitable for practical laboratory use.

4. CONCLUSIONS

A very low-cost fuel consumption measurement system was designed, calibrated, and tested under laboratory conditions using a diesel engine. The system is built from accessible components such as a modified kitchen scale, an HX711 amplifier module, and an Arduino Nano microcontroller. The scale's load cells were connected in a full Wheatstone bridge configuration, providing compensation for temperature variations and load distribution. Calibration was performed using reference weights, allowing the system to report accurate mass values in the desired measurement units.

After repeated testing under identical operating conditions, the system demonstrated sufficient precision to detect small variations in fuel consumption caused by changes in injection parameters. As shown in **Fig. 7**, measurement deviation depends on both fuel flow rate and measurement duration: lower flow rates require longer time intervals to reduce relative error, while higher flow rates allow for shorter intervals without significantly compromising accuracy.

With a total cost under 50 EURO, including auxiliary materials, the system offers a practical and reliable alternative to expensive commercial devices. Its low cost, ease of implementation, and dependable performance make it an ideal solution for research laboratories or educational facilities with limited budgets, such as ours.

Furthermore, the setup is simple to assemble and integrate, requiring only basic technical skills, making it especially suitable for academic institutions, research teams, or educational facilities operating on limited budgets.

In summary, the proposed fuel consumption measurement system strikes an excellent balance between cost, ease of implementation, and measurement accuracy. It serves as a reliable and scalable tool for experimental engine testing and educational purposes, fulfilling the needs of low-budget laboratories such as ours without compromising the quality of the results.

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Sistem de măsurare a consumului de combustibil de înaltă precizie și cost redus

Consumul de carburant este un parametru esențial pentru evaluarea performantelor de economicitate ale motoarelor termice. Metodele de determinare a consumului variază de la unele de budget la unele foarte performante precum AVL 735s/735C sau AIC6004 SWISSLINE dar care vin însoțite de un preț ridicat. Sisteme mai economice care utilizează senzori de debit si microcontrolere dedicate oferă automatizarea măsurătorilor dar au limitări in cazul debitelor mici. În această lucrare este prezentată o soluție ieftină dar care oferă o precizie bună pentru utilizare în laborator, aceasta se bazează pe metoda gravimetrică pentru determinarea consumului în regim staționar.

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